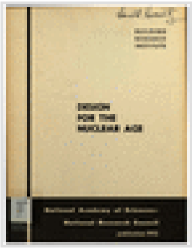

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DESIGN
FOR THE
NUCLEAR AGE

Proceedings of a conference held as
part of the 1961 Fall Conferences of the
Building Research Institute
Division of Engineering and Industrial Research

Publication 992

NATIONAL ACADEMY OF SCIENCES-NATIONAL RESEARCH COUNCIL
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The Building Research Institute gratefully acknowledges the contributions to building science made by the participants in this conference.

Milton C. Coon Jr.
MILTON C. COON, JR.
Executive Director

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1961-62
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Abstracts of Conference Papers

NEW FACTORS OF ENVIRONMENT
By Jack C. Greene, Office of Emergency Planning

The chances of living through a nuclear attack will be considerably improved if future designers provide structures with appropriate protection characteristics, even though these are confined within the limits of present-day aesthetics and economics. What kind and how much protection are not defined exactly, but this paper provides a discussion of risk studies made to establish guidance for designers. Effects on buildings of blast waves, thermal and initial nuclear radiation, and fallout under various conditions are described.

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STRUCTURAL DESIGN OF PROTECTED AREAS
By Gifford H. Albright, The Pennsylvania State University

Structural design for the Nuclear Age requires consideration of many design loads, such as blast, nuclear radiation and thermal radiation. The "utility objective" of the structure greatly influences the structural design parameters established, and the cost of the protected structure. Protection can be provided economically, if inherent protective features are considered at the time a basic structural type is selected. The addition of small amounts of massive structural material at selected locations within a building is suggested as one method of increasing protection against residual radiation at relatively low cost.

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MECHANICAL DESIGN OF PROTECTED AREAS
By Paul R. Achenbach, National Bureau of Standards

This report summarizes some of the experimental work done to identify the design requirements for mechanical equipment, the basic considerations involved in equipment selection, and the research and development work yet needed before criteria can be exactly established. The amount and kind of mechanical equipment needed to provide building services in protective structures are related to the degree of protection to be afforded, the level of useful activity to be maintained in the structure, and its size. The required amount of food, fuel and potable water are assumed to have been stored in the structure prior to an emergency. The difficulties to be encountered in supplying ventilation, heating and air conditioning, air cleaning, humidity control, power supply and lighting are examined in terms of the size and type of equipment necessary for medium and large-size shelters.

* * * * * * * * * *

ARCHITECTURAL DESIGN OF PROTECTED AREAS
By Lyndon Welch, Eberle M. Smith & Associates, Inc., Architects and Engineers

This paper reports on studies made of shelter in schools, multistory office buildings and multistory apartment buildings to determine the extent and cost of modification necessary to protect the building population from fallout radiation and from blast. School studies were performed by preparing detailed drawings and specifications for schools, or school components including shelter. Multistory buildings were studied by analyzing existing structures to determine what changes could be made, or might have been made in the original design, to provide shelter. Case studies of individual building designs are presented in detail. It is concluded that the requirements of blast shelter pose a much greater problem for the architect than those of fallout shelter, and that the cost of shelter construction can be reduced by protecting normal-use utilities so they will continue to be available during emergencies.

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FALLOUT SHELTERS AND HUMAN BEHAVIOR
By George W. Baker and Mary Lou Bauer, National Academy of Sciences-National Research Council

This paper reviews and comments on a limited body of research falling under the general heading of fallout shelters and human behavior, done by the Disaster Research Group of the NAS-NRC and by others. In evaluating the data examined, the authors take note of the fact that except for the 1945 residents of Nagasaki and Hiroshima, man has not had any actual exposure to the effects of atomic or nuclear weapons, and that the results of tests of physiological deprivation and internment, etc., can only be considered in the light of the fact that the subjects are aware that they will eventually return to a normal environment. From the evidence developed through the various studies described, it is concluded that "normal man" has considerable ability to endure extreme demands on his physical and emotional resources. It is recommended that those planning protective structures take into consideration the limitations imposed by spatial arrangements on the formation of productive groups and on the kinds of activities to be undertaken by persons within the shelter.

* * * * * * * * * *

DESIGN OF A NUCLEAR CITY
By F. W. Edmondson, Jr., Cornell University

A graduate school project at Cornell University, extending over a full year, is described in this report. It involved the site selection, planning and design for a town of 9,000 people to service a hypothetical electronic manufacturing facility. Certain protective criteria were established, and a site selected by regional surveys. The site provided a readily accessible limestone formation capped by an over-layer of shale. The electronic plant was located underground in the limestone. The town itself was located above-ground, but certain public use areas and the mass transportation system were located underground and structured to survive against nuclear effects. The protected underground areas were planned for regular daily use by the population, but in an emergency, could be closed up and converted into refuge living space for the entire population of the city. The design solution is described in detail.

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PANEL DISCUSSION: IMPLEMENTING THE NEW DESIGN

DEPARTMENT OF DEFENSE POLICY

By Paul Visher, Office of Civil Defense

The primary target of the Department of Defense is protection for the civilian population against radiation from fallout. Present policy is to provide community and dual-use shelters in existing buildings and to work with the Federal Government to provide shelter space in all new and recently-constructed Federal buildings. Problems are lack of sufficient information on shelter needs and on cost.

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OFFICE OF EMERGENCY PLANNING POLICY

By Ralph E. Spear, Office of Emergency Planning

The Office of Emergency Planning has the responsibility of advising and assisting the President with respect to non-military defense developments. Policy has developed from "duck-and-cover" to evacuation of cities and finally to increasing emphasis on shelter protection. A national policy conceding that fallout shelter was a good thing was formulated, and it is now being carried out by the Department of Defense.

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DESIGN OF ABOVE-GROUND PROTECTED AREAS

By Darrel D. Rippeteau, Sargent-Webster-Crenshaw & Folley, Architects & Engineers

Building design is evolving to incorporate considerations for fallout protection, but multi-purpose use of the fallout shelter is almost mandatory in conventional buildings. The additional cost for building mass to create shelters above grade leads to locating them in the earth under the structure. Self-contained spaces below grade could be built for daily use, with total air treatment, and could become shelters in an emergency.

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DESIGN OF BELOW-GROUND PROTECTED AREAS

By John J. O'Sullivan, Mitre Corporation

The two types of underground shelters considered are the cut-and-cover type and the deep underground shelter. By deep underground is meant thousands of feet deep. The

Introduction

By Milo D. Folley,* Partner in Charge of Design & Research
Sargent-Webster-Crenshaw & Folley
Architects, Engineers, Planners

The BRI 1960 Conference on Cleaning and Purification of Air in Buildings† offered important information on control of the interior environment. At this conference, it was pointed out that we can no longer assume exterior air is pure, and that the interior atmosphere which is purified by modern equipment and recirculated is better, and less expensive than treated outside air. Exterior environment has become laden with gases, dust, pollen, bacteria and now, with the advent of the Nuclear Age, radioactive debris.

Much of the equipment developed for the most advanced control of the interior environment that can be accomplished today was engineered for space machines, rockets, and atomic submarines.

A recent issue of House & Home magazine described the development of equipment for reclamation of sewerage and brackish waters. It is obvious that, as our cities outgrow their water supplies, means of renewing the wastes for reuse will be an important factor in their development. I believe we can assume that, in the near future, economical and efficient methods will be available for supplying treated water, even for a single residence.

The problem of obtaining power is being attacked on many fronts. The fuel cell, the atomic power package, the solar battery, and other once fantastic-sounding programs will offer autonomy to our structures, giving us freedom to build wherever we choose.

New techniques and materials of construction offer innovations never before possible: structural foams, high tension steel, low-cost, dense sheet material, luminescent lighting, temperature control, and many others which science has developed. Certainly, we have at our fingertips the knowledge and materials to develop whatever type of structure we desire. This freedom is newly found, owing its birth to the developments which have come with the advent of atom-splitting. The ability to conquer space in a sealed capsule offers the architect and engineer new techniques with which to develop living space.

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*FOLLEY, MILO D., B. A., Syracuse University; M. A., University of Pennsylvania; Member AIA, Inter-Society Color Council, Building Research Institute; Chairman, BRI Programs Division II.

†See Cleaning and Purification of Air in Buildings, Pub. No. 797, 62 pp., illus., proceedings of the Conference, 1960, $4.00. Available from BRI.

Another important aspect of our life today is found in the new science of city and urban planning. With new ground rules, we are not restricted to thinking in terms of landscaped plazas, paneled cubes of various heights, widths and colors, superhighways or even monorail transports. These are exciting thoughts today, when they are new, but what of tomorrow? Remember the great achievement known as the New York City elevated lines? What an improvement when these were placed below ground!

Urban sprawl has consumed much of the open area between our cities. Much of this is unsightly, and is costly to dismantle and replace. Glass cubes designed to let in the outside environment are wonderful spaces to accommodate certain portions of our waking hours, but the cost of heat removal makes these buildings inefficient for many uses. The modern factory encloses itself, to provide a controlled atmosphere wherein efficiency can be developed. There is no reason why a factory could not be built below the ground, leaving the openland and natural environment for those functions requiring it. Is this not also true of a shopping center, a downtown city center, a community government complex, or many other habitats of man which do not need the forces of environment acting upon their shells?

Man's continuous return to nature hints at a historical cycle of development. Primitive man left his cave because he was better able to secure his food by traveling with the herds, and relied on his capability to live off the land. It is logical that man's own genius has developed a life pattern whereby his knowledge will allow his return to the cave, with the highest degree of technology used to improve his environment. Here he has achieved supreme livability, with greatest safety and at lowest cost.

Although the papers to follow will treat with the problems of protection against blast and fallout, I am attempting to see beyond this current dilemma—to show that although we see the subterranean environment as a protective shield in today's bomb shelter solutions, building below the ground may be a major step in our cultural development. From the evil of today comes the seed of tomorrow's culture.

New Factors of Environment

By Jack C. Greene*, Chief, Review and Evaluation Branch
Research, Policy and Review Division
Office of Emergency Planning

One of the most influential factors today, as to whether or not we become exposed to a nuclear war environment, is the Russian decision-maker, Khrushchev, himself; tomorrow it may be a Chinese decision-maker, Mao Tse-tung. However, let us leave discussion of the motivations, aspirations and personality traits of these two gentlemen to the political scientists, or perhaps better, to the psychiatrists. Rather, let us focus attention on those new environmental factors against which you, as architects, engineers and representatives of the building industry, must provide protective designs—not with the expectation of eliminating all casualties in a nuclear war, but with the expectation of reducing the degree of the catastrophe that would otherwise occur, and which would surely occur if the present degree of preparedness is not improved.

The science and technology that underlie the capability of all concerned to deliver and to protect against the weapons of the Nuclear Age are changing rapidly. Therefore, we will consider only those environmental factors associated with a nuclear war now or in the near future, say until about 1965.

Compilations of data in the form of tables, charts and slide rules covering the various phenomena associated with nuclear weapons are available from many sources. Even the government of India has published a book, "Nuclear Explosions and Their Effects." It is very well done, and is not just a copy of our own book, "The Effects of Nuclear Weapons," prepared by the U. S. Department of Defense and published by the Atomic Energy Commission. Such documents provide excellent reference material on the characteristics of blast waves and the thermal and initial nuclear radiation at various distances from various sizes of bombs detonated under various conditions. They also discuss fallout and the means of protecting against it. I, therefore, do not propose to describe these phenomena individually in this paper. Rather, I hope to reflect, in a very broad sense, how nuclear weapon effects might integrate to influence the environment in a nuclear war.

Knowledge that the blast overpressure from a 5-megaton weapon can destroy almost all conventional structures within a distance of 8 to 10 miles of ground zero, or that a

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*GREENE, JACK C., B. S. E. E., Massachusetts Institute of Technology; Member, Health Physics Society.

two-day dose of 5,000 roentgens might occur 50 miles downwind, is not very helpful when the problem is to design protection in a new office or school building in a particular city. One needs to know something about the blast pressures and the radiation doses that might occur in the city in question, as well as something about the probability that they would occur.

We cannot base this thinking on experience. There is no precedent; no nation has fought a nuclear war. The strategic considerations of World War I and World War II do not apply. Many people, and I include myself, believe the next war would differ more from World War II than World War II differed from the Crusades. So, if we cannot rely on past experience, how do we estimate the risks? We can use intuition, or we can be a bit more scientific and try to calculate them. This is done by a technique called "war gaming."

To estimate the risks at various places, including the city we are concerned about, we have to assume the enemy's nuclear stockpile; the number and capacity of his delivery vehicles; the aborts and the aiming errors. We have to be specific about the time period. Will he have a Nike-Zeus type of anti-missile missile system? Will he have a Polaris type of submarine, etc.? We must assume a degree of effectiveness for our own air defense system, and we must assume he has various target objectives. We even have to assign probabilities that the assumptions are right. A program is written based on these assumptions, so that a high-speed electronic computer can simulate an enemy attack. Then we see what happens. The aiming errors, the aborts, the effectiveness of air defense are allowed to vary in a random way, as they might in an actual attack. Such Monte Carlo runs are made and remade, until patterns with statistical significance develop.

Figure 1 shows how the data may be tabulated. Various levels of H + 1 dose rate are listed along the ordinate, and blast overpressures are listed along the abscissa. Let's say this is the chart relating to the city we are studying. With the assumptions used, there are three chances out of 100 that the H + 1 dose rate would be between 3,000 and 10,000 r/hr and the overpressure would be between 10 and 20 psi. The total probability of dose rates of 3,000 to 10,000 r/hr occurring is 0.13, while the total probability of the overpressure being 10 to 20 is 0.24. These data are no better than the assumptions, and apply only to the time period being studied, but they are the best we have and should be far better than intuition. For obvious reasons, many of these "risk" studies are classified, although results for individual locations are being made available to the civil defense authorities concerned.

So far we have established three points: First, the various effects of nuclear weapons are quite well known and damage-distance data are widely available in the open literature. Second, access to such data alone does not provide a sufficient basis for deciding the protection needed at any given place. And, third, studies of risks at various locations have been made and are being used, but even these are limited by the uncertainty of the assumptions. However, we know that:

1) There is now, and probably will be for some time to come, a finite chance that a nuclear war will occur.

2) In a nuclear war any area in the U. S. might be at risk from fallout.

	PEAK OVERPRESSURE (psi)											
RADIATION INTENSITY R/HR H + 1 HR	UNDER 1.2	1.2-2.1	2.1-3.5	3.5-6	6-10	10-20	20-50	50-120	120-400	OVER 400	RADIATION TOTALS	CUMULATIVE RADIATION TOTALS
OVER 100,000												
30,000 - 100,000												
10,000 - 30,000												
3,000 - 10,000						.03	.01	.03	.03	.03	.13	1.00
1,000 - 3,000				.03	.07	.08	.16	.10	.07	.05	.56	.87
300 - 1,000			.03	.02	.04	.13	.01				.23	.31
100 - 300	.01	.04	.01	.01	.01						.08	.08
30 - 100												
10 - 30												
UNDER 10												
OVERPRESSURE TOTALS	.01	.04	.04	.06	.12	.24	.18	.13	.10	.08	1.00	
CUMULATIVE OVERPRESSURE TOTALS	.01	.05	.09	.15	.27	.51	.69	.82	.92	1.00		

Figure 1. Blast and fallout probabilities for hypothetical city.

3) Smaller, but still tremendously large, areas would be at risk from blast and from thermal radiation damage.

In the past, architectural designs have not considered these risks, but certainly they should be considered now. There are many fundamental things that can be done at little or no extra cost which would improve the inherent protection of any structure, particularly against fallout and fire. It seems only prudent to exploit whatever protection can be obtained cheaply. How far to go beyond this, what price we should pay, is a more difficult question, having no simple or universal answer.

We can get some useful insight by considering the problem of the Russian military strategist. First, he has an objective that is fundamental—he must win. It also follows, and this is important, that he doesn't want to suffer any unnecessary damage in doing so. Winning would have two principal but not unrelated elements: (1) the neutralization of the forces that appear to the Soviets to pose a military threat; and (2) the removal of impediments to the spread of Communism. U. S. military power is a principal factor in both.

The primary elements of the U. S. military power with which this adversary must contend are those which threaten what we might call the present-day version of the World War II term, "air superiority." Obviously, now we have to include space. Russian air and space superiority calls for reduction of the striking power of the Strategic and

Tactical Air Commands, the Navy's aircraft striking force, and the total U. S. missile capability, to the extent that any remainder which could penetrate the Russian air defense would cause no more damage to the Soviet homeland than they judge acceptable. Their superiority also calls for destruction of the U. S. air defense, i.e., air defense bases, Sage, and other warning and control systems, so that the Russians could strike U. S. continental and overseas targets at will, even with bombers. In summary, the main objectives of a pre-emptory attack by the Russians would be those military bases affecting use and control of air and space. The civilian population and industrial complexes would probably not be first priority targets and, if the Russian first strike were successful, they might not become targets at all.

The element of surprise would be tremendously important to the Russian strategist, the maximum surprise and minimum warning time being perhaps the 10 to 15 minute period between the time of detection of a missile salvo by our early warning radar, and the time the missiles strike. Surprise would mean catching our offensive aircraft unalerted, or with only a partially alert status, for a maximum reduction of effectiveness. It would mean reduction of our missile retaliatory capability, since it would at least decrease the probability that the missiles which could be fired on such short warning would be fired. A logical enemy is not likely to use missiles to destroy population centers when the same missiles, aimed at particular retaliatory or air defense installations, would increase his chances of knocking out these installations. Missiles expended on population centers would not contribute to an increased probability that the retaliatory force would be destroyed. In short, they would not increase his chances of getting air and space control, and the lack of this control reduces his chances of avoiding major damage to his homeland.

Shown below is the equation for the distance "r" from a target beyond which bombs have a probability "S" of landing, or, conversely, "r" is the distance from target within which the bombs have the probability of "1 minus S" of landing.

$$r = 1.2\ (\text{CEP})\ (1/n^{1/2})\ (1n_e\ 1/S)^{1/2}$$

"CEP" is the circular error probable and, using the laws of probability, is defined as the radius of the circle around the target within which a weapon has a 50-50 chance of landing, and "n" is the number of weapons. If the attacker's CEP is, for instance, 2 miles, the odds are that 50% of his weapons will land closer than 2 miles and 50% will land beyond 2 miles. If you wonder how far beyond 2 miles, the odds are that 79% will be within 3 miles of target, 94% within 4 miles and 99% within 6 miles.

The curve in Figure 2 shows overpressure versus distance for a 5 megaton warhead, a size which many assume current Russian ICBM designs are capable of delivering.

At about 2.5 psi overpressure, occurring a little over 7 miles from ground zero, almost all conventionally designed, above-ground structures would be severely damaged. Six psi, at a little over 4 miles, would assure destruction of soft missile sites and parked aircraft. Twenty-five psi, which occurs at about 2 miles from ground zero, is the design criteria for the medium-hard, so-called "coffin-type" missile sites; while 100 psi, occurring at about 1.2 miles on this curve, is what the hard missile sites—silos for Atlas, Titan, and Minuteman—are designed to withstand.

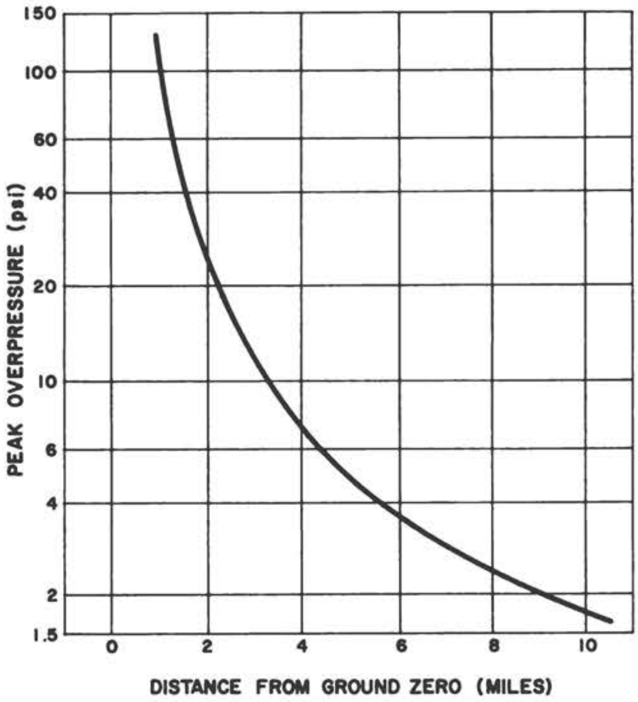

Figure 2. Peak overpressure vs. distance from ground zero for 5-MT surface blast.

Let's look at this equation and this curve from the point of view of the Russian strategist. Obviously, he wants to maximize the probability of hitting his target, which he does by making "r" as small as possible. What sort of things contribute? First, "r" is directly related to CEP, his missile accuracy. If he can reduce the CEP from 2 miles to 1 mile, "r" would be cut in half. The payoff of this reduction in CEP is much greater than doubled, since in these ranges the curve of overpressure versus distance is very steep. For a 5 megaton weapon, for example, at 2 miles, the overpressure is about 25 psi; whereas, at 1 mile it is well over 100. If he increases the number of missiles, he reduces "r" by the inverse square root. That is, he would have to go from 1 to 4 missiles to reduce "r" by a factor of 2. If he increases the yield of his weapon, his advantage goes up approximately as the cube root of the ratio of the larger weapon, as compared to the 5 megaton size. To effectively decrease "r" by a factor of 2, he would have to go to a 40 megaton weapon, since 40 divided by 5 is 8; the cube root of which is 2.

There is another factor the Russian military strategist would consider—whether to air- or ground-burst his weapons. This can be examined by referring to the same equation. The radius of kill for an air burst for soft targets, below about 15 to 20 psi, (these include almost all of our existing SAC, TAC, missile and air defense installations) can be as high as about 1-1/2 times the radius of kill for a ground burst, such as the case illustrated on the curve shown in Figure 2.

It has been fallaciously argued that the kill radius of a ground-burst 5 megaton weapon is enough to assure an overkill of almost any kind of target, but this does not consider inaccuracies of aiming or uncertainties of knowledge of target locations. In playing war games, using probability theory, the advantage of an increased radius of kill becomes strongly evident. The Soviets play war games just as we do, and their mathematicians certainly are among the world's best.

To illustrate the dividends from using an air burst as opposed to a ground burst, assume that in a particular calculation made by the Russian strategist he finds a one-third chance of getting a particular soft target or targets with a particular number of ground bursts. When he then repeats his arithmetic using air bursts, he finds that the probability increases to 60%, i.e., it improves by 60 minus 33, or 27%. He is going to think twice before throwing away this kind of improvement in kill probability just to produce fallout to kill people at some distance from the target who would probably do him no harm if they lived.

However, when considering hard targets, such as the silos being built for Atlas, Titan and Minuteman, this increased dividend from an air burst no longer applies. Actually, because of the ground shock produced by a surface burst, it probably would be the detonation of choice. So, the program of hardening military installations seems to portend increased fallout hazards in the future.

TABLE I

Number of 5-MT Weapons with Different Accuracies Required for a Given Probability of Destroying Various Types of Targets

Types of Targets		NO. OF 5-MT WEAPONS REQUIRED											
Site Category	Peak Over-pressure (psi)	CEP											
		0.5 MILES			1.0 MILE			1.5 MILES			2.0 MILES		
		Confidence Level											
		90%	95%	99%	90%	95%	99%	90%	95%	99%	90%	95%	99%
Soft Site	6	1	1	1	1	1	1	1	1	1	1	1	2
Medium-Hard Site	25	1	1	1	1	1	2	2	3	4	4	5	7
Hard Site	100	1	1	2	3	4	6	6	8	12	11	14	22

Table I, showing the number of 5 megaton weapons with different accuracies required for a given probability of destroying various types of targets, dramatically illustrates the importance of aiming accuracy. If the attacker has a 50-50 chance of getting his weapon within one-half mile of target (CEP of 1/2 mile), he need commit only one weapon to a soft or medium-hard target to get a 99% probability of kill, and only 2 to the hard target. Whereas, with a 2 mile CEP, a 95% probability of kill would require 1 missile for the soft target, 5 for the medium-hard one, and 14 for the hard site. Since these 14 weapons would likely be ground bursts, we would have a real fallout problem.

Therefore, in a war in the early 1960's, it seems logical that the Soviets would assign a very high priority to knocking out our retaliatory capability. This would increase their probability of winning the war quickly, and decrease their probability of suffering severe damage to their homeland. In this period, most bombs might be air bursts, because our targets are predominantly soft and, as I have illustrated, the probability of knocking out these targets is increased when weapons are detonated at optimum altitude. So, the principal hazards to the general population during this period may be those incidental to a military-oriented attack. These hazards are primarily blast and thermal radiation effects on those people within the damage range of bombs detonated within a few CEP's from the target points. These distances are not great. A typical structure, 16 miles from the target, would have better than 99% chance of surviving the blast from a 5 megaton warhead, even if the missile CEP is only 3 miles. If it is less, the chances would be even better than 99%. This can be calculated from the equation given before.

The thermal radiation also would produce many casualties. The area of thermal ignition is larger for an optimum height air detonation than for a ground burst. Vast fires would probably result in target areas, and might spread to great distances. At the moment, fire-fighting equipment and techniques probably would be incapable of controlling this spread. The limits of fire might be such natural barriers as large cleared areas, rivers, lakes, plains and mountain ranges. However, there would not be widespread fire storms such as occurred in Hiroshima and Hamburg. The size of the area and the building density required to sustain such a fire storm occur only in limited portions of a very few of our largest cities. Heavy fallout would not be produced, since nuclear weapons detonated so as to maximize blast and thermal damage to soft targets are high enough so that the fireball does not touch the ground, and serious local fallout does not occur.

I may seem to have de-emphasized the importance of fallout protection, and of the requirements for providing it in future construction. I do not mean to do so, and certainly think that any effort such as that presently under way for locating and identifying fallout protective spaces is extremely important. As the number of missile bases hardened above 25 psi increases, the probability of surface-burst weapons, which are fallout-producers, goes up. With a given CEP, the harder these missile bases become the more weapons the enemy will have to commit to provide a suitable probability of kill. In this case, the fallout problem becomes extremely severe, since multiple detonation of 5 or 14 bombs would produce fallout levels 5 to 14 times those with which we have had experience in the nuclear test series, and those illustrated in the "Effects of Nuclear Weapons." The maximum dose levels produced under these conditions might go to many hundreds of thousands of roentgens, and extremely high protection factors would be required.

Biological and chemical warfare must also be included as new factors of environment in the nuclear age. The use of chemical warfare agents in a strategic attack on the U. S. seems quite unlikely, however. The logistic problems associated with the delivery of chemical agents are so vast compared with those associated with nuclear weapons delivery that chemical warfare, except for tactical application on the battle front, seems to have gone the way of the "block buster."

Biological warfare may be another story. Vast quantities of BW agents can be delivered rather easily. If they can be dispersed and kept alive, large numbers of people could be exposed, although the threat does not seem to compare with the nuclear threat—BW cannot knock out missiles or parked aircraft. We know the Russians have some measure of capability to wage a BW attack. For this reason, the Office of Civil and Defense Mobilization and its predecessor, Federal Civil Defense Administration, built up a sizable stockpile of immunological agents, including those for smallpox, cholera, plague, Botulism, and a dozen others, which would be useful in helping to control natural communicable disease, as well as forms of deliberate warfare. Also distributed throughout the country are sizable stocks of various antibiotics and sulfa drugs, but there is more to be done. Education of the general public as to the nature of the BW threat is an important step. This will be the responsibility of the Department of Defense and the Department of Health, Education, and Welfare; and of Agriculture where plants and animals are concerned.

In summary, our chances of living through the Nuclear Age will be considerably improved if future designers provide structures with appropriate protection characteristics, even if they are confined to those within the limits of present aesthetics and economics. Other structures, constituting targets themselves, and those which are at high risk because of their proximity to high priority targets, require additional protection. What kind and how much protection can never be answered exactly, but useful guidance can be provided through the type of risk studies discussed. We do not advise you to design everything to provide a particular radiation protection factor of 100 or 1,000, nor to withstand a blast overpressure of 25, 30, or 50 psi. The answer is not that simple.

It is gratifying to find professional groups turning their attention to the questions of survival in the nuclear age. It will take the best efforts of all of us to identify, analyze and develop appropriate answers to the problems that confront us now, and that promise to become more numerous and complex as time goes by.

Structural Design of Protected Areas

By Gifford H. Albright*, Shelter Consultant;
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INTRODUCTION

The new factors of environment in the Nuclear Age include blast, residual radiation, initial radiation and thermal radiation, as well as chemical and biological agents. The impact of these factors upon the professions responsible for the design of structures is quite significant when one considers that many technical fields of a diverse nature, such as blast loading, structural dynamics and radiation shielding are involved—fields not normally considered or encountered in the design of conventional buildings today.

GENERAL STRUCTURAL DESIGN CONSIDERATIONS

It is important to recognize initially four basic points of structural design for the Nuclear Age:

1) The specific design loads which might be considered could consist of many varied combinations of blast, residual radiation, initial radiation, and thermal radiation. A decision as to what combination to use for design depends upon the functional requirements of the structure, or more specifically, upon the desired utility objective and location of the structure.

2) The design loads which should be considered do not automatically produce a balanced or integrated design. In fact, many factors of environment introduce divergent requirements.

3) The loads used for design depend to a large extent upon the desired utility of the structure, and those design loads which are actually used in a specific case obviously influence the cost of the structure.

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4) The desired utility of a structure can vary widely, hence there is need for a carefully considered and understood utility objective for a structure.

Logically, one might ask, "What are the design loads that might be considered?" "What utility objective of a structure should be considered?" Both of these questions can cause considerable confusion both for the public and persons in the design professions today.

Let us look at the matter of design more specifically by means of some simple examples. Taking two extremes, we might consider first a structure housing construction supplies. If it is the desired utility objective that the supplies be protected from the effects of nuclear weapons and be usable, and if a specific cost limit is established, the structural design problem would be relatively simple. The nuclear radiation loads would not be considered; the thermal radiation load would be considered in order to select appropriate structural materials; and the blast loading would, in fact, play a major role in the design of the structural system. It may be possible to allow some distortion in the structural system without damaging the supplies. It would be desirable for the doors of the structure to remain operable. No nuclear radiation shielding materials would be needed for either initial or residual nuclear radiation.

In another case, one might state the utility objective as protection for persons operating sensitive equipment during and after a situation where blast pressures, initial nuclear radiation, residual nuclear radiation, and thermal radiation are present. In this case, the structure must not only stand up against blast loads, but also provide sufficient shielding for the occupants against gamma rays of residual radiation, and against the higher energy gamma rays and neutrons of initial nuclear radiation. In addition, the structure must be basically autonomous, that is, must be habitable and isolated from conventional support services such as ventilation, power, food, water, and sanitation. In order to provide the necessary power and ventilation, a structural system must be designed to protect those support service systems. Blast doors would also be required, and blast valves might be needed to protect the ventilation system from excessive overpressure.

It is obvious that the design of this second structure is considerably more complicated than the first example. However, both structures have a different utility objective and both can be designed to meet those objectives. It is also obvious that, for comparable overpressure resistance, the unit cost of the second structure will be considerably greater than that of the first. Between these two extreme examples are many combinations of design factors which must be considered for specific conditions for design in the Nuclear Age.

Environmental conditions which must be satisfied independent of Nuclear Age loads in conventional building design include air temperature, air motion, air moisture, odor, particulate matter, solar light, solar heat, sound, sight and precipitation, as well as matters relative to security, fire, earthquake, flood, and windstorm. It is recognized that each of these design loads is not unique as a Nuclear Age design load. However, in Figure 1 we can see that structural design in the Nuclear Age includes a consideration of many new factors. The left of the Figure shows a series of design loads; the center includes a series of environmental requirements; and on the extreme right of the Figure are indicated support systems which must be designed to provide the necessary environmental condition. It is important to recognize that many of these design

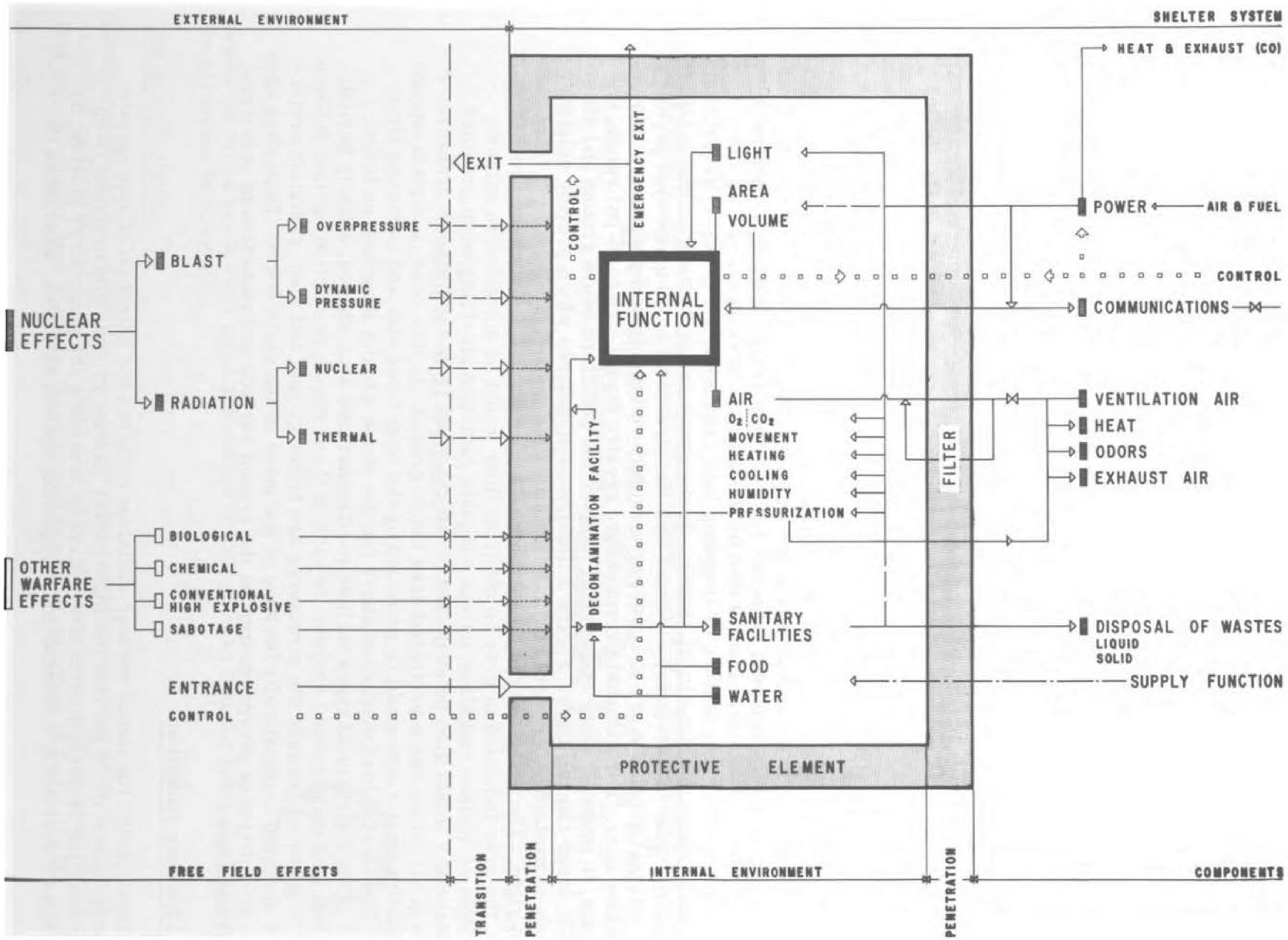

EXTERNAL ENVIRONMENT
SHELTER SYSTEM
HEAT & EXHAUST (CO)
EXIT
EMERGENCY EXIT
CONTROL
LIGHT
AREA
VOLUME
POWER
AIR & FUEL
OVERPRESSURE
BLAST
DYNAMIC PRESSURE
CONTROL
INTERNAL FUNCTION
COMMUNICATIONS
NUCLEAR EFFECTS
NUCLEAR
RADIATION
THERMAL
DECONTAMINATION FACILITY
AIR
O2 CO2
MOVEMENT
HEATING
COOLING
HUMIDITY
PRESSURIZATION
VENTILATION AIR
HEAT
ODORS
EXHAUST AIR
FILTER
BIOLOGICAL
CHEMICAL
OTHER WARFARE EFFECTS
CONVENTIONAL HIGH EXPLOSIVE
SABOTAGE
SANITARY FACILITIES
DISPOSAL OF WASTES
LIQUID
SOLID
FOOD
SUPPLY FUNCTION
ENTRANCE
WATER
CONTROL
PROTECTIVE ELEMENT
FREE FIELD EFFECTS
TRANSITION
PENETRATION
INTERNAL ENVIRONMENT
PENETRATION
COMPONENTS

Figure 1

systems exist in our day-to-day environment; however, many of them, because of the autonomous nature of the structure, are necessary for existence in a nuclear environment. Consider a protective structure as one which provides a protection for the interior environmental conditions illustrated inside the area identified as the "Protective Element." Many of these conditions are common in our day-to-day environment, but many are unique because of the nuclear effects which, in turn, generate special conditions.

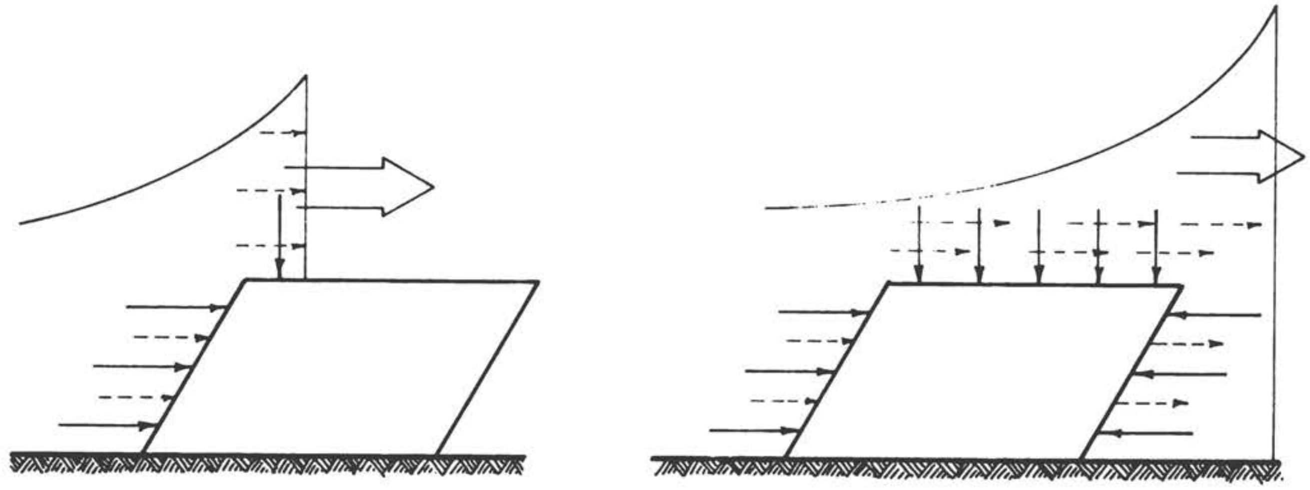
In summary then, as formulation of the problem, it should be stated that the utility objective is most important, and can be defined only when there is a clear understanding of external loads, internal requirements and supporting subsystems. Without a clear definition of each of these factors, it would be impossible to design an effective structural system. Loads are not limited to those creating a need for strength (flexure and shear) resistance, but include radiation as an external "load" on the structure. Some of the specific effects and their impact on design considerations in the Nuclear Age will be discussed below.

Blast

Structural design for blast protection involves selection of appropriate structural materials which provide sufficient resistance against loads of two basic types: the overpressure load, and the dynamic pressure load, as indicated in Figure 2. Here are shown the effect of a lateral load caused by the dynamic pressures; and the other effect, namely the overpressure or crushing load created by the general overpressure as it moves through a structural system. In designing for protection against blast pressure, it may be necessary to insure that the structural envelop does not permit a large internal overpressure to occur, or a rapidly rising internal pressure within the protection area. For external overpressure greater than the 25 to 35 psi range, it becomes, in general, more economical to place the structure below ground and eliminate the large lateral loads. Figure 3 illustrates structures which provide relative degrees of protection against both blast and radiation, generally increasing from the left to right. The structure on the extreme left is an above-ground structure. Obviously, the area indicated in gray on the first floor would be subjected to extreme quantities of nuclear radiation, unless adequate radiation shielding were provided. The structure would also be subjected to lateral loads from the dynamic pressure. The next structure has a protected area below ground. In this case, a certain amount of radiation protection would be provided by the first floor slab and overhead structure. The lateral load discussed above for the above-ground structure no longer exists. Other structural types include rectangular and arch shapes, slightly buried, and also deep underground shapes. In each of these cases, protection against dynamic loads is inherent because the structures are below ground and also, radiation protection is achieved automatically because of the mass of the earth cover. Depending upon depth, attenuation of overpressures on the ground surface and reduction in acceleration are achieved.

Initial Nuclear Radiation

Structural design for initial nuclear radiation requires the selection of appropriate shielding materials to prevent the high-energy gamma protons and neutrons from penetrating the protective structure. Mass is desirable for gamma ray shields; hydrogenous materials are desirable for shielding against neutrons. Entrances to



Unbalanced overpressure (solid lines) and dynamic pressure (broken lines).

Equalized overpressure (solid lines) and unbalanced dynamic pressure (broken lines).

Figure 2. Pressures on large enclosed structures

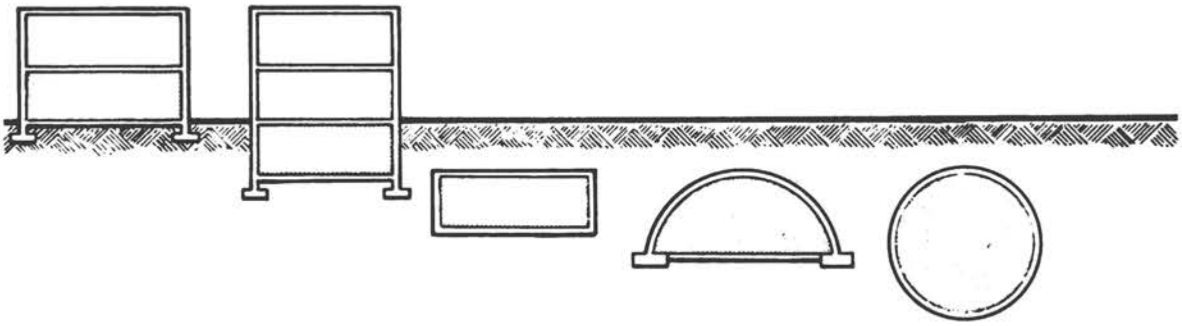


Figure 3. Types of shelters

protected areas are a weak point and should be designed so that the total shielding of the structure is adequate.

Thermal Radiation

Structural design for protection against thermal radiation involves selection of construction materials that will not ignite or support combustion. A vivid illustration of this was given by a test made on three experimental structures, of basically the same materials, but in different conditions of maintenance. One structure was not painted, and had a certain amount of deterioration in the wood surfaces. The second was painted with a highly reflective surface, and the third was not painted and was in a relatively poor state of maintenance, with debris lying in the yard around the structure. When these three structures were exposed to simultaneous comparable levels of thermal radiation, the painted house did not burn; however, the other two burned to the ground, due mainly to the surface characteristics of the structures.

Residual Radiation Fallout

Structural design for protection against fallout involves time, distance, and material. Time is important because radiation decays with time, and hence its intensity is reduced considerably as time passes. Distance is important in two ways. When an area is at a distance from a hypothetical target, the fallout will decay as it travels that distance and will be reduced by the amount of time involved. Also, the farther one is from fallout particles as they deposit on the roofs and the ground surfaces surrounding a building, the more protection is achieved.

Finally, material is most important in providing protection, because it provides the necessary mass or weight of shield needed for protection from the external radiation. Figure 4 demonstrates the barrier effect. It is noted that in the case of fallout radiation, 1-1/4 MEV gamma photon energy would be emitting and striking a shield. Three specific characteristics of the shield are noted:

1) A certain amount of radiation will pass directly through the shield

2) A certain amount of radiation will pass through but be scattered by the shield

3) A certain amount of radiation will be absorbed by the shield.

Our concern is with the direct radiation passing through the shield, and that which is scattered. For a specific structure, it can be seen that radiation falling on a roof surface would contribute a portion of the radiation dose to persons inside such a structure. Figure 5 indicates various factors to be considered in the design or analysis of a structure for radiation shielding protection. These include both the mass thickness of the overhead construction identified here as X_0 and also the area and height of the structure, which are included in the solid angle identified here as omega. It can be

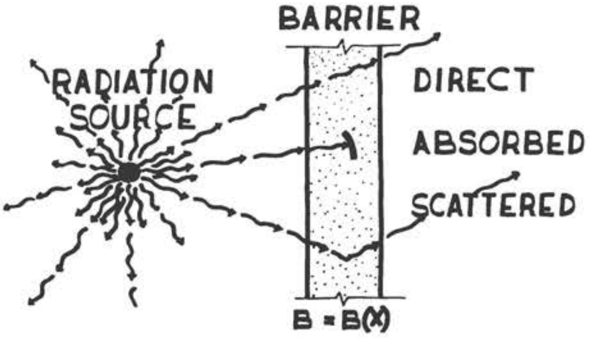


Figure 4. Barrier effect

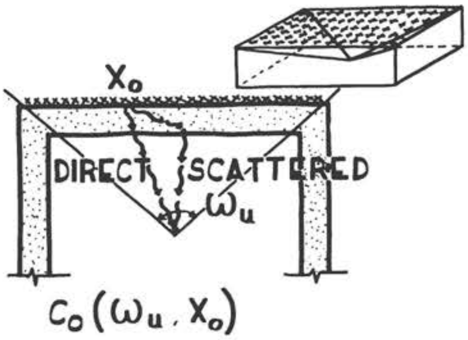
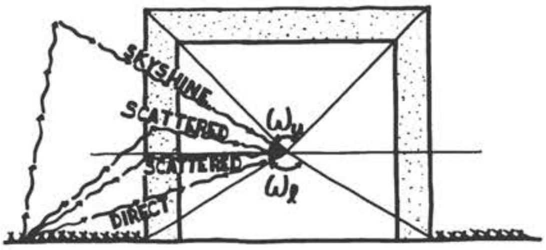
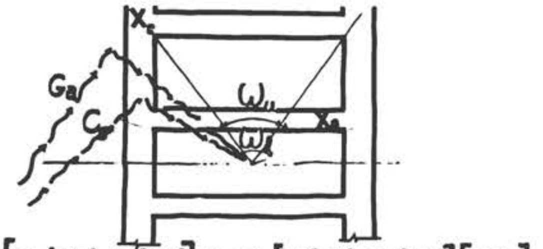


Figure 5. Roof contribution—combined effect



$$G_g = [G_s(\omega_u) + G_s(\omega_l)] S_w E + [G_d(\omega_u) + G_d(\omega_l) - K_d(\omega_l, H)][1 - S_w]$$

Figure 6. Geometry reduction factor



$$G_g = [G_s(\omega_u) - G_s(\omega_l)] S_w E + [G_a(\omega_u) - G_a(\omega_l)][1 - S_w]$$

$$C_g = G_g B_e B_i B_o M_s P_r$$

Figure 7. Ground contribution through ceiling

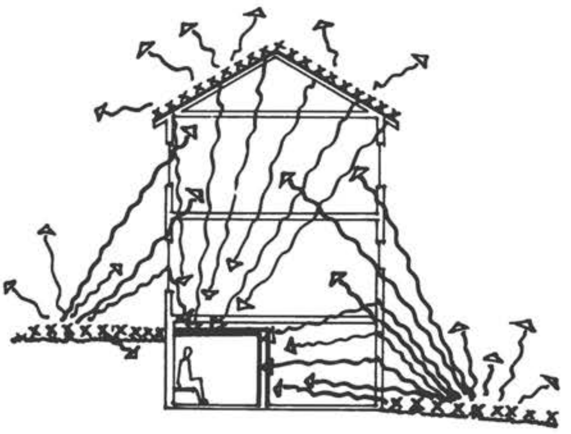


Figure 8. Radiation paths

seen that both mass and solid angle (or omega) are functions of the contribution which would pass through the roof surface.

In Figure 6 the geometry reduction factor for fallout accumulating on the ground is considered. There are three basic components: skyshine, or radiation which reflects from the sky as a result of moisture and other material in the atmosphere; scattered radiation; and a certain amount of direct radiation. It can be observed that the scattered radiation penetrates the wall both above and below the point of interest, or detector location. Note that the direct radiation penetrates only that section of the exterior wall below the detector location. This is particularly important when one considers the location of additional mass in a given structural system. The direct radiation component is very significant; consequently, it is important that mass be placed for protection at those areas which will be subjected to direct radiation.

In Figure 7 it is noted that, in a protected area below the surface of the contaminated plane, the radiation would pass through both the exterior walls, which are important because of their mass, and through the overhead surface or floor above, which is also important because of mass. By passing through these two masses, a considerable reduction in intensity is achieved. Figure 8 illustrates the radiation one might experience in various locations in a typical two- or three-story, small structure such as a garden apartment or small office building. Note that on the second or third floor of the structure, one would be subjected to radiation from the roof surface as well as radiation emitted from the ground. As one is farther from the roof, the intensity of radiation from the roof is reduced. If one were in the basement or ground floor of this particular structure, there would still be a considerable dose accumulated because of the contribution from the side on the right. In this case, the direct radiation is still penetrating, and a sufficient wall mass or barrier would be required to provide protection against that radiation, in addition to an overhead mass.

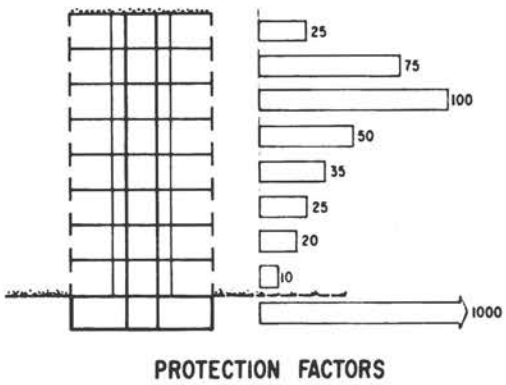


Figure 9. Protection factors

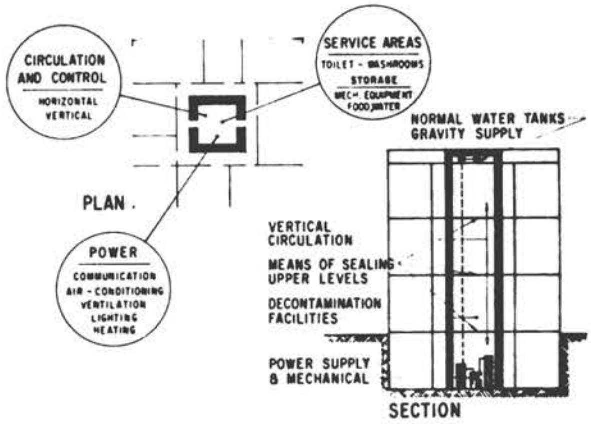


Figure 10. Core concept

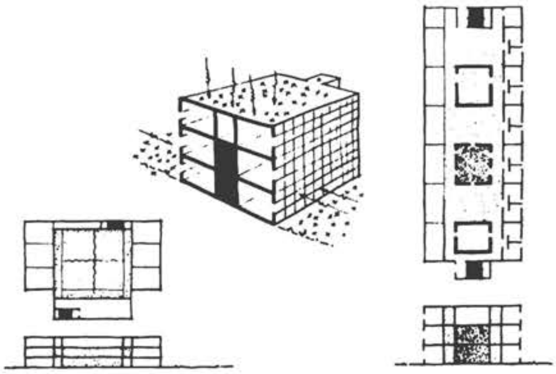


Figure 11. Core concept

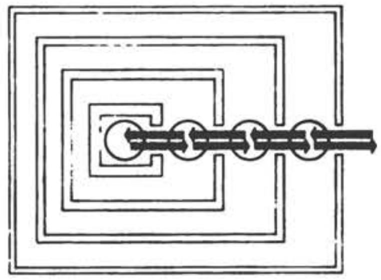


Figure 12. Modulating concept

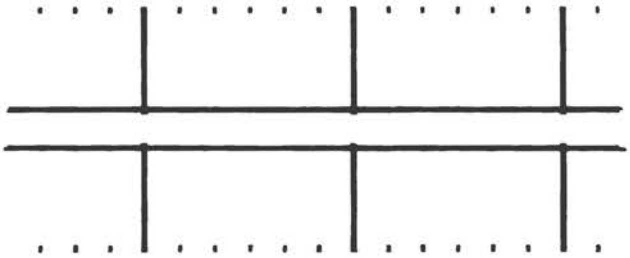
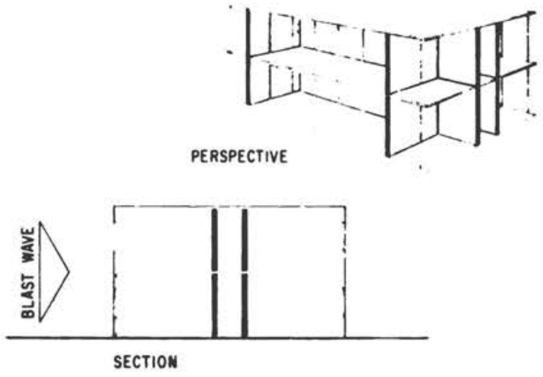


Figure 13. Shear walls



STRUCTURAL CONCEPTS

There are many factors in the design of a structure which can increase the radiation protection including geometry, material selection, and the plan or a configuration of the structure. Figure 9 shows the protection factors for a heavy multistory structure in bar graph form (the protection factor being the ratio of the external dose to the internal dose). Note on the third floor from the top, a protection factor of about 100 is achieved. As one goes closer to the roof, the protection factor is reduced because, in this case, the dose from the roof is a major source contributing at these locations. Note also that, as one goes lower in the structure, a considerable reduction in the protection factor also occurs, because of the closeness to the ground and the contribution made by the ground surfaces. In the basement area, a protection factor of over 1000 is achieved, because there is no direct contribution, and radiation from the ground surface must pass through both the external walls and the overhead or floor mass. Because of the large mass of the overhead floors (two through eight) practically no contribution from the roof is received in this area.

Figure 10 illustrates typical core concepts(3)‡. By careful planning and design of a structure, and care in selection of materials, the protection factor in certain areas can be increased considerably. In many areas of the structure illustrated, sufficient layers of material or mass are present between the protected area and the external surface. Figure 11 develops this example a little further, particularly for a military barracks or dormitory(4), indicating the number of walls between the protected area and external surface. It is important to recognize that the modulating concept(5), whereby series of protected areas are developed inside of other areas, provides varying protection (Fig. 12). It is possible, by moving from one area to another as the external radiation dose decreases, to maintain protection at adequate levels. Figure 13 indicates directions in which many structures will be developed through the use of exterior and interior shear walls—walls which are designed to resist lateral loads by providing protection against those loads structurally,(6,7) as well as providing sufficient mass for radiation shielding purposes. The advantages are quite apparent. Flexibility is one of the problems, but by careful selection of the location of shear wall positions, flexibility in planning can still be achieved.

CONCLUSION

Structural design for the Nuclear Age requires consideration of many design loads such as blast, nuclear radiation, and thermal radiation. The utility objective of a structure greatly influences the structural design parameters and the structural costs. Design of economical structures can be achieved if inherent protective features are considered at the time a basic structural type is considered. Addition of small amounts of massive structural material at proper locations in a building can increase protection against residual radiation at relatively low cost.

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Mechanical Design of Protected Areas

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INTRODUCTION

Inherent in the concept of protective structures is the provision of building characteristics that will protect personnel or materials from some force or environmental characteristic that is different from normal, and more adverse. The adverse environmental characteristics that would currently require consideration in war-time are: initial and residual nuclear radiations; blast and shock effects; direct thermal radiation and secondary fires; chemical, biological, and radiological agents. All of these factors except nuclear radiation and radiological agents required consideration before 1945, but the duration of confinement in a protective structure before the era of the nuclear bomb was a few hours at the most, and oftentimes terminated immediately after a bombing raid with high explosives.

With the advent of the atomic bomb, the time factor became more important, and the present concept is that a continuous stay of two weeks in a protective structure will sometimes be necessary, with a shorter period of shelter occupancy being more probable. In addition, greater protection from blast and thermal effects is now required. In fact, the structural requirements for complete blast protection are so severe that such facilities would rarely be provided even for personnel engaged in essential activities. Other persons will be saved or lost, depending on the ability to disperse them to less critical areas in advance of the attack, coupled with a widespread availability of structures offering only moderate protection against some or all of these environmental factors.

Protective structures may be classified in several ways, namely, (1) degree of protection afforded, (2) kind or degree of activity to be maintained during occupancy, and (3) size. In the first category, protective structures will probably be designed either to provide nearly complete protection from nuclear radiation, blast, high temperature, chemical, biological, and radiological agents for personnel engaged in essential activities, or they will be designed to provide protection primarily against radioactive fallout with limited protection against blast and fire exposure. Correspondingly, personnel in

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essential work would probably be required to approximate normal activity during confinement, whereas other persons would be provided with a near minimum of space, comfort, subsistence, and convenience.

The size of protective shelters would probably range from family-size structures with less than 100 sq. ft. of floor area to huge structures of 300,000 to 400,000 sq. ft. that would accommodate thousands of people, depending largely on the temporary or average population density in the immediate vicinity. Some structures would be equipped to take the initiative in rehabilitating their occupants and the occupants of other structures after the emergency was over, whereas others would not.

Protective structures are usually constructed partly or wholly below ground level, probably because the mass, density, heat capacity, and temperature of the earth provide inherent protection against the hazards of nuclear radiations, excess pressure and temperature, and atmospheric contamination, and also offer a high degree of concealment. However, in some areas protective structures may have to be built above ground, because of the prevailing high water table, or for economic reasons.

This paper summarizes some of the experimental work that has been done to identify the design requirements for mechanical equipment in protective structures, the basic considerations involved in equipment selection, and the research and development work yet needed.

BASIC CONSIDERATIONS

It is quite obvious that the mechanical equipment needed in a protective structure depends in some measure on the degree of protection to be afforded, the level of activity to be maintained, and the size of the shelter. In the family shelter, manual effort may be substituted for mechanical power in some activities, and the degree of comfort and subsistence available will depend on individual preparation made in advance. At the other end of the scale, large shelters providing for maximum protection during normal activity of the occupants will require nearly all of the services of normal existence, plus some additional special apparatus to provide for continuity of water supply, air supply, and power supply.

Functions Requiring Mechanical Equipment

For the purpose of this discussion, mechanical equipment needs have been divided into two categories:

1) Those required to provide adequate protection for personnel who must continue essential activities

2) Those required for life, safety and health of persons not engaged in essential activities.

The equipment or facilities in each of these categories have been listed in Table I in the order of the urgency of need after first occupying the structure. The order of urgency may vary somewhat in different structures in each category, depending on size and nature of the activity carried on therein. In some cases all of the facilities listed may not be needed. It is obvious that this writer has taken a rather broad definition of the term, mechanical equipment.

TABLE I

Building Services Requiring Mechanical Equipment

Structures for Essential Activities	Structures to Protect Life, Safety and Health
1. Ventilation (Air Supply)	1. Ventilation (Air Supply)
2. Mechanical Power	2. Toilet Facilities
3. Lighting	3. Water Supply
4. Communications	4. Mechanical Power
5. Absolute Filters	5. Food
6. Toilet Facilities	6. Waste Disposal
7. Water Supply	7. Lighting
8. Food	8. Heating or Cooling
9. Waste Disposal	9. Humidity Control
10. Heating or Cooling	10. Odor Control
11. Humidity Control	11. Communications
12. Odor Control	12. Air Filters

Occupancy tests of underground shelters and protective structures of various types and sizes have been conducted in the United States, Canada and several European countries. These investigations have not been coordinated with each other. Some have been conducted in existing structures, and in other cases, differences in shelter policies and criteria have resulted in different objectives and test procedures. Consequently, the available data do not present a comprehensive picture of design requirements for mechanical equipment for underground structures, nor do they provide clear answers to a number of important questions. Some of the results of a number of these investigations will be summarized in this paper.

Building Services Provided on a Storage Basis

In this discussion, the principal attention will be given to the problems of ventilation, heating and cooling, air cleaning, humidity control, power supply and lighting. More general statements will be made about handling of the problems of food and water supply, waste products, and odor control.

In normal living, most building services are provided on a flow-through basis, i.e., food, water, fuel, air, light and power are either brought to the building steadily or at more or less regular intervals, and the food waste, waste water, toilet waste, combustion gases, foul air and heat are discharged steadily or intermittently through appropriate means. In protective structures, food, drinking water, domestic water, fuel and in some cases, waste disposal would not be available on a flow-through basis.

In practically every protective structure the required amount of food, fuel and potable water would have to be in storage prior to the emergency. In small and medium-size structures the water storage tanks would probably be in the same room as the occupants or adjacent thereto, and there would be virtually no distribution system. In large structures with many rooms, and where normal activity was preserved, a water distribution system would be needed to serve lavatories, drinking fountains, kitchens, etc.

Exceptions to this rule with regard to storage of drinking water occur in some structures where underground springs exist, or where good ground water can be obtained by drilling down through the rock floor of the structure. This latter situation occurs in Stockholm, where ground water is obtainable generally beneath their large shelters. Two-week occupancy tests(1)‡ performed by the Naval Radiological Defense Laboratory in a 100-man shelter indicated that the average drinking water consumption was about 1/2 gallon per day per person. However, the shelter temperatures averaged about 78° F. during this test, and the water requirements were not maximal. A drinking water storage of 1 gallon per day per person would be a better design figure, if temperatures above 80° F. were anticipated during shelter occupancy.

In large structures where water-cooled internal combustion engines are used to drive electric generators, refrigeration compressors, or other mechanical equipment, cooling water from streams or wells would be used with above-ground cooling towers, supplemented in some cases by underground water storage reservoirs if these former sources were vulnerable to enemy attack. The Corps of Engineers recommends(2) 0.54 gpm/kw as a suitable design value for the cooling water requirement for power-generating equipment.

Food would be stored and prepared close at hand in small and medium-size shelters with a minimum of heating and special preparation, whereas food storage rooms, kitchens with considerable equipment, and dining areas would be needed in structures where normal activities were maintained for large groups of people. Conventional food-processing equipment would probably be used in large structures housing personnel carrying on essential activities.

Food waste and waste water would probably be stored in covered containers or tanks in small and medium-size structures, and chemical toilets would be used to treat and store toilet waste. In large structures, a sanitary system would be required and the waste would have to be stored in large underground tanks, unless a discharge to a stream or to the ground surface could be provided that would not be subject to operational failure during an emergency. Such an effluent waste system would have to be equipped with blast protection to prevent rupture and back-flow.

Fuel would normally be stored near the point of use, with due regard for fire safety and danger of fuel leakage. Such points of usage might be: a small, vented, combination cooking and heating device in a family shelter; a gasoline engine driving a generator and blower in a medium-size structure; a diesel engine or a heating boiler in a large structure. The fuel storage tank could be placed in an area of marginal radiation protection near the structure, but should be well protected from blast and fire

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‡Raised figures in parentheses refer to list of references at end of paper.

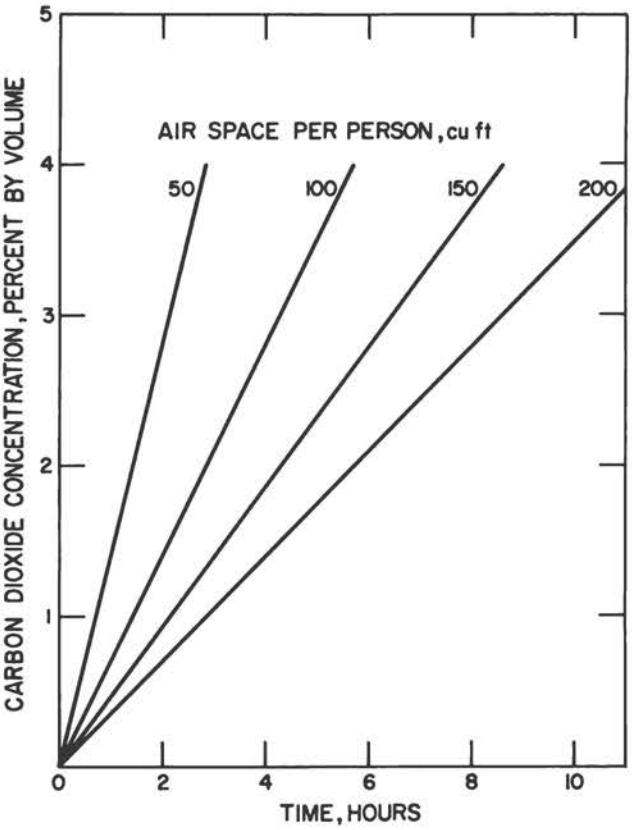

Figure 1

exposure. A heat exchanger in the exhaust gas circuit or in the water jacket circuit of an internal combustion engine is preferred as a source of heat in large structures designed to withstand blast, in order to avoid the stack or chimney needed for a furnace or boiler. If heating were necessary during standby operation when the emergency power plant was not in use, an alternate source of heat would be required.

Ventilation

The need for air for respiration is immediate and continuous after entering a protective structure. However, the volume of air in the structure is usually adequate to prevent the carbon dioxide content from becoming excessive for a few hours. Occupation of a shelter or structure for a limited period without outside air supply is frequently a design criterion, because of the probability of fire conditions near the air intake or other sources of contamination of the air supply. An adult at rest consumes about 0.85 cu. ft. of oxygen and liberates about 0.7 cu. ft. of carbon dioxide per hour on the average. The rise of CO_2 content of the air ordinarily becomes hazardous before the depletion of oxygen as a result of the respiration process. Figure 1 shows the relation between the carbon dioxide content in a closed space, the volume of air space per person, and the elapsed time.

Some authorities(3,4) concerned with shelter design in Europe consider 2% CO_2 to be an acceptable working limit for prolonged exposure. More recent laboratory work(5) at the U. S. Naval Research Laboratory, New London, Conn. indicates that the CO_2 content should not exceed 1.5% for prolonged periods, if basic performance and physiological functions are to remain unaffected. Carbon dioxide can be absorbed by chemicals such as soda-lime, potassium hydroxide and lithium hydroxide to control the carbon dioxide concentration. Chlorate candles can be burned to liberate oxygen, or other chemicals can be used to absorb carbon dioxide and liberate oxygen at the same time.

When ventilation with fresh air can be provided at a ventilation rate of 1 cfm per person this will be more than adequate to prevent excessive rise in CO_2 concentration for adults at rest. However, it has been found by experiment(6) that the ventilation rate required in an underground structure to prevent excessive temperature rise or undesirable humidity conditions often exceeds 1 cfm per person. Manually-operated blowers selected for small shelters should have a higher air delivery rate than that required to prevent excessive CO_2 concentration, so continuous operation would not be necessary.

In an underground structure without air conditioning, two methods are available for dissipating the heat produced inside the structure, namely, heat conduction into the walls of the shelter and surrounding earth, and heat removal by the ventilating air. In a small structure, such as a family-size fallout shelter, the ratio of wall surface area to floor area is higher than in a large structure, and the small effective radius of the small structure provides a greater heat sink per unit floor area in the surrounding earth than for the large structure. Consequently, a small structure would be expected to transfer a higher percentage of the interior heat release to the earth than the larger one. Other factors which determine the relative effectiveness of the earth and the ventilating air as means of heat removal are: thermal conductivity, density and moisture content of the earth; the depth of the structure below the surface; the latitude of the site; the season of the year; the average temperature and dew point of the ventilating air; and solar radiation.

Air Filtration

The filtration or purification of the ventilating air is a factor of considerable importance in the design of fallout shelters and the selection of equipment. In addition to the direct radiation from a bomb burst, which will be intense, instantaneous and of short duration, the fallout will constitute a principal source of nuclear radiation over a wide area and for an extended period of time. The particle size in the fallout for any given situation will depend on the nature of the soil, the kind of weapon exploded, the height of the burst, and other factors. Data collected during some of the U. S. bomb tests and subsequent analysis by the Naval Radiological Defense Laboratory and the Rand Corporation indicate the probable relation(7) between particle size and percentage of the total radioactive dosage from the fallout, as shown in Table II.

TABLE II

Fallout Particle Size vs. Radioactive Dosage

Particle Size	Radioactive Dosage
microns	percent
> 400	10
200 - 400	10
100 - 200	30
50 - 100	30
25 - 50	10
< 25	10

Particles of 5 micron size will be brought down by rain. Particles of 1 micron size will be distributed world-wide. For comparison, a 1000 micron particle is about the size of a grain of salt or sugar.

In considering the distribution of the fallout from a bomb burst it is usually assumed that the radioactive particles will begin their descent from an altitude of 80,000 feet, and that a cross-wind of 15 mph may exist during the period of descent. On this basis, particles of 350 micron diameter would be deposited 2 to 3 miles down-wind, and would fall in about 3/4 of an hour, whereas particles of 75 microns in diameter would be deposited about 200 miles down-wind, and would fall in about 16 hours. It is estimated that most of the radioactive deposit would have fallen in 12 to 24 hours.

The present opinion is that the particles constituting the source of the major part of the radiation dosage would be too large and heavy to be drawn into properly-designed air intakes of a ventilating system. However, research on the sizes of particles that can be sucked into the ventilating system and on the design features of intake hoods that will minimize the intake of fallout is needed.

Underground structures housing personnel that must maintain important military or civilian activities should be equipped with air purification equipment for chemical, biological and radiological agents, since such installations are more likely to be selected as targets of attack, and are therefore more subject to air contamination during and after an attack. Such equipment has been extensively studied and design information is available in a publication(8) of the Army Chemical Center.

Adequate filter media for radioactive fallout particles of the type needed for small and medium-size shelters are also available. The principal unknowns involved in their use are the pressure drop created in the ventilating air circuit, and information on the amount of fallout material they will hold in relation to pressure drop and efficiency. The pressure drop of an adequate filter for particles of 1 micron and larger creates special problems in the family-type shelter, if manually-operated blowers are used for ventilation and if heating is needed in the shelter, emphasizing the importance of having mechanical power available in all fallout shelters. These problems are also under study by the Office of Civil Defense.

EXPERIMENTAL STUDIES

Family-Size Shelters

A study(6) of the thermal characteristics of a family-size, concrete underground fallout shelter with six simulated occupants was carried out for the Office of Civil and Defense Mobilization by the National Bureau of Standards. The simulated occupants had sensible and latent heat output characteristics similar to those for human beings. The primary objective of the study was to obtain engineering data on the environmental factors of temperature, humidity, ventilation rate and heat exchange in such a shelter, during periods of occupancy up to 14 days under severe summer and winter conditions.

An experimental shelter was built on the grounds of the National Bureau of Standards in general accordance with plans shown in a bulletin(9) of the Office of Civil and Defense Mobilization. Figures 2 and 3 are schematic drawings of the shelter showing its position relative to the ground surface and much of the instrumentation used for the study. The interior dimensions were: length, 10' 8", width 8', and height 6' 6". The hatchway on the north side was 2' wide, and the shielding wall was 8" thick, leaving the main room with floor dimensions of 8' x 8'. The floor and ceiling of the shelter were 6" thick, and the walls 8" thick, all of reinforced concrete.

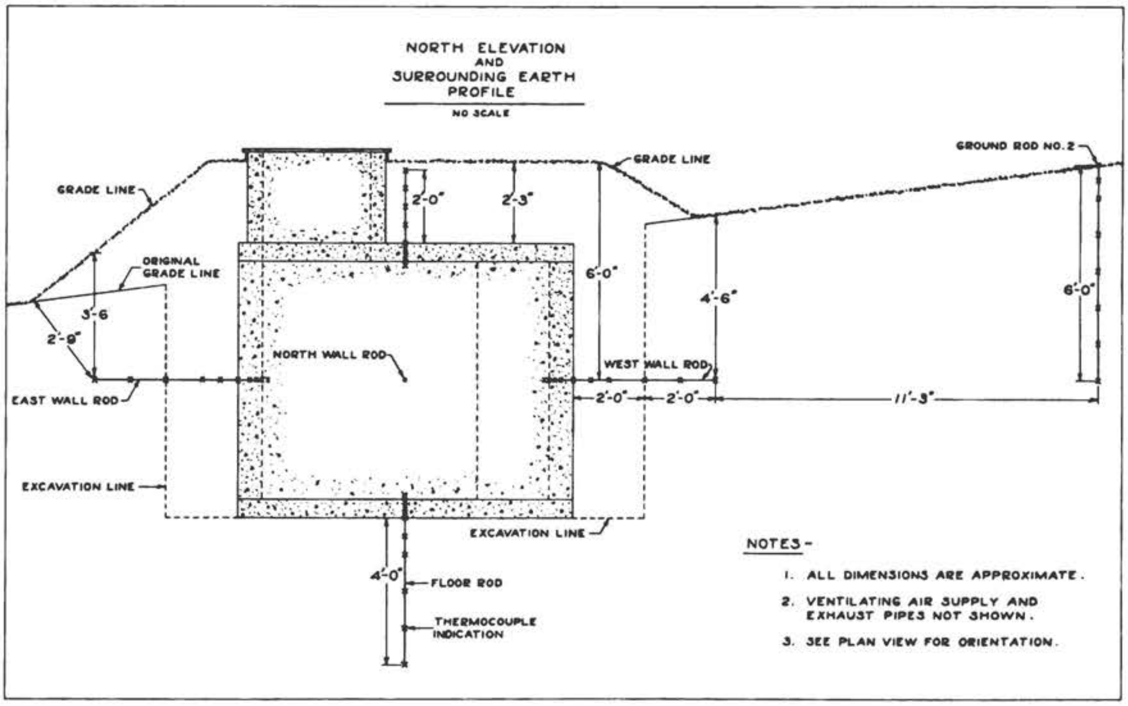

Figure 2. North elevation of prototype underground fallout shelter showing profiles of earth over shelter and nearby unexcavated earth

The shelter was equipped with a thermocouple system for measuring temperatures in the concrete floor, ceiling and walls; in the adjacent earth to a distance of 4' from the walls; in the undisturbed earth at a greater distance; in the shelter space itself; and in the supply and exhaust air ducts for the shelter. Relative humidity was also measured at several stations in the shelter. An apparatus for conditioning the ventilating air to the selected dry bulb and dew point temperatures, and for regulating the flow rate, was provided in an adjacent building. Six simulated occupants made of metal, jacketed in cloth and having a surface area of 21.5 sq. ft. each, were used to represent sedentary adults in the shelter. Adjustable electric resistance heaters inside the simulated occupants produced a total heat output equivalent to the human metabolic rate. Water was dripped on the cloth jacket in proportion to published values of latent heat output of human beings as a function of dry bulb temperature. Heat flow meters were secured to the center of each of the six exposures of the shelter to measure the heat transfer into these surfaces.

Five tests of either one or two weeks duration were made in the shelter, and with the ventilation rate, dry bulb and dew point temperatures of the supply air, and occupancy as shown in Table III. Four of the tests were performed near the end of the summer when earth temperatures were near a maximum, and one was performed in the winter when the earth temperature was near a minimum.

TABLE III

Schedule of Test Conditions

Test No.	Duration of Test	Ventilating Air Supply			Number of Simulated Occupants	Approx. Internal Heat Input
		Flow Rate	Avg. Dry Bulb Temp.	Dew Point Temp.		
	(days)	(cfm)	°F	°F		(Btu/hr)
1	7	42	85	69	0	110
2	7	0	--	--	6	2500
3	14	42	85	69	6	2500
4	14	18	85	69	6	2500
5	14	18	35	33	6	2500

The tests showed that the rise in dry bulb temperature in the shelter ranged from 12 to 15 degrees F during the two weeks' simulated occupancy for summer and winter conditions, tests 3 to 5 inclusive. The maximum dry bulb temperatures observed in the shelter during summer Tests 3 and 4 were about 82° F, whereas the temperature rose to 62° F during two weeks' occupancy in the winter test. The dry bulb temperature tended to level off in two weeks, although this tendency was more pronounced for the summer tests than for the winter tests as illustrated in Figures 4 and 5. This difference between winter and summer characteristics can be explained by the changing proportions of latent and sensible heat output of human beings with rising ambient temperature in the range from 60° to 80° F. At 60° F, only 10 to 15% of the human heat output is represented by moisture, whereas at 80° F the latent heat output is about half of the total. In most climates, ventilating air in moderate amounts has the capacity for removing all of the latent heat output of the occupant at a temperature of 80° F, thus leaving a lesser amount of sensible heat to be absorbed jointly by the shelter enclosure and the ventilating air than is the case at a temperature of 60° F.

The shelter humidity was high during both summer and winter tests. Condensation began to appear on the interior surfaces of the shelter during the first day of summer Tests 3 and 4, and continued throughout these 14-day tests. About 190 lbs. of water were siphoned off the floor in Test 4 when the ventilation rate was 3 cfm per person, whereas about 50 lbs. of water were collected on the floor in Test 3 with a ventilation rate of 7 cfm per person. In the latter test, the walls of the shelter had dried off at the end of the test, whereas the ceiling and floor were still wet. In the winter Test 5, a small amount of condensation was evident 3 days after the start, but no water collected on the floor and all of the shelter surfaces were dry at the end of the test. However the ventilation rate of 3 cfm per person was marginal for the winter test, because the relative humidity in the main room of the shelter averaged about 90% as indicated in Figure 5.

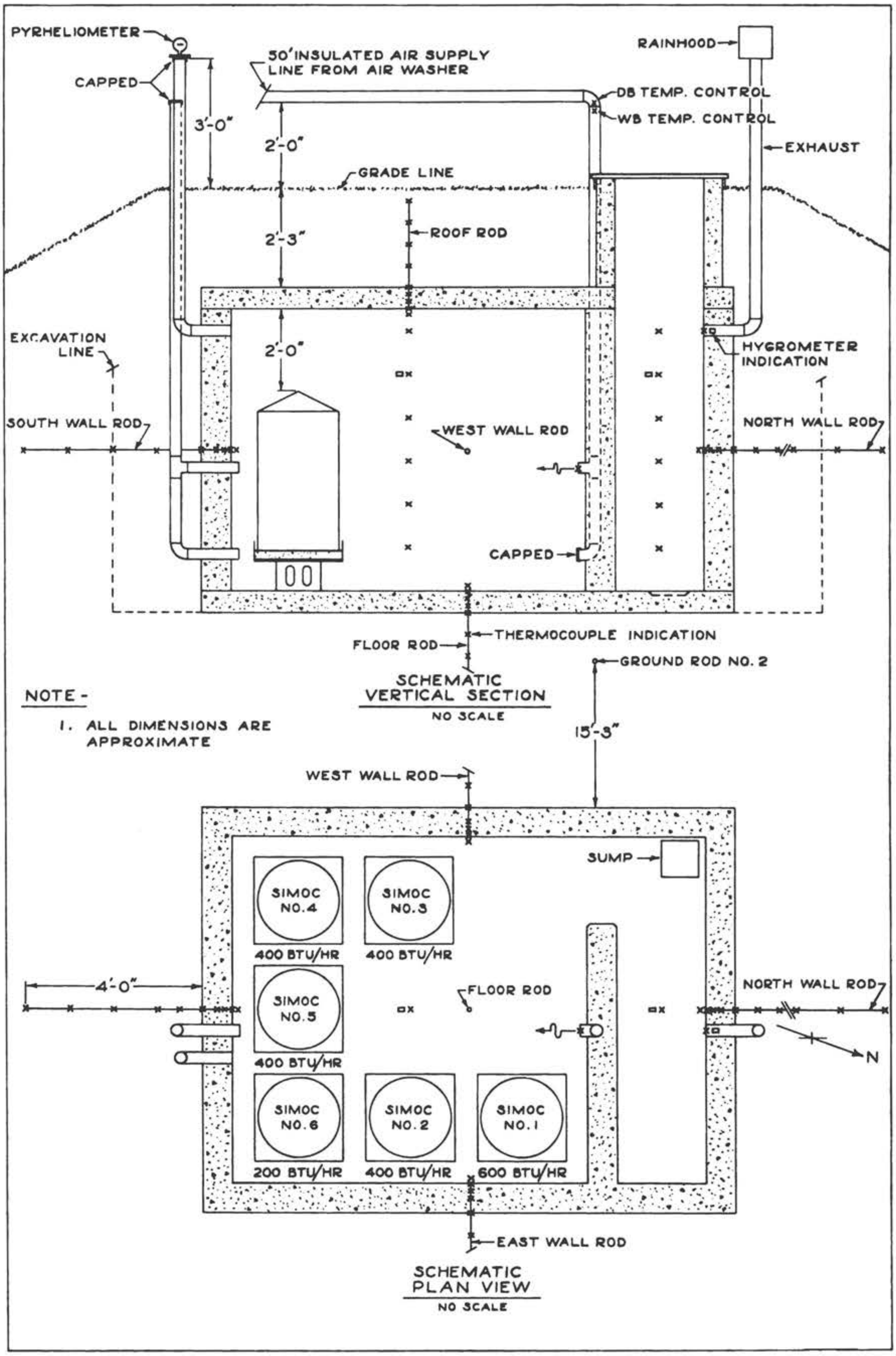

Figure 3. Schematic vertical section and plan view of prototype underground fallout shelter showing locations of the simulated occupants, air supply and exhaust lines, and some of the instrumentation

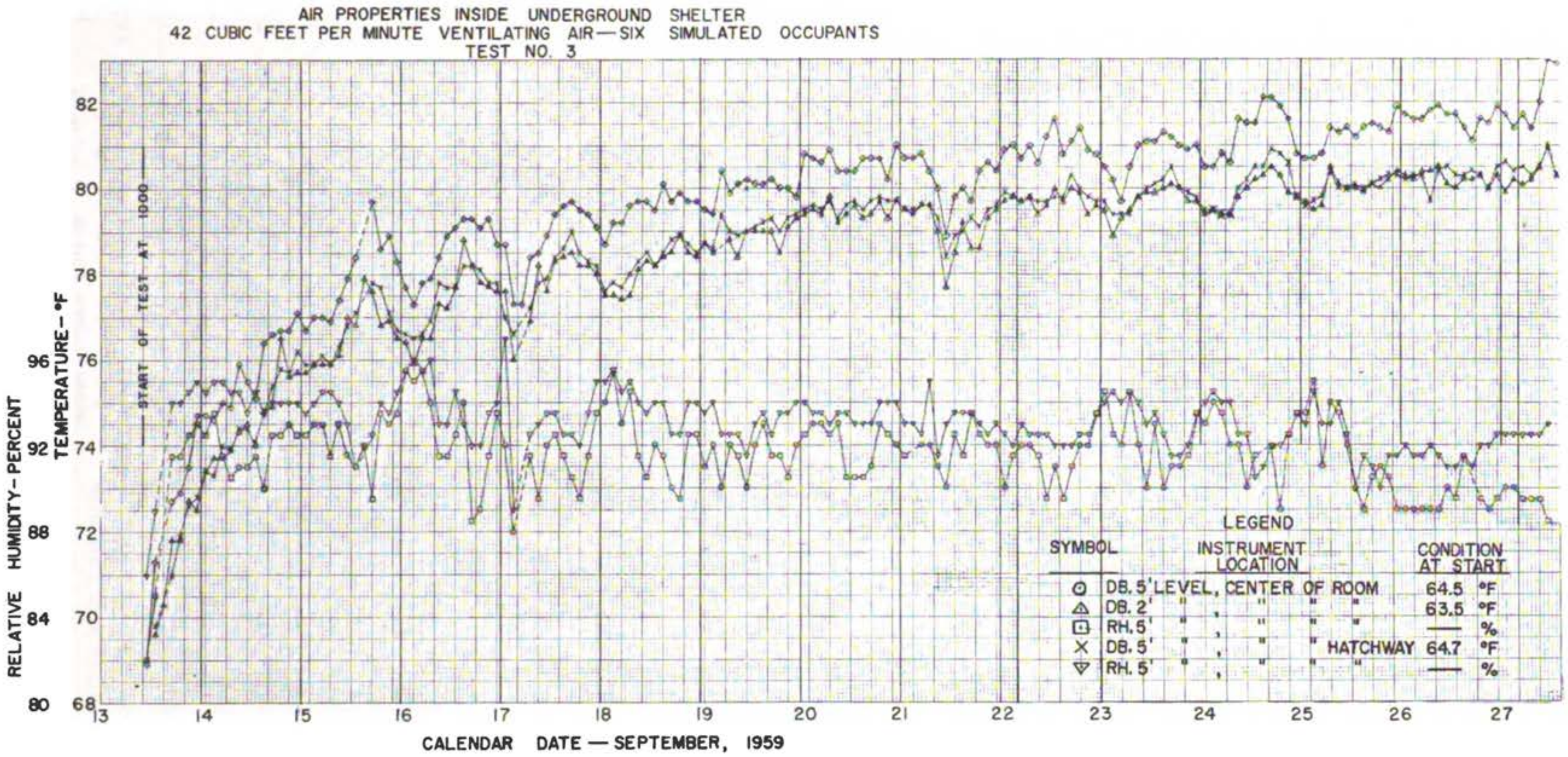

Figure 4. Dry bulb temperatures at three stations and relative humidity at two stations inside the prototype shelter during summer Test 3

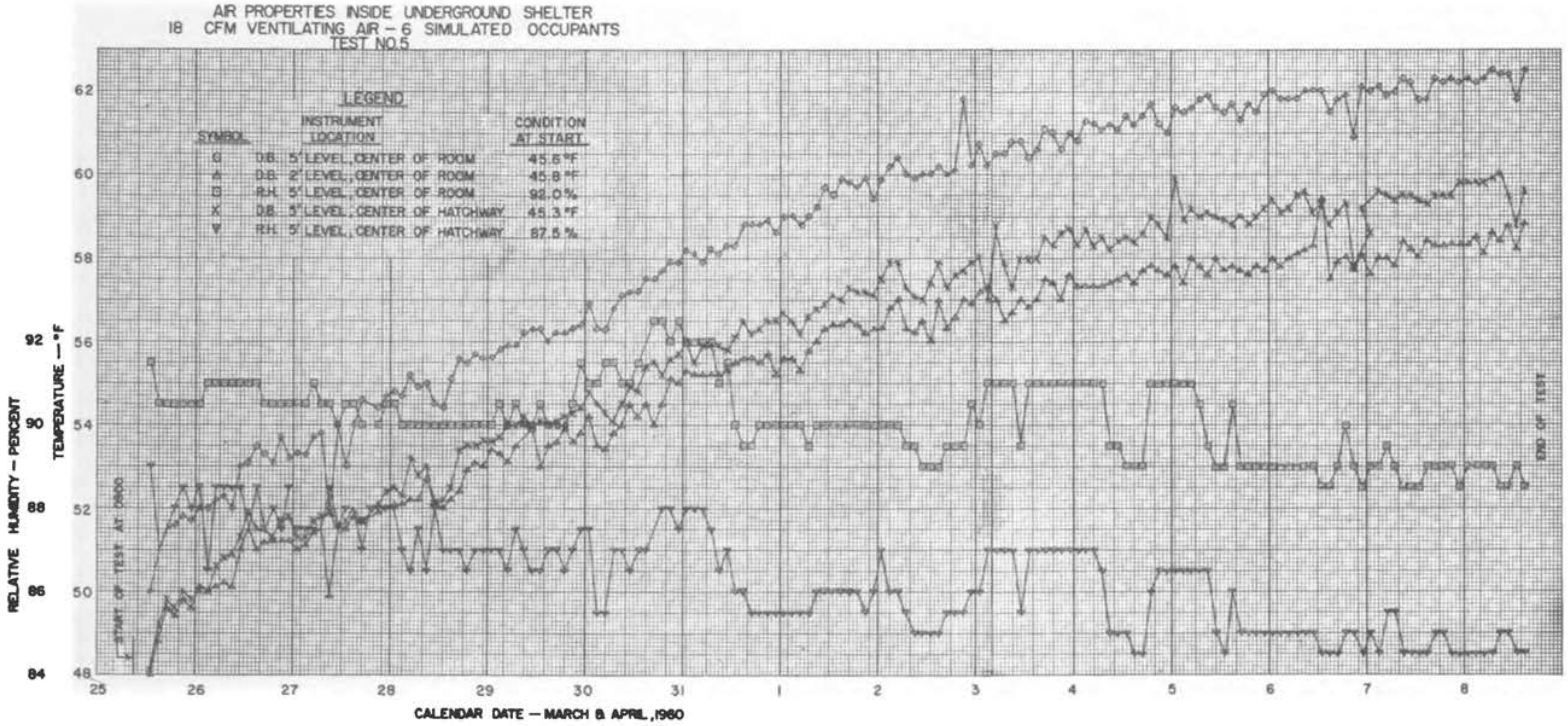

Figure 5. Dry bulb temperatures at three stations and relative humidity at two stations inside the prototype shelter during winter Test 5

Because the interior surface area of the family shelter was large in relation to the internal sensible heat release, only a small temperature difference existed between the shelter air and the enclosing surfaces. In effect, the interior surface temperatures controlled the dew point temperature of the shelter air and of the exhaust air during the conditions of the summer test. Thus it was concluded that the amount of ventilating air required for removing moisture from this type and size of shelter depended largely on the interior shelter surface temperatures, the dew point temperature of the incoming air, and the amount of heat released within the shelter. The calculated relation between these variables is shown in Figure 6, for which it has been assumed that the dew point temperature of the exhaust air was equal to the average interior surface temperature, and the moisture loss and total heat emission of each of the six occupants were equal to that shown in the ASHRAE Guide(10) for adults seated at rest.

In Figure 6, each curve is asymptotic to a vertical line for which the shelter surface temperature and dew point temperature of the supply air were equal. Any point on the graph below or to the left of a curve represents a combination of surface temperature, dew point temperature, and ventilation rate that would result in condensation inside the shelter, whereas any point above or to the right of a curve represents a combination of variables for which all of the moisture would be carried out by the ventilating air. The predictions of this set of curves agreed quite well with the observed results on condensation in Tests 3, 4 and 5. In larger shelters, the interior shelter surface area per occupant would usually be less; the temperature difference between shelter air and surface would usually be greater than for the family shelter; and Figure 6 would be less useful in evaluating shelter environment.

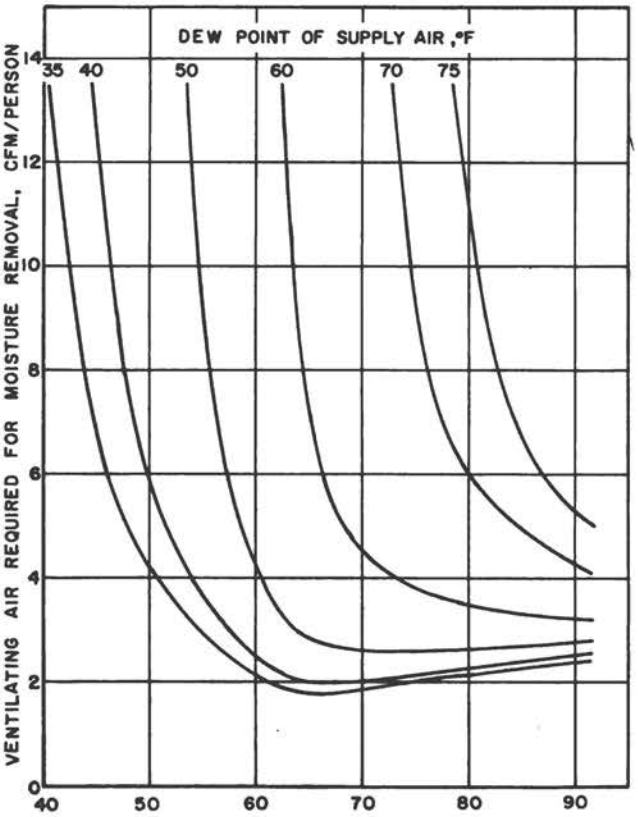

Figure 6

Since the summer tests were made with the inlet ventilating air at a rather high dry bulb temperature, namely 85° F., some heat was surrendered to the shelter surfaces throughout these tests, but it was less than 10% of the internal heat release inside the shelter during most of the time in Tests 3 and 4. On the other hand, the ventilating air removed latent heat or moisture from the shelter whenever the shelter air temperature exceeded the dew point temperature of the inlet air, i.e., 69° F. The latent heat removal amounted to about 50% of the total internal heat release at the end of Test 3, and about 25% of the total internal heat release at the end of Test 4. These relationships are shown in Figures 7 and 8 for Tests 3 and 4, respectively.

In the winter test, inlet ventilating air temperature was always lower than shelter air temperature, so it removed significant amounts of sensible heat.

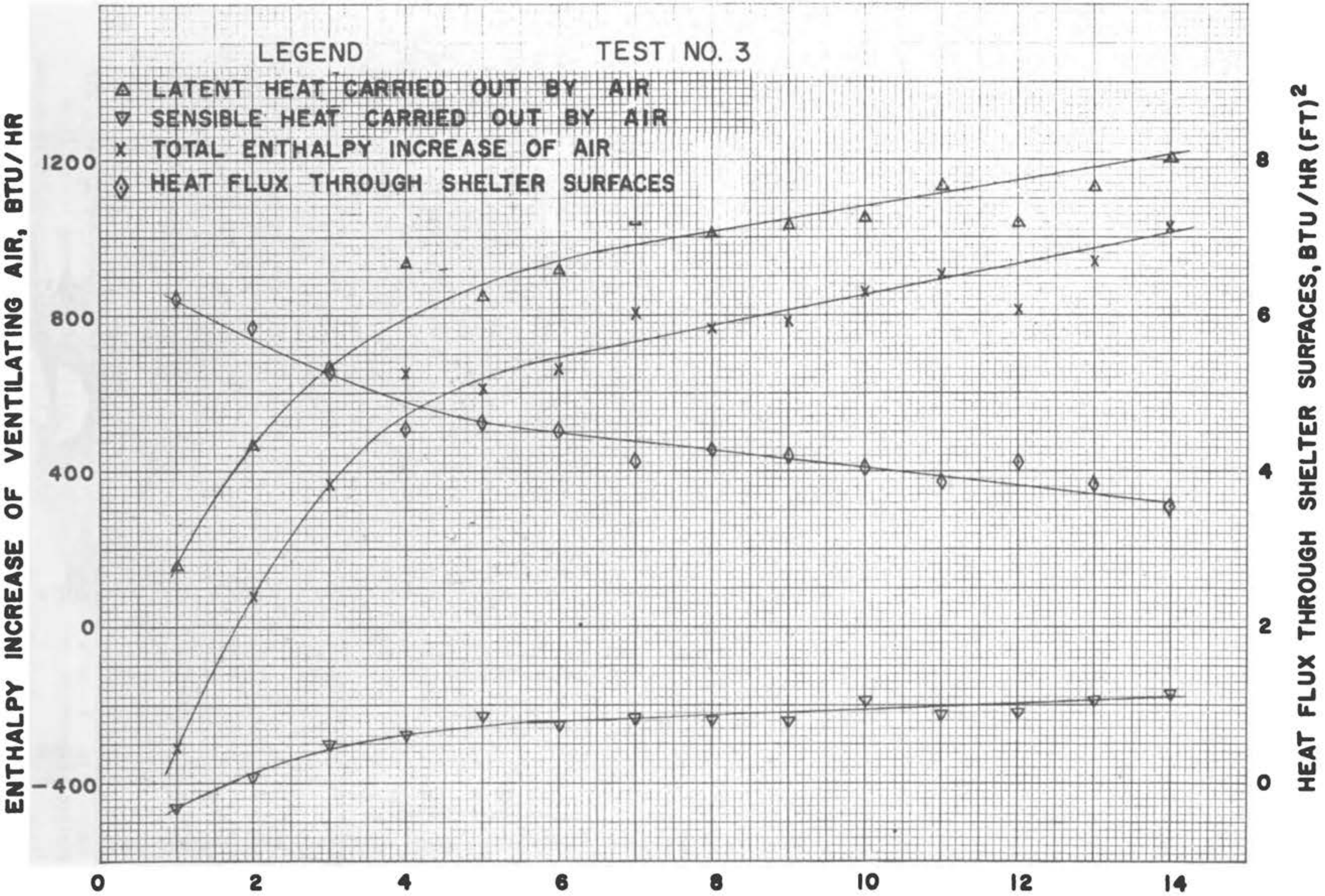

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Figure 7. Curves showing the latent, sensible, and total heat carried out by the ventilating air and the average heat flux through the interior surfaces of the shelter during summer Test 3

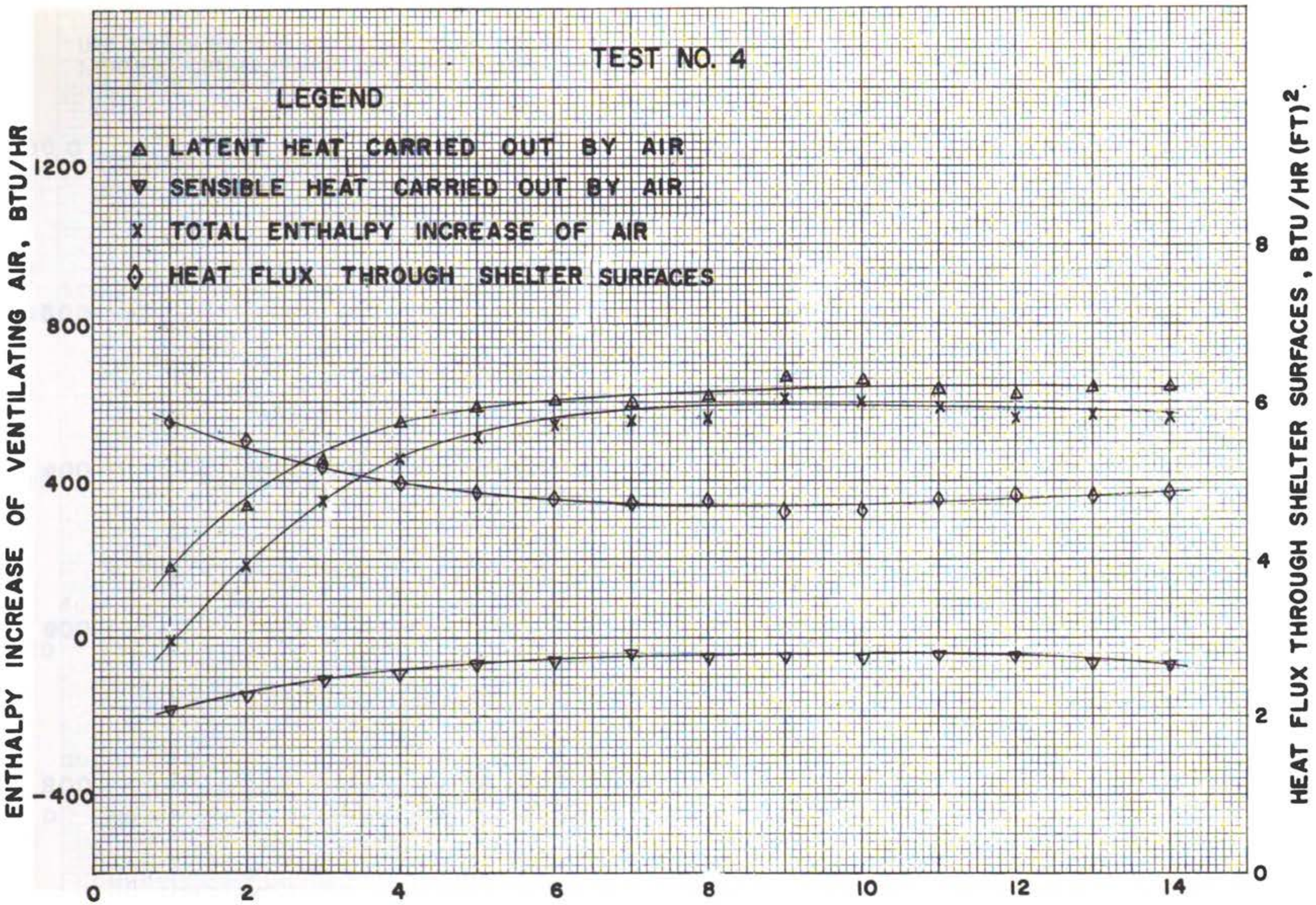

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Figure 8. Curves showing the latent, sensible, and total heat carried out by the ventilating air and the average heat flux through the interior surfaces of the shelter during summer Test 4

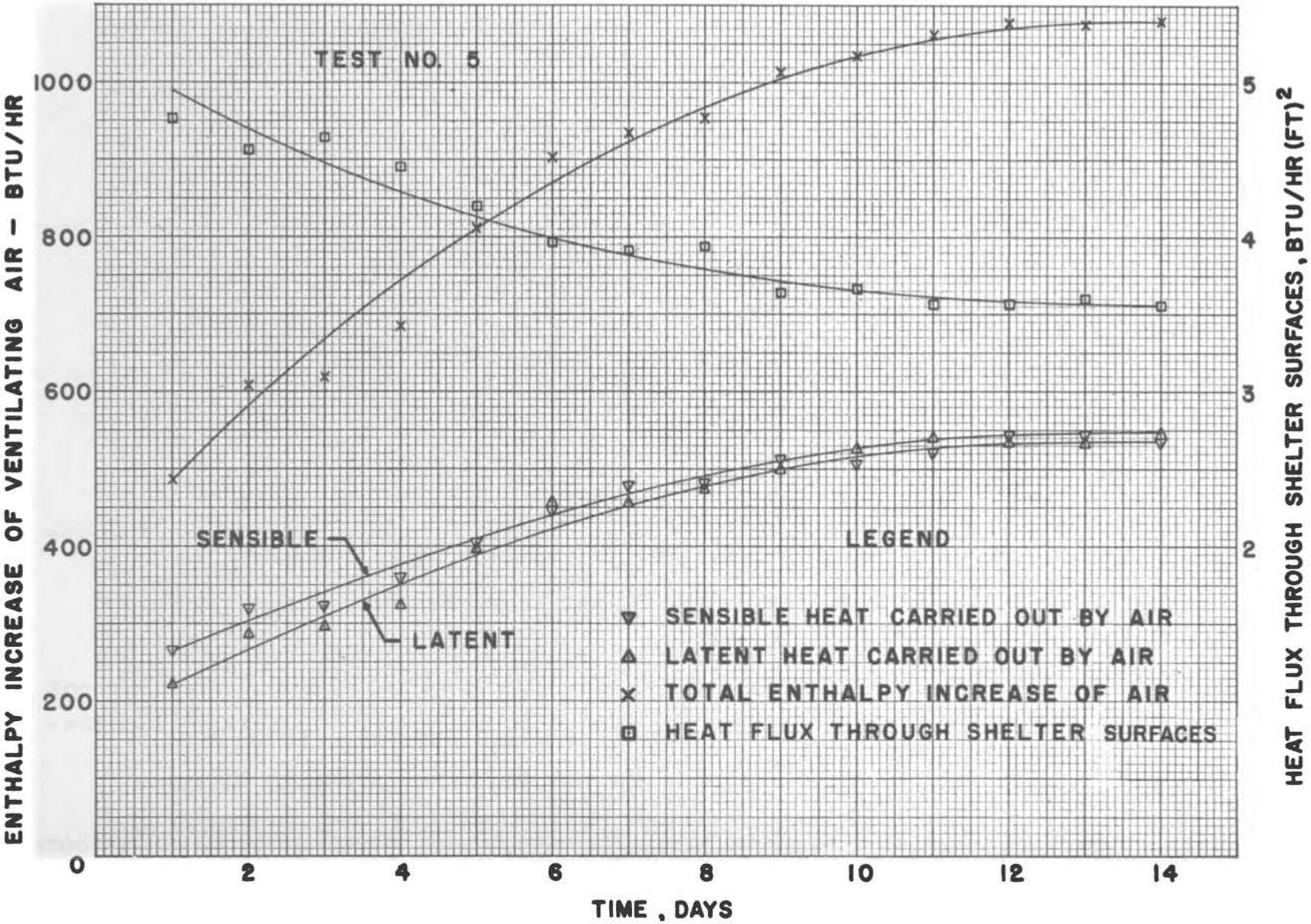

Figure 9. Curves showing the latent, sensible, and total heat carried out by the ventilating air and the average heat flux through the interior surfaces of the shelter during winter Test 5

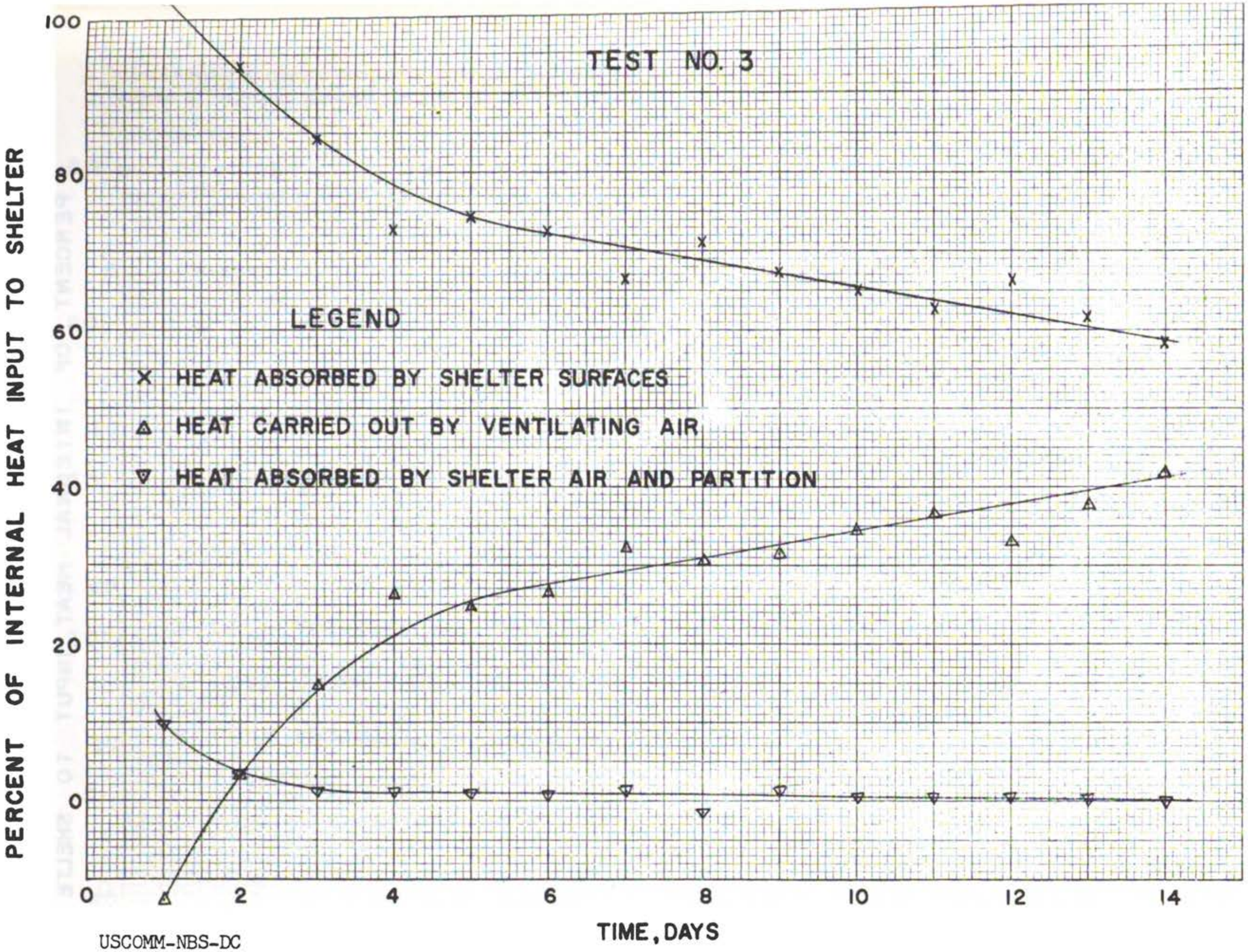

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Figure 10. Curves showing the heat transfer to the shelter surfaces, the shelter partition, and the ventilating air as a percentage of the internal heat input by the simulated occupants and the lights during summer Test 3

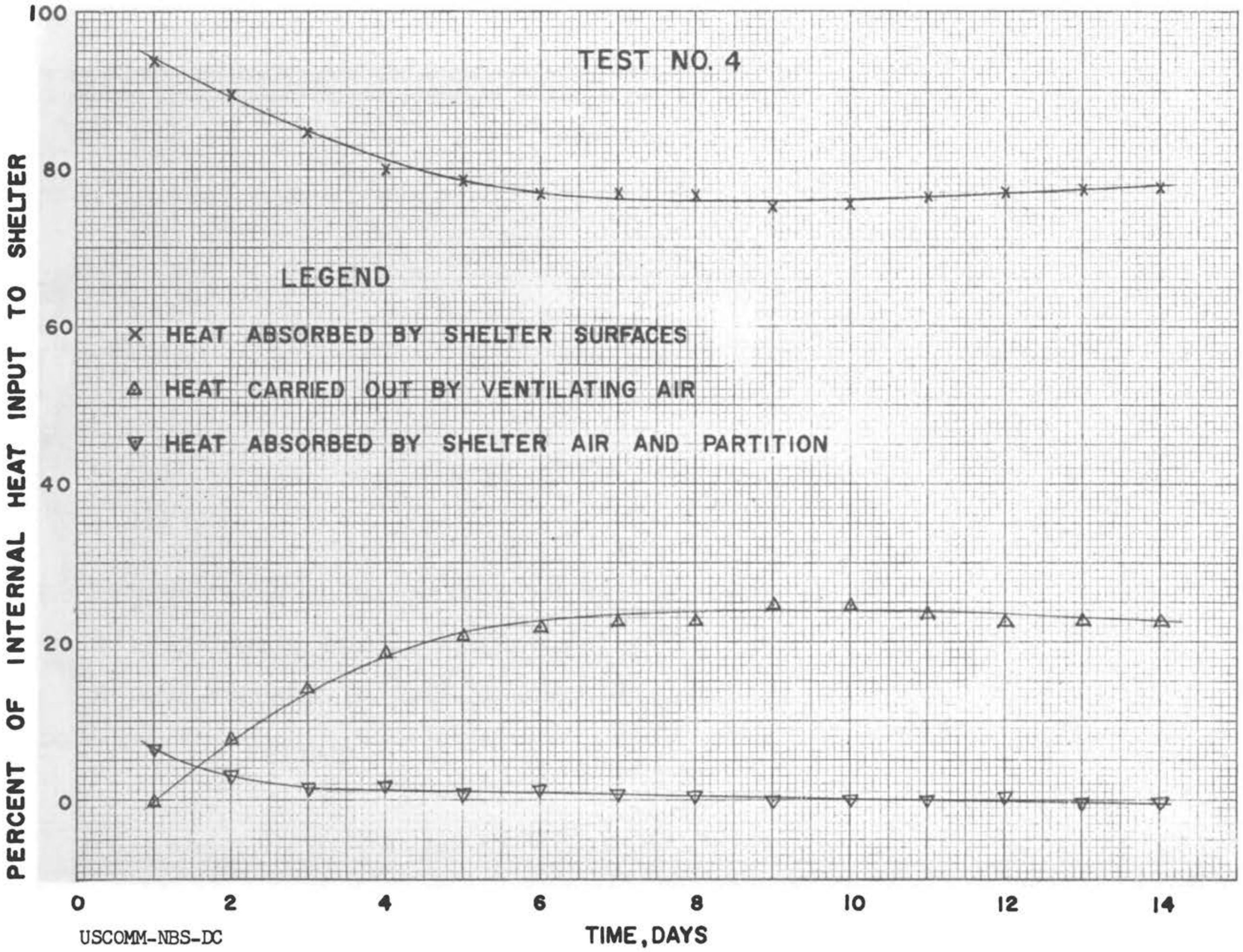

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Figure 11. Curves showing the heat transfer to the shelter surfaces, the shelter partition, and the ventilating air as a percentage of the internal heat input by the simulated occupants and the lights during summer Test 4

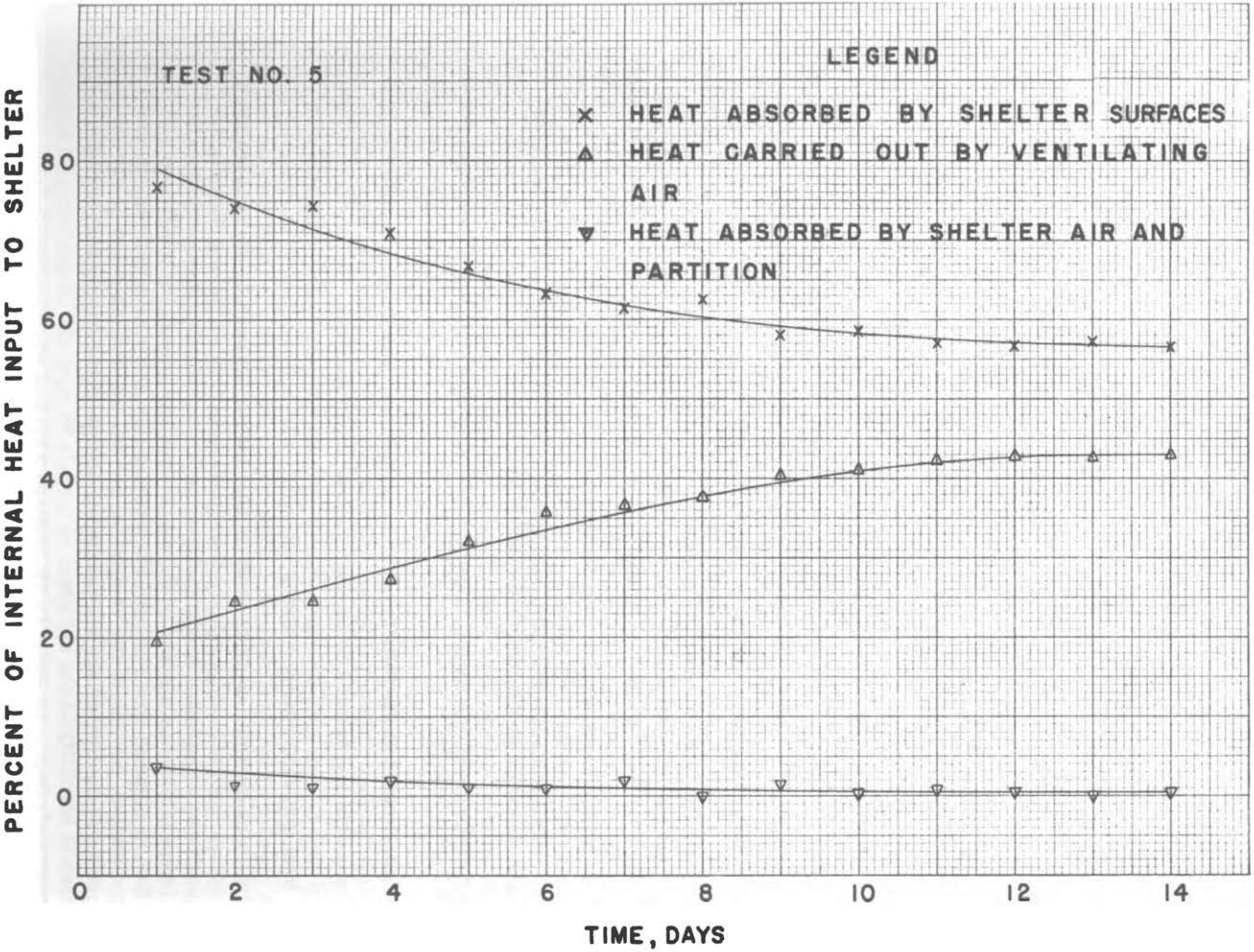

Figure 12. Curves showing the heat transfer to the shelter surfaces, the shelter partition, and the ventilating air as a percentage of the internal heat input by the simulated occupants and the lights during winter Test 5

The sensible and latent heat removals by the ventilating air were each about 20% of the total internal heat release at the end of Test 5, as shown in Figure 9.

The daily average value of the heat transfer rate to the interior shelter surfaces was determined by subtracting the heat carried out by the ventilating air from the total heat released inside the shelter. Figures 10 to 12 show these values expressed as percentages of the total internal heat release for Tests 3 to 5, respectively. In these tests the heat transfer rate to the shelter surfaces decreased as the test progressed, and reached a reasonably steady value at the end of the two-week tests. This component of heat absorption ranged from about 57% at the end of Test 5 to 78% at the end of Test 4. The heat transfer from the shelter air to the interior shelter surfaces was all sensible heat in Test 5, but had both sensible and latent components in Tests 3 and 4. The average heat flux through the interior surfaces of the enclosure ranged from about 3.5 Btu/hr $(ft)^2$ at the end of Tests 3 and 5 to about 4.7 Btu/hr $(ft)^2$ at the end of Test 4.

The results of these tests of a family-size underground fallout shelter indicate that the shelter air temperature was closely related to the mean interior surface temperature and, therefore, that excessive shelter air temperatures would probably not develop during a two-week summer occupancy of such a shelter by six adults in areas where the initial earth temperature was less than about 73° F. These tests further showed that condensation would probably be prevalent during spring, summer, and fall seasons in areas having summer weather conditions similar to those in Washington, D. C. Increasing the ventilation rate would not always prevent condensation, depending on the difference between the dew point temperature of the supply air and the temperature of the shelter surfaces. It is believed that condensation will be a serious problem in small shelters, and that some measures to control it will be needed. Various approaches to this problem will be discussed later.

Climatic, site, and occupancy conditions that would cause higher shelter air temperatures than those observed in the experimental shelter are:

1) Earth around the shelter having lower thermal conductivity, lower moisture content, or lower density

2) Higher initial earth temperature

3) Higher sensible and latent heat contents of the ventilating air

4) Higher heat output by the occupants.

Handbook data(10) on summer weather indicate that higher average earth temperatures and higher average dry bulb temperatures than those experienced during these tests occur in the southern and southwestern parts of the United States. It is probable that the dry bulb temperature in a shelter could not be kept low enough by ventilation and earth conduction in some of these areas. However, in the more arid midwestern and southwestern climates, cooling of the ventilating air and the shelter could be accomplished without great cost by using an evaporative cooler in the supply air, accompanied by a rise in humidity in the shelter.

More emphasis has been placed on the basement fallout shelter for family protection in Canada(11) than in the United States. The Division of Building Research of the National Research Council in Ottawa is carrying out investigations of heating and ventilation needs in such shelters. These investigations(12) have already shown that heating will probably be needed in the basement shelter under winter conditions if the main heating system of the house is inoperative, but that ventilation may be more easily handled in a basement shelter than in the backyard type of shelter.

The basement-type shelter probably has several advantages with respect to the subterranean backyard shelter. Because it is connected to or a part of the house proper, it is somewhat more accessible, and would probably be easier to keep properly provisioned and cared for during standby conditions. Ventilation could usually be provided by a planned exchange of air by natural convection between the shelter and the remainder of the basement space. The natural leakage of air into the basement would, in some cases, provide enough fresh air for the shelter. High humidity and condensation during standby conditions would ordinarily not be as much of a problem in a basement shelter, and moisture generated in the shelter during occupancy would be distributed to the entire basement and condensed or absorbed on a much larger area than in the backyard shelter. Some of the advantages of the basement shelter could be obtained for the subterranean backyard shelter by locating it near the house and providing a passageway to the basement. An important disadvantage of the basement shelter is the greater vulnerability to contamination of the shelter air supply, and excessive heat if the house burned down during the emergency.

Various methods for providing ventilation air for small subterranean backyard shelters have been suggested. There are little test data and limited experience available on this equipment. Some of the methods are:

1) A dual-powered centrifugal or positive-displacement blower equipped with an electric motor and a gear box and hand crank for manual operation. The blower could be arranged for hand-cranking or for operation by a foot-pedal drive like a bicycle. Hand-driven blowers are available from several commercial sources. A positive displacement blower is preferable if filters are used in the ventilation air supply.

2) A bellows-type of positive displacement air pump. These have been used experimentally in England. They could be designed for hand or foot operation.

3) Ventilation induced by the chimney effect of a small heater. A fuel-burning heater designed for maximum inspiration of fresh air could probably be built into the base of a vertical flue, to induce enough fresh air to provide for the needs of the occupants without manual effort. This ventilation function could probably be combined with the heating and cooking needs of the occupants, and could be enclosed in fitted pieces of insulation for summer use when heat release in the shelter was undesirable. This type of ventilation system would not be satisfactory if filters were used in the ventilating air supply.

The results of the winter test in the family-size shelter indicate that some heating should be provided in this type of shelter in many parts of the United States, inasmuch as the shelter temperature had only reached 62° F after two weeks' occupancy. The ventilation rate can be reduced to approximately 3 cfm per person in winter weather without serious condensation problems, and could probably be reduced to a level between 1 and 2 cfm per person during the coldest weather or when the supply air was sufficiently dry.

Besides reduction of ventilation rate, other methods for increasing winter comfort in shelters are as follows:

1) Wear additional clothing
2) Use a curtain at the doorway of the main room to reduce the wall area for heat loss
3) Drape aluminum foil over all or parts of the walls to provide air spaces at the walls and present a surface for reflection of radiant energy from the body
4) Use a small portable heater.

In colder climates there may be no alternative to the use of a heater. A heating capacity of 2000 to 4000 Btu/hr is probably adequate for family-size shelters depending on the severity of the climate. The heater should be of the vented type to minimize the hazard of excessive CO_2 or other toxic gases in the shelter. Kerosene or liquified petroleum heaters are probably best suited to this application. Only heaters that have been tested for safety should be used for shelter heating. Leak-tight containers should be used for fuel storage and great care should be exercised in filling the heater. If ventilation were being provided manually, the operation of a fuel-burning heater would have to be coordinated with the blower operation.

Some steps to control or minimize condensation in small shelters are desirable. The ceiling is considered to be the most critical surface from the standpoint of condensation, because the condensed moisture would drip on everything in the shelter. The ceiling might be insulated or lined to prevent condensation, leaving the walls and floor as condensing surfaces from which drainage could be more readily controlled. Film-type movement of the condensate from the ceiling to the side walls could be promoted by doming or by sloping the ceiling surface downward to the side walls, and by treating the ceiling surface with a wetting agent. An alternate method for moisture control would be the storage of a quantity of desiccant in the shelter for absorbing the moisture during periods of occupancy.

The amount of condensate collected in summer Test 3 with a ventilation rate of 3 cfm per person was equivalent to a depth of about 1/2" of water over the entire floor of the shelter. If this condensate could have been absorbed in the concrete of the shelter and evenly distributed, the moisture content of the concrete would have been increased a little less than 1/2% by weight. Thus, if the concrete surfaces inside the shelter could be kept at a moisture level considerably below saturation during standby, they could probably absorb all of the excess moisture resulting from a two-week occupancy. From the standpoint of moisture absorption, metal walls would be less desirable than masonry walls for shelters.

Group Shelters

A few experiments have been carried on in larger shelters housing 50 to 100 people. The U. S. Naval Radiological Defense Laboratory in San Francisco conducted a two-week test(1,13) in a 100-man shelter in December 1959, for which 100 men of various ages, ranging from 17 to 62, were used as subjects. The shelter was a buried flexible-arch metal structure with a floor area 25' x 48', corresponding to an average of 12 sq. ft. of floor area per person. Figure 13 is an exterior view of one end showing the entrance and Figure 14 is an interior view looking toward the entrance door. A gasoline engine-driven generator provided electric energy for lights and for the ventilation blower. The blower was adjusted to provide ventilation air at the rate of 1600 cfm.

Figure 13. Exterior view of one end and entrance passage to the 100-man metal shelter

Figure 14. Interior view of shelter showing supply duct and grille

The test was conducted in December, and the entering air ranged in temperature from 36° to 67° F. The shelter air temperature ranged from 70° to 82° F. The ventilating blower was turned off for short periods during the coolest part of the night because of cold drafts. The relative humidity ranged from 35 to 90%, and there was no condensation on the walls when the blower was running. Analysis by the NRDL indicated that approximately 40% of the internal heat release was absorbed by the earth surrounding the shelter, and the remainder was carried out by the ventilating air which experienced a temperature rise of about 18 degrees F. between inlet and outlet.

Since the temperature in the shelter during this test seldom exceeded 80° F., approximately half of the heat emission of the occupants was in the form of sensible heat at this maximum condition. At a shelter temperature of 90° F., the sensible heat emission of the occupants would be only about one-fourth of the total emission, so the temperature rise of the ventilating air would be reduced considerably. Nevertheless, it is anticipated that the temperature in a shelter of this size could become excessively high in midsummer, when daily average temperatures were considerably higher than those experienced during this test, and that air conditioning would be required in some climates in such a 100-man shelter.

Unless the dew point temperature of the supply air was considerably below the interior surface temperature of the shelter, condensation and high humidity would occur in the shelter as a result of the moisture released by the occupants. Somewhat lower relative humidity would be expected in a 100-man shelter than in a family shelter for the same atmospheric conditions, because a greater temperature difference between shelter air and interior surfaces would normally occur in the larger structure.

In Swedish cities, fallout shelters have been required by law in all new buildings since 1950. A typical apartment house has a 100-man shelter in the basement with reinforced concrete walls about 1' thick. It is equipped with two hand-operated blowers, each capable of delivering about 42 cfm at a crank speed of 30 to 40 rpm. The air intakes are equipped with canister filters about 18" in diameter and 3" thick. The shelter has blast doors and gas-tight doors. In 1959 these shelters were typically equipped with dry-type toilets, but did not have beds or a supply of food. At that time, tests of only a few days' duration had been made in such shelters.

Large Underground Structures

During the period 1951 to 1955, research(2) was carried out by the National Bureau of Standards to develop engineering data on heating, air conditioning and ventilation for deep underground structures for the Corps of Engineers. The investigations applied to structures built far enough underground to provide a high degree of blast protection, and for which the heat transfer characteristics were essentially similar to those for an infinite medium around the occupied space. In carrying out the investigations, the mechanical equipment requirements for standby operation, normal operation, attack condition, post-attack condition, emergency condition and disaster condition were considered.

In addition to the need for storing drinking water, cooling water, and fuel, and the need for special protection against blast for the waste discharges that were mentioned earlier in this report, the principal differences between the design procedures and the mechanical equipment requirements for such a deep underground structure and those for a normal above-ground activity were shown(2) to be as follows:

1) An air conditioning system would usually be required to control temperature and humidity.

2) A self-contained power supply with provision for obtaining combustion air and discharging exhaust gases above ground would be needed.

3) One or more ventilating air intake and discharge passages from the ground surface to the structure would be required. The air intakes would need protection with absolute filters for removing chemical, biological, and radiological agents, and both the intake and discharge passages would need blast protection.

4) The procedures for computing the heating and cooling loads of deep underground structures involve complicated heat conduction calculations. The rock surrounding the chamber would absorb heat at a constantly decreasing rate with time. Simplified procedures for evaluating this heat transfer were developed.

5) Long tunnels or shafts for supplying ventilating air would cool and possibly dehumidify the air in summer, and would warm and possibly humidify the air in winter, thus affecting the heating and cooling loads of the chamber somewhat.

6) Some equipment may be needed for absorbing carbon dioxide and for liberating oxygen, if the outside air supply must be closed for long periods of time during extended power failure.

7) Dehumidification may be needed in certain applications when neither heating nor cooling is required, because of damp rock surfaces or underground streams or pools of water.

8) Water from a river or stream may be brought to the structure for waste heat disposal, or alternately, an air-cooled condenser or cooling tower may be needed for heat dissipation during normal operation of a large underground structure.

9) An underground reservoir may be needed in emergency conditions. The heat-absorbing capacity of such a reservoir can be increased by making ice and storing it in the reservoir during normal operation.

10) The air conditioning equipment and power generating equipment may have to be operated with cooling water at the maximum permissible temperature, if outside sources of cooling water are interrupted too long during an emergency condition.

A number of such large underground structures have been built in the United States principally to keep important military functions operative during emergency conditions.

In Stockholm, Sweden, four deep, underground civilian shelters have been built in the city, each with a capacity of 20,000 persons. One of these is shown in Figure 15.

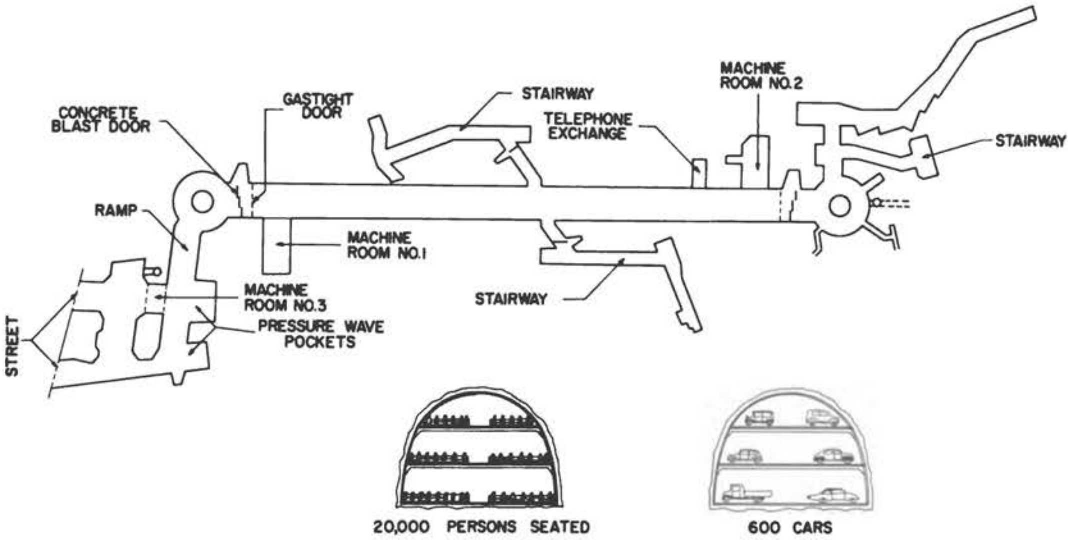

Figure 15. Diagrammatic sketch showing plan of a 20,000-person shelter in Stockholm

The total floor area of each of these shelters is about 300,000 sq. ft. for three levels. The shelters have about 65' to 70' of rock cover and are lined with concrete 10" thick. The four shelters were planned for housing essential personnel in the downtown area for an indefinite time. In addition, 15 large fallout shelters, capable of caring for 40 to 50% of the total population of Stockholm, have been built in the suburbs. It is anticipated that most of the population would be evacuated in advance of the emergency. These shelters are used as public garages during peace time to help amortize the initial cost of construction. The parking capacity is 600 automobiles.

These large shelters are equipped with an emergency power plant of 750 KW capacity; a refrigerating plant that can make 4400 pounds of ice per hour; a storage basin for ice and ice water of about 50,000 gallons capacity; ice water circulating pumps of 700 gallons per minute capacity; 130 chilled-water cooling coils for temperature and humidity control; and air filters with a capacity of 17,600 cfm, corresponding to slightly less than 1 cfm of fresh air per person. The shelters are equipped with blast doors.

Since these shelters were designed to meet the requirements for protection at the end of World War II, they may not be entirely adequate for current needs. However, they represent a massive investment in protective facilities for a large city; they are currently in good condition and can probably be modified to provide better fallout and blast protection than is presently contemplated for much of the United States' population.

SUMMARY OF PRESENT KNOWLEDGE AND FUTURE NEEDS

Present knowledge regarding the mechanical equipment requirements for protective structures is inadequate principally in the area of fallout shelters. This inadequacy stems from the fact that the amount of experience and experiment has thus far been small, and because the present effort has been directed toward providing such protection at a minimum of cost and minimum of adjustment in the pattern of present-day living.

The available information on family-size shelters indicates that for a space allowance on the order of 10 sq. ft. of floor area per person and an occupancy period of 14 days, heating would be required during the winter in half or more of the United States; cooling would be required for summer use where the maximum earth temperature exceeded about 73° F.; and high humidity and condensation would be prevalent in spring, fall and summer seasons unless preventive measures were taken. A ventilation rate of 1 cfm per person is adequate to provide for the oxygen requirements in a shelter, but higher rates up to 7 cfm per person or more are advantageous in reducing the condensation in the shelter during hot-humid weather by carrying out more of the moisture liberated by the occupants. There is little experience with the use of manually-driven blowers for providing ventilation in family-size shelters, but it is probable that this task would become a rather rigorous duty on a day-and-night basis during a 14-day period. When air filtration or heating, or both, are required in a family-size shelter, it would be difficult to coordinate these functions with each other and with manual blower operation.

The ratio of surface area to floor area is less favorable in larger shelters, so a smaller percentage of the internal heat release would probably be absorbed by the walls. Thus, in group shelters, higher ventilation rates would be required and the need for cooling during summer occupancy would be more widespread geographically than for family-size shelters. Correspondingly, there might be less need for heating in larger shelters than in the family shelter during winter use. A source of mechanical power for ventilation, electrical energy, and in some cases for heating and cooling, would be a practical necessity in a group shelter.

Both family-size and group shelters could be closed up without ventilation for periods of 4 hours, more or less, without excessive rise of carbon dioxide concentration in the event of fire or toxic gases in the vicinity of the air supply intake. Provision for longer periods of occupancy without access to outside air could be made, but these methods require considerably more apparatus and material. The need for air filtration equipment, and the characteristics of the contaminants against which protection should be provided in fallout shelters, are not clearly defined at present.

Some of the problem areas related to mechanical equipment for protective structures, for which better engineering data are needed, are:

1) Criteria for the conditions of climate, latitude, earth characteristics, shelter size and occupancy for which air conditioning or heating, or both, will be required

2) Methods for controlling moisture in small shelters

3) Economical and practical devices for ventilating small shelters with combination manual and mechanical drives

4) An equipment package consisting of a prime mover, ventilating blower and electric generator for small and medium size shelters

5) Simple and economical equipment for cooling a small shelter

6) Efficiency, pressure drop, and dust-holding capacity of filter media in relation to air-flow rate for typical fallout particles

7) Design data for air intake fixtures to inhibit ingress of fallout particles

8) Simple devices for measuring or monitoring carbon dioxide, oxygen, carbon monoxide, and hydrocarbon vapor concentrations in shelters

9) Criteria for determining whether the natural ventilation in protected areas of existing structures is adequate

10) Methods for protecting shelter occupants when combustion gases or fire, or both, approach the shelter

11) Automatic blast valves that will protect ventilating systems, plumbing systems, power generating equipment and personnel against temporary overpressure during attack conditions

12) Maintenance procedures for keeping small and medium shelters and their equipment at a ready state during standby conditions

13) In large protective structures housing essential activities, the length of time that the facility can function and endure under attack conditions would often depend on how long the waste heat could be rejected to available heat sinks(2). Developments that would augment present capabilities in waste heat rejection are:

    a) A refrigeration cycle that could effectively reject heat at temperatures above the boiling temperature of water

    b) An internal combustion engine designed to reject heat at temperatures above the boiling temperature of water

    c) A refrigeration cycle that could reject heat to a subterranean bed of broken rock at temperatures up to 500° F. or higher.

Obviously, more effective mechanical facilities can be provided by incorporating them into the design of new buildings. However, attention must be given to adding the essential equipment to the spaces in existing buildings that provide, by reason of their location or construction, a reasonable measure of protection against radioactive fallout. In selecting such equipment, the design requirements described in this paper for preserving life and health must be considered.

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Architectural Design of Protected Areas

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Planned shelter against the weapons effects which threaten radical changes in man's environment may be discussed under three general classifications:

1) Single Purpose Shelters—Shelters in this classification (Fig. 1) are designed solely for the protection of personnel in an emergency. Under normal conditions they stand empty. Their design is quite straightforward, once the weapons effects against which protection is required have been established. Shelters of the type illustrated provide protection factors of 5000 or more against fallout radiation and can resist blast overpressures in excess of 35 psi. A comprehensive shelter program will require numbers of single-purpose shelters, properly stocked with food, water, blankets and medical supplies to meet a sudden emergency. A schedule of inspection, custodial care, rotation of supplies, and exercise of mechanical equipment will have to be established for each shelter. Relatively austere shelters of this type have been constructed at a cost of about $125.00 per occupant.

2) Shelters for Essential Facilities—Shelters in this classification are designed to protect essential military installations, public utilities, communications, or other services that must be maintained through an emergency period. The design of such shelters may be extremely complex, requiring protection of vulnerable system components and controls as well as personnel. In some cases it will be possible to provide protection in a normal use location; in others it will be necessary, during emergencies, to transfer operations to remote protected locations. For obvious reasons, little information can be made public on the character or costs of shelters of this type.

3) Multipurpose Shelters—Shelters in this classification are protected structures which may be converted from their normal use into personnel shelters during emergency. They may include part or all of a building, and the major design problem is to provide adequate shelter without compromising the suitability of the building for its normal use. Where the shelter space is below grade, our studies

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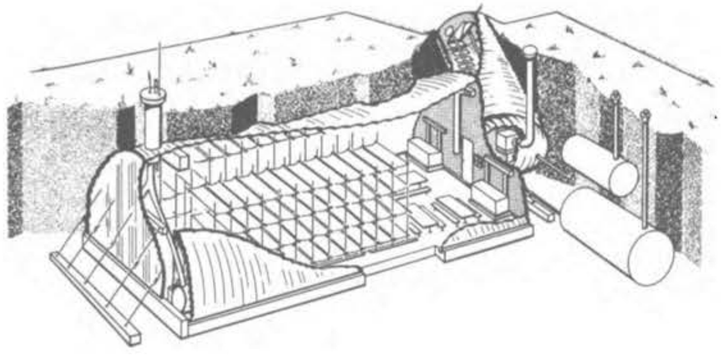

Figure 1. Cutaway view of shelter

indicate that shelter costs per person sheltered are less than, or comparable to, those for single-purpose fallout shelters and the accommodations are generally more comfortable.

Protection is a technical problem which can be solved by competent civil, structural, mechanical and electrical engineering. Little more is required for single-purpose shelter. For multipurpose shelters, and shelters for essential facilities, it is necessary that the architect understand the shelter problem and develop designs in which shelter can logically be incorporated. To this end, the Office of Civil and Defense Mobilization sponsored a series of workshops in which interested architects have been able to develop competence in shelter techniques.

Most sizable buildings offer some degree of radiation protection and at least a token resistance to blast. Some years ago the OCDM instituted studies of various building types to determine the extent and cost of modifications necessary to provide shelter for the building population from fallout radiation, and, in some cases, from blast. Much of the material in this paper is drawn from studies of shelter in schools, multistory office buildings, and multistory apartment buildings, performed for OCDM.

These studies were primarily concerned with radiation protection, although all structures were analyzed for inherent resistance to blast, and some were redesigned for improved resistance up to 15 psi overpressure. The following protection factors were adopted for study purposes:

Underground school shelter - 5000
Above-ground school shelter - 1000
Basement shelter in multistory buildings - 1000
Upper story shelter in multistory buildings - 100

It was assumed that normal water supply, power and sanitary systems would be disrupted and not available for use.

Designs were based on a minimum net area of 10 sq. ft. per occupant. Slightly larger allowances were made in certain school studies. Width and character of access was determined according to normal use requirements. Two cu. ft. of food storage area per occupant was provided on the basis of a two-week supply of packaged food, powdered milk, and dehydrated vegetables. Drinking water was stored in the amount of 14 gallons per person, although this requirement, as well as the problems of sanitation, keeping down air temperature, and cooling the engine-generator, can be relieved by developing a well on the site where possible.

Additional storage was provided for disassembled bunks, bedding, medical stores, radiation monitoring equipment, portable toilets, spare clothing and Conelrad receivers. Three-tier bunks make it possible to accommodate sleepers in about 4.5 sq. ft. of floor area per child or 6 sq. ft. per adult, including aisles, if the bunks can be entered from the narrow end. Portable toilets were assumed necessary in a ratio of one for each 35 occupants, and wash basins in a ratio of one for each 50 occupants. In order to conserve water, provisions were made in each of the shelter designs to abandon normal flushing fixtures, and to remove sewage through a sump and sewage ejector.

The mechanical installation was designed to furnish at least 3 cfm of filtered fresh air per occupant and to maintain effective temperatures between 67° F and 85° F. Provision was made for optional installation of chemical, biological and radiological filters in the fresh air supply. Recirculated air passes through activated carbon filters to remove odors and also passes germicidal lamps. Emergency power to operate fans, pumps, communication equipment, lights and hot plates was made available, through automatic load transfer devices, from two emergency engine generators, each with a stored two-week supply of fuel. Each generator was sized for one-half the anticipated requirements but was capable of maintaining the absolute essentials of survival in the event of failure of the other generator.

In all studies, the time of emergency was assumed to coincide with the period of maximum occupancy of the building, that is, a weekday for schools and office buildings, and night for apartment buildings. School studies were performed by preparing detailed drawings and specifications for schools or school components including shelter. Multistory buildings were studied by analyzing existing structures to determine what modifications could be made to the existing building, or might have been made in the original design, to provide shelter.

The studies confirmed that multipurpose shelter, where feasible, offers many or all of the following advantages:

1) Easier and quicker access to the shelter for the occupants of the buildings.

2) Greater familiarity with location, surroundings and shelter equipment for shelter occupants.

3) Assurance of proper maintenance of shelter and equipment until emergency arises.

4) Generally better and more comfortable facilities.

5) Usually, an existing administrative pattern.

6) Frequently, a possibility of expanding occupancy into less sheltered portions of the parent building as the radiation hazard decreases.

7) Frequently, economy in shelter cost per person sheltered, computed as an increment to the cost of the normal-use structure without shelter.

8) Occasionally, opportunities to improve or enlarge shelter through improvisation. This would ordinarily require early warning or anticipation of attack.

Interest in school shelter is largely due to the fact that students in elementary, junior high and high schools comprise nearly one-quarter of the population of the United States, a genetically essential fraction. Except for housing, schools are currently the most prevalent building type in the country, are well distributed in relation to population, and are frequently the most substantial and best equipped buildings in the community. They have the advantages of a permanently established organization with responsible leadership. These factors all favor the establishment of large group shelters in schools.

Attempting to combine the ideal school with the ideal shelter creates a problem when it becomes necessary to shield or eliminate windows and doors, and to surround educational spaces with sufficient mass to give radiation protection. Obviously, this approach conflicts with current educational and architectural thinking directed toward achieving spaces as open as possible, with maximum natural light. In addition, many local building codes prohibit the use of basements for instructional purposes. Enclosed and underground instructional spaces can be made attractive and comfortable, nevertheless, and enjoy certain advantages over conventional construction such as improved control of temperature and humidity, and more uniform lighting (as well as more effective darkening when required for audio-visual purposes).

The six basement classrooms and central corridor of the first case-study school (Fig. 2) are adequate to shelter an ultimate school population of 500. In this building, the basement is only partially depressed, and is surrounded by an earth embankment which provides inexpensive radiation shielding for the shelter classrooms, and atgrade access to those at the upper level. A wide central corridor gives a degree of visual relief to the windowless classrooms and provides a general activity space for special projects and large-group teaching.

The second case-study school (Fig. 3) is designed to shelter a school population of 500 above grade in the central, multipurpose room and associated smaller spaces. These are shielded by thick masonry walls and a heavy, pyramidal, reinforced concrete roof. Corridors to the four classroom clusters at the corners are provided with offsets to prevent direct entry of radiation.

The third case-study (Fig. 4) is a four-classroom underground addition to an existing school, designed to shelter a total school population of 375. Tunnel and above-ground connections can be made to the existing school. Skillful use of light, color and spatial interest will help to create a psychologically comfortable environment. As in the first case-study, a central activity area is provided for spaciousness and for improved circulation and control. Using a split-shift schedule, half the occupants can be sleeping in one classroom while the other half are obtaining food in a second classroom or taking part in morale-building activities in the other spaces.

The fourth case-study (Fig. 5) is a multi-use addition to an existing school designed to shelter a school population of 375. It is set deeply enough into the ground so that the occupants are below grade. Two spaces are provided; one for active games, the other for dining and assembly, separated from each other by a two-story service and circulation core.

Figure 2. Case-Study No. 1

Figure 3. Case-Study No. 2

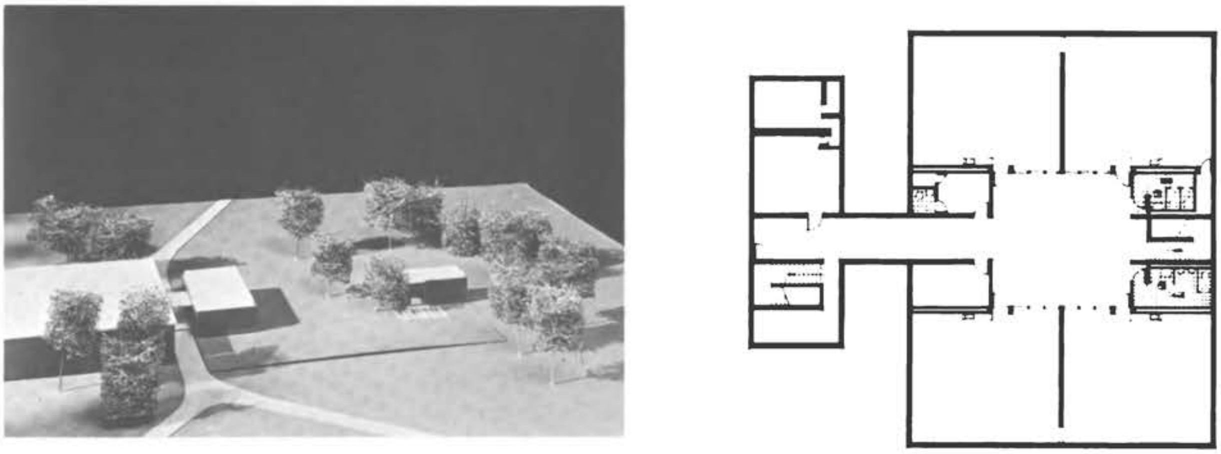

Figure 4. Case-Study No. 3 and Underground Floor Plan

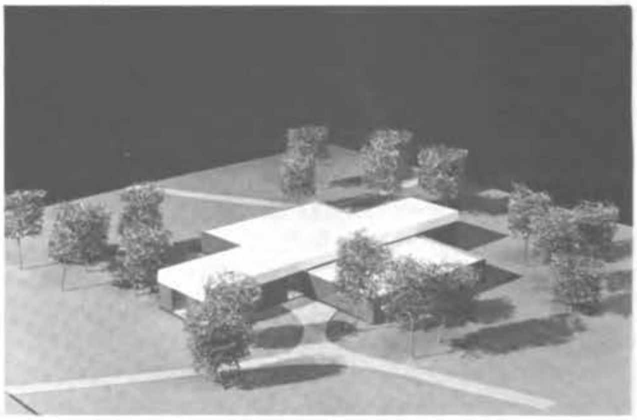

Figure 5. Case-Study No. 4

Plans and specifications for the four case-studies were prepared in sufficient detail to permit quantity take-offs and complete cost estimates. These estimates were compared to average costs for a number of recently built schools of comparable size and facilities, and the differential, termed "basic shelter cost," was expressed as shelter cost per occupant, allowing 10 sq. ft. of net area per person.

TABLE I

Cost Estimates

Case Study School	Maximum Occupancy	Basic Shelter Cost (per occupant)
No. 1	735	$ 66.00
No. 2	511	127.00
No. 3	484	50.00
No. 4	460	180.00

Not too surprisingly, the case studies using earth-shielded classroom space for shelter are considerably more economical than those with relatively large spaces left partly or wholly above grade. Even where local conditions make necessary the installation of all the auxiliary equipment listed, the incremental cost of the shelter will bear comparison with that of single-purpose shelter, and the resulting structure will be better finished and more comfortable than single-purpose shelter. The costs shown are for southeastern Michigan in 1958. They do not include the cost of such items as stored food and food handling equipment, sleeping accommodations, medical supplies, or portable toilets.

As contrasted with schools, multistory office and apartment buildings are primarily types that must make a profit from tenant rentals. In providing shelter, care must be taken to avoid changes which detract from the utility or attractiveness of the rentable area. Tall buildings create serious radiation shelter problems by imposing heavy concentrations of population on limited areas. Some New York apartment projects have population densities of 450 persons per acre, and total populations averaging 3000. Some tall Manhattan office buildings have daytime populations of 15,000 and population densities as high as 3500 persons per acre.

Obviously, buildings with basements and buildings with massive walls offer the best inherent radiation protection. Multistory buildings with interior corridors or central cores may afford useful protection on upper floors. Where basement shelter does not exist, or is inadequate for the total population to be accommodated, shelter in upper stories becomes increasingly important:

1) As expansion space to relieve overcrowding of basement and underground shelters after the first day or so.

2) As shelter in areas of light fallout.

3) As temporary shelter in heavy fallout areas until occupants can be evacuated to areas affording better shelter or incurring less fallout.

In the apartments studied in the Detroit area, gross floor area per person (excluding basements) varied from about 180 sq. ft. in low-rent housing to 420 sq. ft. in high-rise, luxury apartment buildings. In office buildings, space allotments may range from 200 sq. ft. per person to as low as 100 sq. ft. per person (in buildings housing a large group of clerical workers). Through analysis of a broad range of hypothetical buildings of each type, curves were prepared relating basement shelter capacity (at 10 sq. ft. net area per person) to building population. For both types, on the average, it will be possible to shelter the population of 10 or 12 stories in a single basement.

In a characteristic high-rise apartment building the floors closest to the roof and immediately above ground level afford the least protection against fallout radiation. Intermediate floors have a useful shelter potential except in cases where they may be exposed to radiation from fallout on the roofs of nearby lower buildings. In the 22-story case-study apartment building, (Fig. 6) a privately-financed, luxury type, the uppermost floor is used to house mechanical equipment and the ground floor is used for lobby and circulation space. Consequently, there are no residents on the floors with least protection. The normal population of this building is 700 of whom 120 can be accommodated in basement shelter with a protection factor of better than 5000. Additional basement shelter for 390 can be developed by providing proper ventilation, but because the ground floor is inset, permitting deposit of fallout on the slabs above

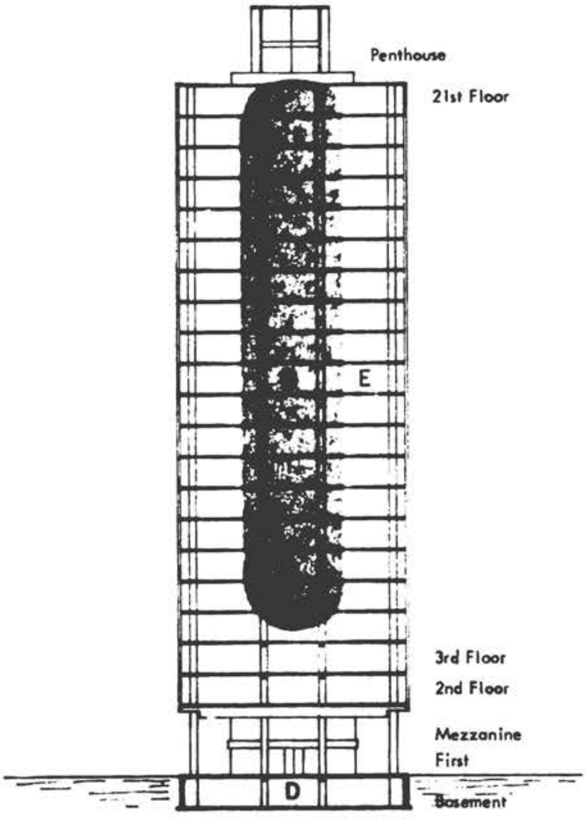

Figure 6. 22-Story apartment building. Area D has protection factor of 10-50; Area E has 2-10.

the shelter, the protection factor in this area is only 250. With minor modifications to the floor plan, the upper floor corridors provide a protection factor of 100 or better for as many as 2500 additional persons.

A second case-study apartment building, a representative six-story public housing unit with a relatively large population of 300, was redesigned to accommodate 380 in basement shelter with a protection factor of 3000. From the standpoint of morale and administrative efficiency, families should be kept together and made as self-sufficient as possible during the shelter period. Food and medical supplies must be planned to take care of everyone from helpless infants to the aged and infirm. Some sort of common activity space may be established for children of school age, but each family should have its own eating and sleeping area. Food and other supplies may have to be brought periodically from the basement to upper-floor shelter. The available emergency water supply consists of the normal tank capacity, the hot water tank capacity, the contents of the building water pipes and the emergency water storage or supply well. If there is sufficient warning time, residents may be able to augment the supply by filling tubs and wash basins.

Demountable, tiered bunks may be used in the basement shelters, and mattresses and blankets from the apartments can be spread on the floors of upper story corridors. Since upper floor corridors can draw uncontaminated air from adjacent apartments, it would not be necessary to supply outside air to these corridors during the first four days, or even longer with normal infiltration. In the case studies, it turned out to be possible to adapt the existing air-handling systems to supply filtered air to the upper floors.

If no house phone or public address system is available for communication between floors, a temporary phone system capable of being strung up through a stairwell should be stored in the basement shelter area. This will be useful not only for scheduling shelter activities, but also in case of fire or other localized emergency.

Many modern office buildings are air conditioned, which permits the successful use of deep, unbroken office space and economical square or nearly square tower plans. Vertical circulation, utilities and other services are usually grouped in a central core. The first case-study office building (Fig. 7) has the thin exterior curtain walls used so extensively because of their lightness, lack of bulk, and the speed with which they can be erected. About 50% of the peripheral wall area is glass. The radiation protection afforded by the exterior wall is negligible. The core area of a typical floor of the case-study building, as actually constructed, is surrounded by circulation area (Fig. 8). The mechanical systems are planned so that the circulation area can be enclosed by light, movable partitions when the floor is occupied by more than one tenant.

In order to provide upper floor shelter, a new design (Figs. 9 and 10) was developed in which the circulation space is brought to a sheltered position at the center of the core. At a slight sacrifice in the flexibility of the floor plan, a serviceable shelter was created, with good visual control of all areas and a protection factor of 100 or better. The building population is 485. The existing basement will shelter 40 and can shelter an additional 490 with a protection factor of 1000 or better, provided there is sufficient warning time to remove materials stored there. The redesigned core areas on upper floors can shelter an additional 450.

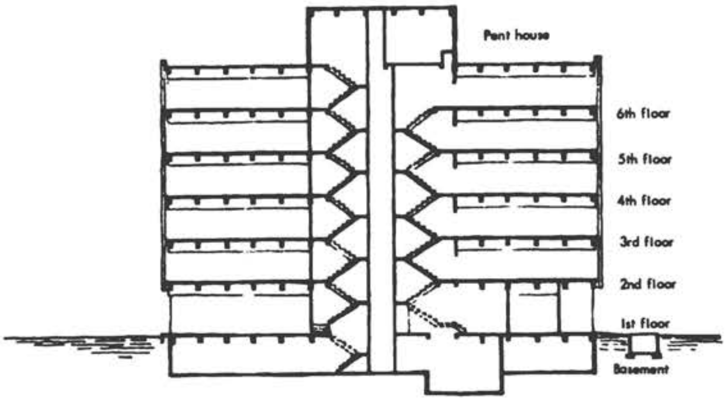

Figure 7. Original section

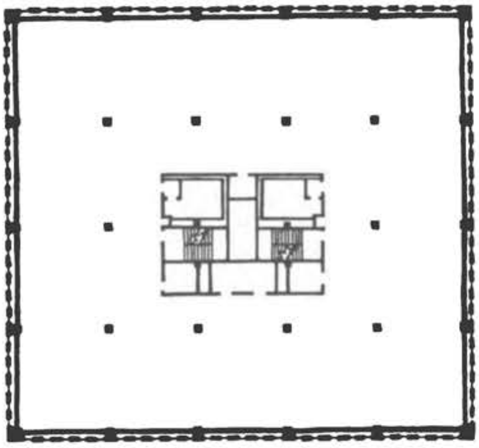

Figure 8. Original floor plan

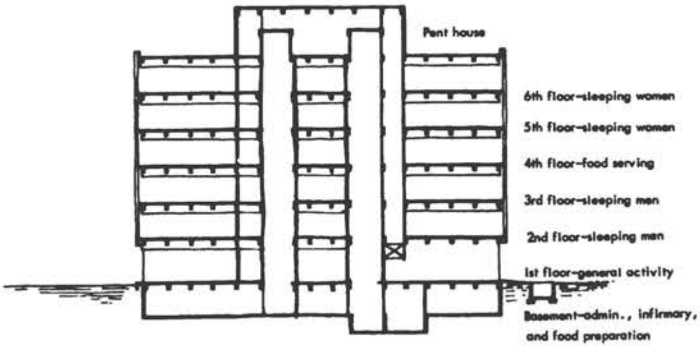

Figure 9. Redesigned section

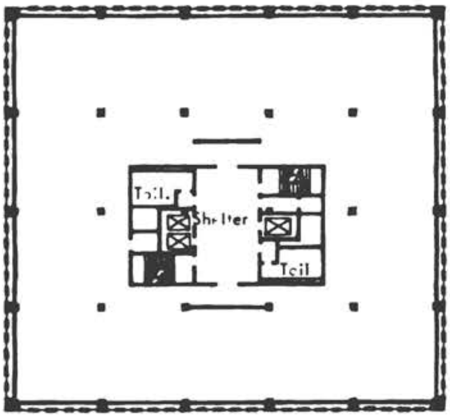

Figure 10. Redesigned floor plan

During an emergency, shelter should be organized to take full advantage of existing administrative patterns. In an office building, each tenant should be responsible for indoctrination of his own personnel, and effective participation in the civil defense plan for the building. The normal building population is not likely to include children or aged persons. Therefore, it should be possible to organize shelter activities on an efficient, split-schedule basis, with segregated dormitories adequate to sleep one-half or one-third of the population at one time in demountable, tiered bunks. Office buildings, unlike apartments, have no large normal supplies of food and bedding; consequently, storage must be provided for these items.

Costs were computed for case-study buildings (Table II) on the basis of typical costs in southeastern Michigan in the spring of 1960. In assessing these, it is necessary to bear in mind that wide differences exist in the original construction and equipment of the buildings studied, and in the type of shelter and degree of protection developed in each case. The most favorable cost ($58.01 per person sheltered) was obtained for an urban utilities building with an existing emergency power supply, an existing well, and a deep, air conditioned basement of adequate size for shelter. The most expensive cost ($182.16 per person sheltered) was obtained for redesign of the basement of a six-story apartment building, and includes not only the cost of ventilation and emergency power, but also additional excavation to put the basement entirely below grade.

In investigating these case studies for inherent and improved blast resistance, it became necessary to eliminate unprotected access and unprotected openings for fresh air intake, boiler stacks, vent pipes, air cooling of the engine-generators, etc. Because of the high cost of blast doors and self-actuated blast valves, openings should be eliminated from blast shelter, where possible, or at least kept small. Boilers should be kept out of the shelter. If a source of cooling water cannot be found, engine-generators also should be placed outside the shelter.

TABLE II

Summary of Costs Per Shelter Occupant

Apartment Structures

Case Study		6-Story Conversion	6-Story Redesign	22-Story Redesign
Shelter Classification		"B"-Basement	"A"-Basement	"A"-Basement "C"-Upper Story
Shelter Population		380	380	2,640
Costs:	Architectural	$ 9.74	$ 28.42	$ 5.71
	Mechanical	104.21	95.00	18.22
	Electrical	8.03	8.03	4.36
	Engine-Generators	50.71	50.71	19.20
	Total	$172.69	$182.16	$47.49

Office Structures

Case Study		Urban Utility Conversion	Suburban Utility Conversion	Urban Commercial Redesign
Shelter Classification		"A"-Basement	"A"-Basement	"A"-Basement "C"-Upper Story
Shelter Population		1,189	268	935
Costs:	Architectural	$ 5.60	$ 4.55	$ 6.49
	Mechanical	41.35	101.12	34.41
	Electrical	11.06	50.37	3.19
	Engine-Generators	—	—	31.60
	Total	$ 58.01	$156.04	$75.69

For the school case studies, costs were determined for the structural modifications necessary to bring points of weakness up to the general average of inherent blast resistance of the structure, which was about 3.5 to 5 psi side-on overpressure. Next, structural costs were determined to bring resistance up to 15 psi side-on overpressure. These indicated definite advantages for case-study schools No. 1 and No. 3, which have shorter spans and are not exposed above ground to the blast wave.

The range of cost (per person sheltered) of developing inherent blast resistance, between the least expensive (Case No. 3) and the most expensive (Case No. 2) was as follows:

Structural	$1.87	to	$11.90
Blast Doors	$4.50	to	$17.00
Blast Valves	$8.90	to	$27.70
TOTAL	$15.27	to	$56.60

As compared with the case study schools, which in no case exposed more than one story above ground level to blast pressures, the multistory buildings are quite vulnerable to blast. It was assumed that light curtain walls would be swept away immediately by the blast, leaving only the shelter cores, which would be reinforced to resist direct blast pressure and the drag pressure caused by the blast wind passing through the skeleton of the rest of the building. The blast resistance of the case-study buildings was then compared with idealized curves of blast resistance plotted against building height (Figs. 11 and 12). The idealized curves were developed for hypothetical buildings with shelter cores, both for the case of light exterior walls which are blown away, and for the case of conventional exterior walls which are subjected to reflected blast pressure.

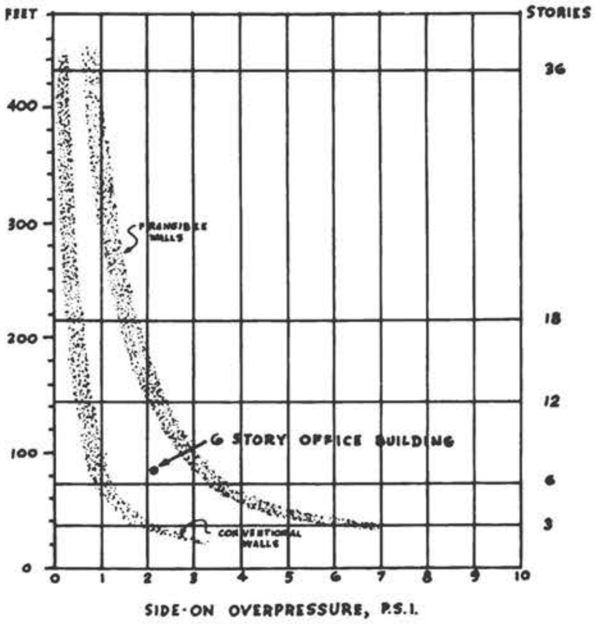

Figure 11. Office buildings—shelter cores protected by concrete shear walls.

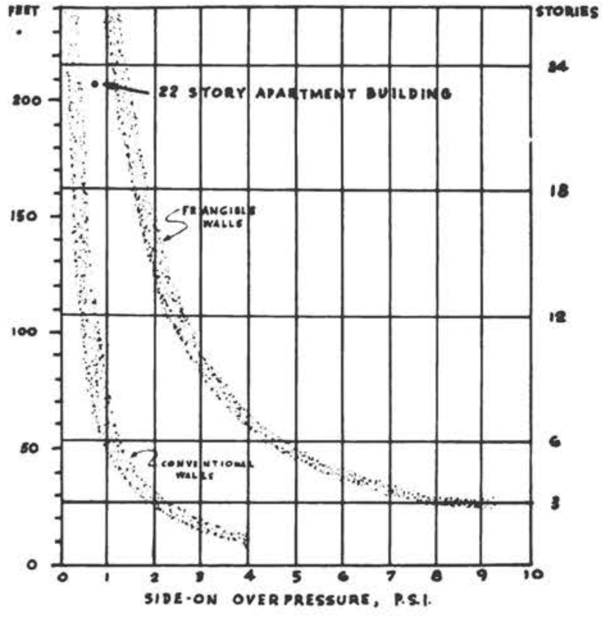

Figure 12. Apartment buildings—shelter cores protected by concrete shear walls.

The curves indicate that little useful resistance to blast pressures should be expected from conventional buildings over two or three stories in height. Above 12 stories, blast resistance is negligible, at least as calculated by simplified methods.

Typical apartment buildings enjoy certain natural advantages with respect to blast resistance. They are usually not over 12 stories in height, have relatively close spacing of columns, and are customarily framed in concrete, with many interior walls which can be adapted to resist lateral forces. Those with long, slender plan elements may have the disadvantage of exposing a large area to the blast front. Tall office buildings usually have the advantage of a compact plan, but are otherwise very vulnerable to blast. Current speculations that a nuclear attack will be directed against some large cities, as well as military targets, tend to cast doubts on the usefulness of this type of building as shelter, at least in the upper floors.

Conclusions

Although limited to consideration of a few building types, the study program has formed a basis for the following conclusions:

1) Nearly every major building offers some possibility of shelter against the effects of warfare in the nuclear age. It is frequently possible to develop this potential quite economically without affecting adversely the normal use of the building.

2) Substantial economies and better protection result when shelter is incorporated in the architect's original design for the building. Even though shelter involves a number of engineering specialties, and may appear to be primarily a technical problem, it is important for the architect to be well grounded in the fundamentals of shielding, access, storage, mechanical space requirements, sanitary provisions, shelter activities and shelter administration in order to achieve the best and most economical solution.

3) The requirements of blast shelter pose a much greater problem for the architect than those of fallout shelter. Even where budget will not permit construction of blast shelter, it is good practice to design fallout shelter with the fewest and smallest possible openings in the exterior protective wall, and to set span lengths and detail the structure so as to develop maximum resistance to blast forces. If this is done, it will not be too difficult to add blast closures at a later date.

4) Engine-generators and fuel storage for emergency power are expensive. Equipment for cooling the shelter is also expensive. The cost of shelter can be reduced by protecting normal-use utilities, if possible, so that they will continue to be available during emergencies, and by careful design of the shelter's mechanical system.

5) Shelter below grade is generally better and cheaper than shelter above grade. In densely populated areas, above-ground shelter should be considered as a useful and relatively inexpensive supplement to below-grade shelter, even though it offers less protection.

Fallout Shelters and Human Behavior

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INTRODUCTION

This paper will review and comment on a limited body of research falling under the general rubric, fallout shelters and human behavior, and specifically will summarize the substance of the Disaster Research Group's 1960 Symposium on Human Problems in the Utilization of Fallout Shelters(1)‡ and the Group's 1961 meeting on Behavioral Science and Civil Defense.

At the time this assignment was accepted, it was assumed that most people were poorly informed on this subject. However, events of the past few months no longer permit unreserved acceptance of this assumption. During recent weeks the public has actively sought information, and it has been deluged with details from governmental, commercial and other sources on how to build some kind of fallout protection. Not all of the experts have favored the concept, nor have the details always been consistent. The task of selecting the most appropriate shelter information has become almost impossible for the average citizen, given the technical nature of some aspects of the subject.

Despite the barrage of technical details, there has been no comparable effort to inform the public about likely human behavior in shelters after the shelters are built, i.e., how an individual functions in a group; how physiological, psychological and social factors influence his responses; how his needs and desires are modified by the group in which he finds himself; and how the interaction of individual and group phenomena determines the goals and possible accomplishments of the sheltered group. Attention only to technical matters such as the protection factor provided in the 4' x 6' crawl-in shelter is not adequate. Equally crucial is awareness of the social effects associated with or encouraged by the physical environment of fallout shelters.

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‡Raised figures in parentheses refer to List of References at end of paper.

Basically, the shelter concept involves three variables: people; a structure and the physical environment it creates; and the social environment that people bring to and create within the structure. We have a wealth of scientific information on interaction among people, their physical, and their social environment under a variety of previously experienced conditions. However, our data are relatively meager when the three variables are related specifically to fallout shelters. Information on the social environment is especially deficient and is understandably difficult to obtain, since we have no certain prototypes of the shelter systems which may ultimately become available to members of our society.

REVIEW OF RELATED RESEARCH FINDINGS

Except for the 1945 occupants of Nagasaki and Hiroshima, man has not had any operational experience with the effects of atomic and thermonuclear weapons. The values which govern our society do not permit us to conduct experimental research which actually involves the weapon, resultant fallout, and human beings occupying a fallout shelter. However, limitations of this nature are not unique in science. Man developed quite a body of information and theory on our planetary system long before he started making flights into space.

When civil defense representatives asked the Disaster Research Group in 1958* to provide them with advice on shelter habitability, two recommendations were deemed appropriate: First, survey the completed research work which focused on aspects of individual and group behavior assumed to be related to life in a fallout shelter; and second, recommend that a series of experiments be designed to simulate various problems which individuals and groups would encounter in a shelter, and conduct these experiments as quickly as possible. The survey has long since been accomplished. To date the experimental efforts have been decidedly modest.†

Frames of Reference

In addition to experimental data, completed research on human behavior in natural disasters(2) can provide some useful frames of reference and working propositions for investigating shelter habitability. For example, a common stereotype is that the public will panic as soon as the bomb is dropped.‡ Research findings available for nearly a decade deny the truth of this belief.(3) Mass panic, or nonrational behavior under stress, generally occurs only when there are limited escape routes, or when breakdowns of communication cause people to assume erroneously that there are limited exits. In general, we find that people keep their heads, search for their

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*Federal civil defense officials have been actively associated with the Group and its predecessor, the Committee on Disaster Studies, since its inception early in 1952.

†A few studies of shelter management which employed systems analysis techniques were also conducted for OCDM. Regrettably, few of the findings and recommendations have been subjected to empirical validation.

‡Val Peterson(4), former director of the Federal Civil Defense Administration, reinforced this notion in some of his public statements when he identified our country as the most panic prone one in the world. As recently as 19 November 1961, Harrison Brown, distinguished geochemist at California Institute of Technology, reiterated his belief in the panic stereotype during the course of an NBC television debate with Herman Kahn on "The Nation's Future."

immediate families, and then aid others nearby. This finding is based on studies of more than 100 disaster events, including Nagasaki and Hiroshima.

However, we should keep in mind that today's information has been extrapolated from studies which used as subjects "normal" male adults. More research is needed to determine to what extent the findings about a normal adult male apply to such categories as women, children, the aged and the sick. Second, in evaluating other findings and applying them to shelter habitability, we should keep in mind that experimental data are generally drawn from subjects who, upon completion of the experiment, returned to the normal environment of an intact society. Such an environment provides adequate sources of physical and emotional support for facilitating recovery; a post-shelter environment may not afford such comforts. Finally, in assessing the evidence on man's ability to endure a given physiological deprivation (e.g., hunger), one must seriously consider that two or more deprivations (e.g., heat and thirst) may exist simultaneously. If they do, they may interact and produce a strain whose intensity greatly exceeds the sum of the variables.

Physiological Deprivations

At first glance, the findings from the work of Edward Murray, psychologist at Syracuse University, are generally encouraging with respect to man's ability to endure extreme physiological deprivations.(5) Murray has looked at the available research evidence from the experimental work on such deprivations as hunger, vitamin deficiency, thirst, extreme temperatures, deficiencies in air supply or oxygen loss, confinement and crowding, fatigue, and loss of sleep.

Man can probably do without food for approximately two weeks. After the third or fourth day, he may not experience hunger. After a few more days, he may become anxious, depressed, irritable, and his moral standards may be lowered. Although vitamin deficiencies produce similar psychological effects, these may not show up during the first two weeks of deprivation.

Absence of water presents a much more serious problem. If there is absolutely no water intake, man will probably die after four or five days. We know that complete water deprivation induces people to seek relief by such drastic means as sucking their own blood and drinking their own urine.(6)

Temperatures below 60° F cause manual skill to decrease; below 40° F, tension, irritability, and depression occur. At the other extreme, temperatures above 90° F impair work efficiency, concentration, and emotional reactions. Reduction of the oxygen supply is much more serious. Delusions, hallucinations, and ultimately organic brain damage can result. Carbon dioxide in large amounts induces somewhat similar psychological effects.

Confinement and crowding, if other deprivations are not present, can be endured to an extreme degree. In one experimental situation, a group of young men endured confinement which permitted no more than 2 sq. ft. per person for a seven-day period. However, such a condition tends to induce sleep loss, low morale, and nausea; and, we know that fatigue and loss of sleep make man listless, apathetic, and sometimes irritable.

From the above physiological deprivations, psychological frustration follows. Frustration may take the form of aggression, depression, regression, or withdrawal. In a group shelter situation, all these forms of frustration should be expected. Two or more of the deprivations interacting could magnify the problems drastically.

Sensory Deprivation

During the last 10 or more years, research scientists have developed a new body of information from a series of experiments generally called sensory deprivation (S. D.) studies. Usually, sensory deprivation studies involve confining an individual to a small room, with a drastic reduction in either the amount or variability of sensory stimulation. Light and sound are two variables which have often been studied. Jack A. Vernon, a Princeton University psychologist, examined this body of information in terms of its relevance for shelter habitability.

From his S. D. work,(7) Vernon saw the following implications for shelter occupants:

1) Probable weight loss
2) Emergence from the shelter into a yellow-tinted world, especially if illumination is low
3) Visual and auditory hallucinations if light is low, or if there is relative quiet
4) Increased sensitivity to pain during confinement
5) Temporary deterioration of most kinds of motor performance
6) Inordinate amounts of time devoted to sleep as an escape mechanism
7) Dreams relating to wishes for release
8) A strong desire for bathing, but no detection of odor.

In addition to the above laboratory work, there are many kinds of ongoing group and organizational experiences which provide insights and guidance for shelter planning. Some of these experiences occur as a part of the normal operations of groups and organizations; others are the products of extremely disastrous circumstances.

Prisoner-of-War Studies

Since the last days of the Korean conflict, A. D. Biderman, a social psychologist with the Bureau of Social Science Research, has developed a rich body of information from his internment studies of prisoners-of-war and civilian internees.(8) Drawing on this experience, Biderman has pointed out that depression and apathy present one of the most serious threats for shelter occupants. Onset is apt to occur when occupants regard themselves totally and irrevocably isolated from the world. From this finding, Biderman concluded that our shelter program instead of emphasizing austerity, should advocate a greater use of "luxuries" in shelter design.

While the prisoner-of-war studies indicated that sexual deprivation was rarely reported as a source of distress, we should note that most of the prisoners were not in situations which promoted active stimulation of this need. From our shelter experiments, we do know that sexual needs have been manifested in simulated shelter environments, and that this behavior has been a problem for those responsible for reducing conflict within the shelter group.(9)

Biderman reports that at the outset of internment, the camp was often "a collection of warring primary groups" which were in conflict because of the scarcities of the environment, especially the scarcity of space. Although the development of new forms of social organization tended to solve some of the space problems, conflicts in values arose and overt hostility was expressed toward fellow prisoners.

A Mine Disaster

The major mine disaster that occurred in the fall of 1958 in Nova Scotia has been extensively analyzed by a team of behavioral scientists.(6) Especially worthy of our consideration are the findings on the relations between leadership characteristics and stage of confinement. Distinctly different leader qualities were required during the early (or "escape") period and the late (or "holding on") period of entrapment. Fortunately for the trapped miners, their occupational specialization provided them with trained leaders and social organization, plus a background of folklore and experience for meeting some of the mine disaster problems.

STUDIES OF SHELTER HABITABILITY

So far only pilot research has been conducted on shelter habitability. These studies have been concerned primarily with such gross problems as: Can subjects remain in a confining shelter for two weeks? Can their physical needs be met? Will there be any serious physical or mental disabilities?(9, 10, 11)

Before evaluating the findings from these pilot studies we need to underscore some of the limiting characteristics of the experiments. First, the subjects were either paid to participate, or they were prisoners who had been told that their participation in the experiment could result in decreased sentences.* Second, while the experimental shelters may have satisfactorily approximated the physical characteristics of a shelter, they did not simulate the psychological stress which would be found among postattack shelterees. Real damage to life and property had not been sustained, and radiation did not exist outside the shelter walls. Hence the social environment of the experimental groups did not approximate a true shelter situation.

In discussing the findings of the shelter habitability studies, we shall describe briefly two research efforts. The first of these is a study of "Psychological and Social Adjustment in a Simulated Shelter"(9) conducted by the American Institute for Research (AIR) in the spring of 1960. In this experiment, a simulated shelter was constructed which permitted continuous auditory and visual monitoring of occupants' reactions. The major variables in the study were temperature and the presence or absence of a preselected and pretrained shelter manager. Subjects were paid volunteers—men, women, and children ranging in ages from 7 to 72—who were divided into four experimental groups of 30 subjects each. Three of the groups remained in the shelter for one week, the fourth for two weeks. Only 8 sq. ft. of space was provided per person, but inasmuch as the bunks were demountable, the space was considered adequate. Temperatures up to 85° F were tolerable, although 85° was close to the upper threshold.

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*While the use of rewards in obtaining research subjects is not unusual, it must be recognized that the motivational value of the reward becomes a variable which cannot be discounted in analysis of the experimental data.

Two of the groups had trained managers. It was found that having trained leaders increased the over-all adjustment of the occupants to shelter life, and resulted in more positive attitudes toward shelters, civil defense and fellow occupants, and less interpersonal conflict. In addition, the trained managers were able to conduct in-shelter training programs which prepared the occupants for post-shelter survival. Effective management minimized the tension of the shelter entry and release periods and the depression which occurred in the middle of the internment.

The second study, conducted by the Naval Radiological Defense Laboratory (NRDL), investigated the adequacy of shelter facilities for group living and the adjustment of occupants to shelter life.(10) For 14 days, California state prisoners lived in an experimental 100-man shelter. At the end of the two-week confinement, occupants emerged in good mental and physical condition. The three most difficult hardships were restricted use of water, limited space, and inadequate seating facilities. Conditions were made more tolerable by recreation (card games, chess, shuffleboard, reading, evening programs and makeshift handicrafts) and by the high quality of leadership provided by the shelter commander and his staff.

Special Hardships

The greatest problem reported in the two experiments was lack of water or its restricted use; the NRDL and AIR studies rank this as the most distasteful aspect of shelter life. Other hardships associated with the physical environment centered around less than optimum atmospheric conditions, crowding and the related problems of dirt, noise, sitting and sleeping difficulty, and lack of exercise and privacy.

Comparability of findings from the two studies is difficult since the same variables were not tested in each experiment. Further complication arises because verbal mention of the same problem in two different experiments may not include the same definition of the hardship. For example, the NRDL study mentioned crowding as a serious hardship, but defined "crowding" in terms of lack of privacy and storage space. No distinction was made between lack of space and lack of privacy. The AIR study, on the other hand, gave crowding a discomfort rank of 4 out of a list of 21 factors, but lack of privacy was not considered as one of the components of crowding. Lack of privacy was ranked as 11. Furthermore, when the 105 subjects of this study were questioned on their most unpleasant memory, only one named crowding, and none named lack of privacy as his biggest shelter problem.* The AIR data suggest the possibility that crowding adds to the general discomfort, but is not in itself the most salient difficulty. Research with mutually exclusive variables is needed to determine the extent to which privacy itself is a significant shelter desideratum.

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*We know from other studies that privacy is not equally valued by all persons. Some years ago, Robert K. Merton in a study of the social psychology of housing(12) found that residents of a housing project had different degrees of concern with privacy. By the middle class in general, privacy was highly valued; for lower classes, it had comparatively little importance. We can expect class differentials in community shelters and consequently disparate valuations of privacy. If an imaginative and vigorous habitability research program is initiated, we will know the value of such variables and something about their implications for shelter construction, organization and management.

Conflicts of Values

Problems arising from the limitations of space and facilities may be even more troublesome in group shelters where conflicting values add social stress to the physical discomforts. Conflicts of values have been reported with respect to quiet periods, acceptable language, gambling, sanitation and cleanliness, sexual expression and observance of the Sabbath.(9) When there was no trained leader, people with low standards had disproportionate effects on group standards. It also appears that those with higher standards were frequently older persons of low status within the group, who chafed under the observed violations rather than express disapproval to the conflicting group.

Leadership

Adjustment to shelter life in general was greatly facilitated by preselected and pretrained managers. The tension which characterized shelter-taking, the early hours of confinement and the period before release(13,9) was considerably lessened by the presence of a pretrained shelter leader. If there was no preselected leader, tension was reduced after organization and leadership were established.(13) When tension gave way to depression in the middle of the experiment,(9) the presence of a trained shelter manager reduced even this.

In the two experimental groups which had preselected managers, their leadership was accepted without incident and was not challenged. Group cooperation and morale remained high. Less dissension arose over shelter management; the majority of disagreements had to do with personal disputes. No negative feelings were reported by shelterees toward either of the trained leaders in the post-shelter interviews.

However, in the groups without preselected leaders, adjustment was less good. While a leader did emerge in each of these groups, both the emergent leaders were authoritarian, and their behavior alienated the other members of their groups. Lacking training, they suggested several procedures which were not feasible. As the proposals failed, the group began to lose confidence in the leader. In addition to their lower levels of competence for the job, emergent leaders tended to become more involved in personal contention with other group members than did the designated leaders.(9) In the first group, there had been passive resistance to the leader's proposals from the first. After his behavior became psychotic, he was removed. In the second group, emergent leadership was generally unchallenged, but the leader's authoritarian manner resulted in substantial social distance between him and the rest of the group. Had it not been for two women who acted as his deputies, he might not have been able to overcome some of the hostility that his behavior created.

These findings suggest that emergent shelter leaders may be dysfunctional in two respects. First, shelterees tend to question their authority more often, and second, they are not adequately trained to deal with the practical problems which arise in managing a shelter. These two findings are probably related, i.e., the reluctance of the shelterees to accept the manager's authority may derive partly from his ineptness in handling practical problems.

THE SALE OF HOME FALLOUT SHELTERS

To date we have not had a national census of shelters. If we look at some of the public statements on this subject, we soon discover that opinions differ drastically. In January 1961, Leo J. Hoegh, then Director of OCDM, reported(14) to the President that a million shelters had been built; in the spring of 1961 his successor, Frank Ellis, estimated(15) that only a negligible number existed and he judged the national shelter program to be a failure.

A few real estate developers did try to sell shelters before the summer of 1961. One of these efforts was made in Denver, Colo., by the Cherry Hills Manor Housing Development. John S. Gilmore of the Denver Research Institute studied the sales response. During the course of his study(16) a total of 140 homes costing \$17,000 and up were sold. In each of these homes, the builder offered civil defense approved fallout shelters as optional equipment at an added cost of approximately \$400-\$500. One purchaser out of the 140 voluntarily requested that a shelter be included in his house, and three other persons bought model houses in which shelters were already installed. Before attributing this low sales record to public apathy, we should report that the shelter sales program was inadequate. The sample shelter and the civil defense information center were located in different model houses, and salesmen were not able to answer many technical questions about the shelters.

Interviewing revealed considerable general interest in the civil defense concept, but a great amount of ignorance and uncertainty about the probable characteristics of thermonuclear attacks, technical requirements for shielding, life in a shelter, and the post-attack environment.

BEHAVIORAL CONSIDERATIONS IN IMPLEMENTING A CIVIL DEFENSE PROGRAM

As most of us recognize, scientific attitude and public opinion surveys are now one of the well developed tools for assisting government and industry in the formulation of policies and programs as well as in their assessment. In 1961, OCDM authorized, for the first time in several years, a national study of attitudes toward the cold war and civil defense. The results should help to explain existing behavior and assist in shaping future action. If such studies had been conducted periodically through the years, much of today's response to the shelter program could have been predicted.

One of the problems yet to be solved is the very difficult one of overcoming cultural and psychological resistances to the chosen shelter program. There is no exact precedent for today's shelters in our culture, and the related cultural elements for facilitating acceptance that do exist may not be properly employed in today's program. If any program is adopted, especially one based on voluntary participation of individuals, someone must motivate the people to undertake a course of action with which they have had no previous experience.

As Jum Nunnally(17) pointed out in the spring of this year, the civil defense program so far has relied almost exclusively upon the use of threat in its attempts to induce the public to take appropriate courses of civil defense action. It was his judgment that the threat of annihilation was so great that the public had been paralyzed by anxiety. If threat is to be used effectively, the individual must have some reassurance that the recommended course of action has a high probability of rescuing him from the threatening situation. Research in motivation has long documented the superiority of multiple approaches for influencing behavior. The most appropriate use of this principle in today's program may require both new research and new administrative considerations.

A potential source of influence upon American behavior in the acquisition of shelters may be knowledge of the European and Russian shelter programs. During the 1960 Symposium, an effort was made to acquaint the participants with some aspects of the Russian, Swedish, and West German programs. Our published report(1) presents this information in detail.

Soviet leaders have been interested in civil defense since the early 1920's.(18) During World War II, training in civil defense was compulsory in Russia, and the population at large had shelter experience. Leon Gouré, in his recent book(19) on Russian civil defense, estimated that at least 50 million Russians attended the latest training courses and that the total number trained thus far is between 50 and 100 million. Furthermore, at least one five-man civil defense shelter team for each 150 persons has been trained to operate shelter machinery and supervise the occupants of self-sufficient underground shelters.(18)

SUMMARY AND CONCLUSIONS

This paper has reported some of the findings from existing research which provide guidance in anticipating behavioral problems in the use of shelters, and also summarizes the results of two experimental studies conducted with groups occupying simulated fallout shelters. From this evidence, and from a fairly extensive body of information developed on human behavior in disaster, the authors suggest that normal man has considerable ability to endure extreme demands on his physical and emotional resources. Equally important, we have emphasized several reasons why information from available evidence on human behavior under stress should not be hurriedly extrapolated to a thermonuclear attack. Much of the completed research work is useful for planning purposes, and many of the findings from past disaster studies should have high predictive value. However, models for extrapolation have not been designed, and numerous new behavioral problems are anticipated under a fully developed shelter program. The need to supplement the behavioral information which is relevant to shelter planning cannot be overstressed.*

Our assessment underscores the principle that the development of plans for physical structures which may be used for fallout protection should be accompanied by well-conceived behavioral planning considerations, e.g., the need for preselected and pretrained shelter leaders. Of great importance also are the contributions which architects can make by designing shelters for multipurpose uses, taking into consideration

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*We are optimistic in believing that the initiation of a vigorous research program, directed and implemented by some of the nation's best, professionally trained and experienced behavioral scientists can do much to repair today's deficiencies in behavioral information. If a fully developed and integrated systems approach is to be employed in civil defense, the social systems should receive equal emphasis with the mechanical and structural.

the limitations of spatial arrangements on the formation of productive groups and on the kinds of activities in which shelter groups can engage.(20)

A considerable amount of the recent public controversy about the shelter concept has focused on types of shelters, the family vs. the group and community shelters. Before either of these viewpoints can be implemented, answers may be required for such prior questions as:

1) What do probable enemy attack patterns dictate regarding shelter requirements?
   a) The probable targets
   b) The times of the day or night that an attack might occur
   c) The probable amount of warning time that the public would receive
   d) The magnitude and duration of the attack.
2) Given the answers to the above, how do existing ecological characteristics of today's society bear on shelter decisions?
   a) Location of dwelling units, places of work, modes of travel, and transit time between
   b) Composition of our families and their work and dispersion patterns vis-a-vis their residences.
3) What are the existing values and behavior patterns of our major social classes and categories with respect to preference for confinement with family vs. preference for confinement with community? How do periods of extreme and prolonged stress affect these preferences?
4) To the extent that existing values and behavior patterns do not support the requirements of a shelter system, how can these values and patterns be most satisfactorily modified?

Today we don't have the answers to all of these questions. We are not sure that all of them have been asked. We do suggest that they have considerable relevance for the development of shelter systems in a democratic society. (In framing the questions we assumed that the national shelter program should be aimed at providing maximum feasible protection for all classes of people, regardless of their present place of work and place of residence.)

For those who seek immediate guidance on the general character of a research program which might be undertaken in support of civil defense, we believe that the 1958 report of the Advisory Committee on Civil Defense(21) is still timely. The recommendations of the subcommittee on social science included these comments:

> "The successful use of shelters is dependent among other factors on the planning and public education which precede and accompany the construction of shelters and the effectiveness of warning and communication ... the existence of

> adequate post-attack recovery plans influences the success of pre-attack public education; and so on . . . .
>
> "More lives will be saved and survivors will be better able to cope with the problems of the post-shelter environment if research is increased substantially and immediately on problems of shelter life and habitability, including questions of shelter supply and internal design in relation to human factors; communication within, into and among shelters; shelter organization, leadership and management; and a considerable number of other critical problems."

Since builders and architects have been identified as the "guardians of our future," we believe a shelter program could be of compelling interest to them as well as to representatives of other disciplines.* If we are still searching for new frontiers, we would suggest another one, namely, the utilization of the best established principles and methods that architects, engineers and behavioral scientists can contribute to the development of a shelter program.

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Design of a Nuclear City

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Speculation on cities for the future has been a pleasant pastime of man during the ages. Occasionally those speculations have been prophetic; more often they have been merely dreams of an ideal, a utopia. Few have been constructed. In the past, the time-lag between creative plan and execution has been measured in hundreds of years. During this period the changing needs of man have obsoleted the original concept. Today, this time-lag between developed technology and evolved city form has been reduced materially, and is measured in only a decade or two. The obsolescence rate of city furniture becomes increasingly rapid. Also, information technology is reducing the time-lag for acquiring knowledge about cities, so perhaps we can be increasingly safe in speculating on what our new cities will be.

Historic examples of new cities, ideal cities, suggest that they were conceived and executed because of a driving need of man to better solve his environmental problems by using newly developed philosophy and technology. An interesting example is the town of Nova Palma in northern Italy (Fig. 1). Designed by Alberte Scamozzi in 1593, this new town was inspired by man's determination to free himself from plundering mercenaries. It was planned for defense using the new science of ballistics—the new technology of artillery. Nova Palma was, furthermore, a geometric revolt against the casual, unplanned medieval town. It was a successful plan and established a pattern for many later, planned cities, even influencing the L'Enfant plan for Washington, D. C. There are few such new cities in our world today, including Brazilia and Chandigarh, both geo-political expedients, a few satellite towns, and some scattered resource and industry cities.

For the most part our city-building has been over the old, existing metropolitan areas. Our cities have developed in the industrial age and, somewhat like the medieval town, they have evolved haphazardly, their sole intent being to service industry. When they become heavily diseased, we resort to drastic surgery to correct them, emulating the technique for Hausman in Paris. The prognosis for cities subject to such surgery, however, is poor. There must be new city concepts, inspired by art and science, and created by technology.

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Figure 1. Nova Palma, Italy, 1593

The problems demanding new concepts are many, but a primary one is found in population statistics. We are now doubling our population in every 50 years. In about 2010 our total population will be 400,000,000. The density of the great eastern seaboard megalopolis is about 800 people per square mile. Our present city-building techniques can cope with doubling this density, but the results will be even more chaotic and open space in the great urban fringe areas will be exhausted, which is not a pleasant prospect.

So, the question is whether art, science and technology will succeed in achieving new cities. There seems to be little doubt that technology can service the other two—given the inspiration, any demands can be met. In fact Aaron Fleisher, writing on "The Influence of Technology on Urban Form," found only one possible limitation to a potential city of 50,000,000 people, that of water supply. Desalinization techniques and complete water treatment may solve this.

Assuming then, that technology can meet the specification of art and science, what will be the new concepts? Judging from the recent work of philosophers, planners, architects and scientists, our new cities will be composed of a complex of vast structures. These structures will be nearly autonomous with all functions, from power source to waste disposal, self-contained. They will enclose space designed as perfect environment for man's activities: conditioned air, controlled light and temperature, balanced ionization and pressures. Communications will be by microwave via the grandson of Echo I. Transportation by various mass media, such as vertical take-off and landing craft, will link these great cities and the world. Positioning of these new cities will be free of the tedious requirements of our present ones. They will be located with organic relationship to the regional patterns and, since there will be extremely heavy densities, most of the landscape will be uncontaminated. Our countryside will function for leisure and enjoyment. Figures 2, 3 and 4 are graphic examples of these new city forms in varied concepts.

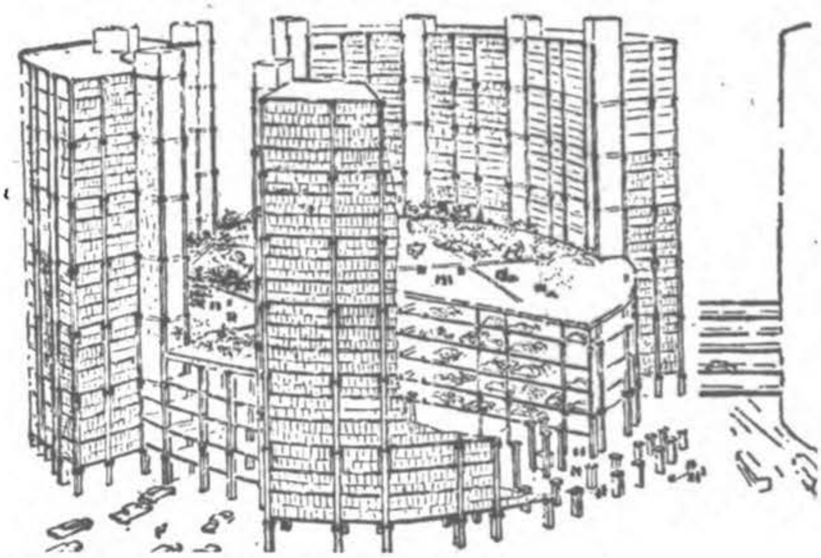

Figure 2. Center City designed by Louis Kahn, 1957. Circular buildings are "vehicular harbors or municipal entrance towers." Street level is used for markets; perimeter for hotels and offices; inner areas for parking and storage.

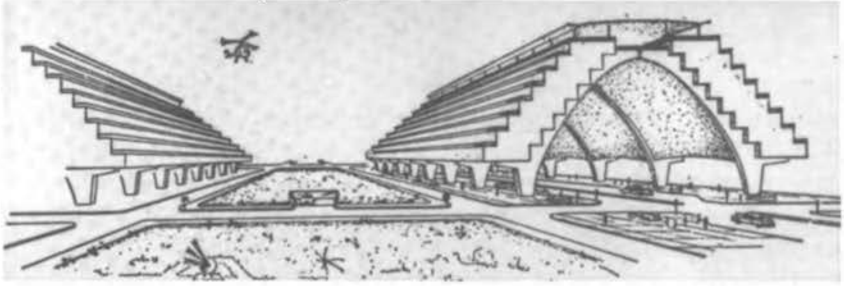

Figure 3. Apartment houses by Camille Frieden, 1959. Arched structures support corbelled living units and form space enclosures for controlled climate in public spaces.

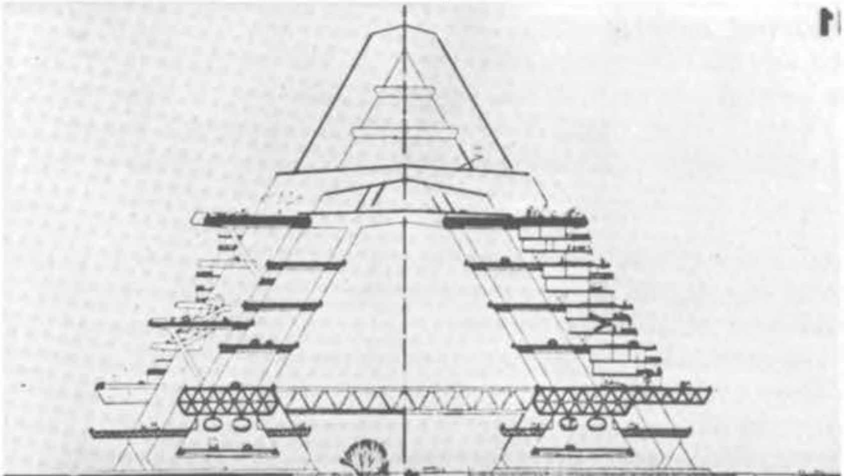

Figure 4. City for 25,000 people by Kenyo Tange and MIT students. Huge "A" frame forms long-term city structure within which are integrated housing, shops, etc., for easy renewal when obsolete.

The Nuclear Age is only 16 years old, and we are just beginning to understand its implications. We are preoccupied today with protective construction against the misuse of nuclear power, but one of the great problems is simply the integration of the thousands of products of the Nuclear Age into our communities. New York State, for instance, finds itself involved in establishing a site for nuclear processing plants and the storage of radioactive materials. The State is studying a plan for a new port to service nuclear powered ships. There are a thousand users of radioactive isotopes in the State, about ten working reactors, and a utilities group is constructing a power reactor. These suggest the many new challenges to man that the atom has brought.

Common usage of nuclear reactors as power sources is inevitable, but man's mastery of the reactor is still incomplete. On January 3, 1961, the National Reactor Testing Station in Idaho experienced proof of this; one of theirs "ran away," killing several of its technicians and spreading radioactive debris. Dr. Ralph E. Lapp, evaluating this occurrence, notes its significance by stating, "Had this tragedy been caused by an ordinary steam boiler explosion, it would have become just another statistic in man's contest with the machine. But, because the machine which turned killer was a nuclear reactor, this was no ordinary industrial accident but an ominous sign post in man's struggle to tame the atom." So, there are new needs of man for containment of nuclear effects, as well as for protection from their misuse.

As a transition, I would like to discuss briefly what I believe to be the first comprehensive study for protective planning and construction for a complete community. This was a Graduate School Project at Cornell University, initiated in the year 1959 and completed a year later. It involved the site selection, plan and design for a town of 9,000 people to service a vital electronic manufacturing facility (EMF). Certain protective criteria were established based on advisory information, and the site, near Schoharie, N. Y., was determined by regional surveys. This site had a readily accessible limestone formation capped by an overburden of shale. The electronic plant was installed in the limestone. The town itself evolved as a rather normal looking one on the surface of the valley floor, but certain public use areas and the mass transportation system were underground and structured to survive against the many parameters of nuclear effects.

The hardened underground areas were planned for dual use. They were to be used daily by the population for normal activities, but when the community was "buttoned up," these areas converted into refuge living spaces. This plan eliminated much of the psychological shock anticipated in the change from normal to below-ground living. Further advantages lay in the fact that families would be immediately joined, and near normal activities continued. Work and recreation patterns were modified, but did persist. The following excerpts from the report* describe the design solution, but not the research aspect of the problem.

> "The development of the Schoharie site followed a procedure which depended upon two major factors: a) Ease of construction and access for the plant facility, and b) Desirability for the layout of a town of 9,000.
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> "Of the number of potential plant sites existing in the limestone clefts of the upper Schoharie Valley, only two development areas had those qualities which would make town growth feasible. Other sites proved inaccessible, vulnerable to flooding at high water, or otherwise poorly located in regard to drainage.
>
> "Two sites, designated 'Fox River' and 'Rock Ledge,' remained under consideration for the ultimate town-plant location. Although it was agreed that the Fox River area had the superior formation and quality of limestone, Rock Ledge, near Schoharie Village, was found to hold distinct advantages for community layout and development.

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*Cornell University College of Architecture, The Schoharie Valley Townsite, 1960, pages 29-46.

"This site afforded desirable topography for drainage, street layout, and utilities, and in addition was much more favorably located in relation to existing transportation. Finally, the amount and quality of developable land in the Rock Ledge location was enough to 'clinch' our decision. It should be noted that a great many objective factors went into the ultimate site selection, and that this discussion mentions only the most obvious considerations.

SHELTER NETWORK

"Working within the structure of one of the original competing teams, members of the group arrived at the shelter concept which would ultimately become the system for the final design.

"Following a procedure designed to focus on the most feasible approach, we first rejected the idea of a totally subterranean community (Fig. 5). Even if the tremendous expense of such a venture proved insufficient to discourage this scheme, the immense psychological barriers would be quite effective in doing so. Our next course ran in divergent directions—either a central community shelter, or individual residential or neighborhood shelters. The adoption of a central refuge would entail an extended amount of warning time, or else a tremendously compact community, in order for residents to get to shelter in a short time. The individual shelter answers the time problem admirably, but leaves the occupants without communication which could be critical in case of sickness, injury, or of families being separated at time of alert. This separation factor could be a serious development, if one envisions a shopping mother, working father, and a child at school attempting to unite upon hearing the alert. The confusion multiplied by many such families could have as serious an effect as to have no shelters at all.

"Obviously, the next development had to be a scheme which synthesized the advantages of preceding proposals, while filtering out the disadvantages. This was done by designing a series of neighborhood shelters which could be interconnected by subterranean corridors. This would answer the primary need of getting people to shelter quickly, and allow for the assemblage of families only after everyone is safely sheltered. Most significantly, though, such a scheme permits the community to function as a community during the period of refuge. The E.M.F. plant, the power source, business district, and the scattered neighborhoods would be interconnected so that plant employees or control center personnel might work effectively, knowing that they could get 'home' to their families. The network also enables these key individuals to get to the plant and control center from their homes if an attack were to occur in the evening or on holidays. Another feature that we found inherent in the network scheme is that the corridor and shelter excavations could accommodate the town's trunk utility lines, and with some manner of closure from outside sources, these lines could then handle the utilities of the shelter network during this refuge period.

"This shelter system necessitated a pattern of fairly well-defined neighborhoods surrounding the central business district. The size and shape of these neighborhoods would be determined essentially by the amount of time it would take to get to the shelter from the periphery of the neighborhood. At a walking rate of

Figure 5. Model of community showing normal, above-ground facilities. Electronic manufacturing facility is in limestone hillside to rear; main shelter complex is next to central business area.

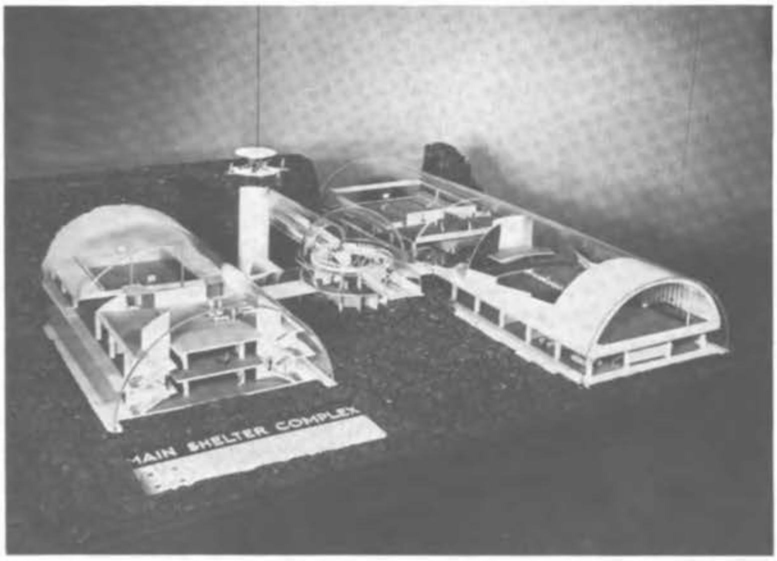

Figure 6. Main shelter complex and a station on the Seatway. These are directly below high school classrooms and serve daily as auditorium, cafeteria, clinic and gym, but in refuge periods, convert to shelter.

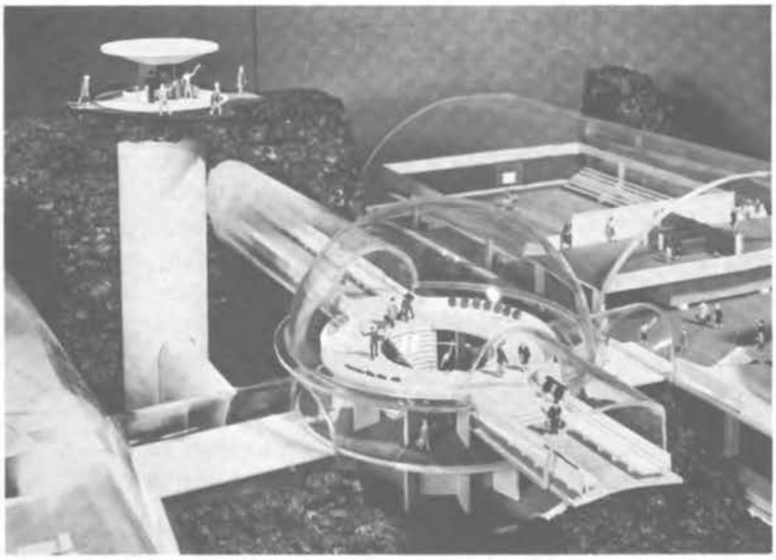

Figure 7. Detail of main shelter complex. On left is surface access via hydraulic blast resistant closure valve.

roughly 300 feet per minute, we felt that the extremity of a neighborhood should not be more than five minutes, or 1500 feet, from a shelter entrance.

"Though this scheme is probably not the most economical proposal outwardly, its inherent assets give it a substantial lead over others. Any concept of unconnected shelter units would entail expensive duplication of equipment for survival, and, in addition, would have to be overdesigned to accommodate possible capacities, whereas overflow crowds at one network shelter could be distributed to less crowded shelters. That the utility trunk lines would occupy the same excavation means an economy through duality of use. Later studies revealed the usability of the network as a transit and delivery element during normal times, which means that this is not just an expenditure for a potentially improbable disaster and nothing else. But, probably the most significant rationale for this system exists in the need to maintain the community as nearly normal as possible under attack conditions.

SEATWAY

"Normally, a mass transit system is feasible only in larger cities—rarely, if ever, in a town of nine thousand. The economics of constructing and operating such a facility speak for themselves. Obviously then, a transit system in this community could probably make sense only if the bulk of the installation already existed, and were virtually 'open' for the inclusion of a transit network.

"Having established the shelter network, we actually found ourselves with the foundation of a transit facility in the nature of the interconnecting tunnels. A transit system utilizing these corridors would create a full-time use for them—rather than their being inert but for use in a nuclear disaster which would, conceivably, never occur.

"The first idea was to employ a pedestrian belt system not unlike those now being projected for large airports and shopping centers. However, such a system would require a number of acceleration and deceleration belts at terminal points in order to maintain a justifiable speed on the main belt. This, in turn, would require more room, thus adding to construction costs. Obviously, a single continuous belt could not stop for any one point without stopping the entire length, so a system of platforms or seats which could be separately stopped was the alternative. As the illustrations show, we arrived at a system of seats, and called it the 'Seatway' (Figs. 6 and 7).

"Mechanically, the Seatway would operate as a continuous belt, with 'trains' of 8 to 10 seats running at such intervals as the volume of traffic would demand. These seat 'trains' would be designed so that they would be disengaged from the continuous belt and stopped at terminal points. After a time interval enabling passengers to get on or off the seats comfortably, the seats would become engaged to the belt again, and continue onward. These seats would have to accelerate, decelerate, and run at rates safe and comfortable enough for both the elderly and the very young.

"In case of disaster, the Seatway could be stopped, and the seats dismantled in order to utilize the subterranean corridors for living spaces. Versi-bed units would be erected along the periphery formerly occupied by the seats, and then screened off. The middle corridor of the Seatway tunnel would then be used for circulation. Sanitary facilities would be located at each access point along the Seatway corridor, so that no one would be more than 200 yards from the nearest facility in a disaster situation.

"This Seatway has access points approximately every 400 yards, and it connects all residential areas with the plant facility via a main central interchange under the central business district.

"Certainly the expense of such an installation would be prohibitive in itself—but in our situation, where the construction of the subterranean corridor has already been justified on vital survival grounds, the Seatway becomes a reasonable normal-time usage for this expansive corridor.

INNOVATIONS

"The design phase of this project resulted in a startlingly comprehensive problem of invention, ranging from industrial plant design to regional planning. The unique aspects of the problem allowed us the luxury of delving into questions that a city planner does not normally encounter. Since designing for a hardened and restricted environment was a new problem for most of us, it is not surprising that several unique solutions resulted from our efforts to provide both flexibility and conservation of space for this environment.

"One interesting item may have been designed with tongue in check—but it gained enough acceptance within the group to become a full-fledged element of the total scheme. This is the 'Family Tree.' Formed by the erection of telescoping poles on an eight-foot module, this makeshift sleeping arrangement includes hammocks which are suspended from the poles at different levels. A number of these hammocks for family members would comprise a family tree. Curtains would then be hung from surrounding poles for privacy. The rapidity with which this arrangement could be erected and demounted has obvious advantages for our shelter system.

"Another device considered as an answer to sleeping and space conservation needs was named the 'Versibed.' In simple terms, this was a light rectangular frame designed to be attached to vertical rods, walls, or portable legs—and thus become anything from a ping-pong table or a dart board to a bed frame. This unit was conceived for demountability, versatility, and ease of storage, as was the 'Family Tree.'

"Another device with which we experimented was a valve closure for the shelter entrances. These valves had canopy tops which literally 'drop down' to seal the spiral entrance stairs after everyone is safely in the shelter. Although these schemes might be looked upon as 'gimmicks' to enliven the project, it should be realized that the unique challenge of this problem demanded equally unique and unprecedented solutions to nearly every detail.

SPACE-TIME ANALYSIS

"Due to the strict tolerances which one must expect of life in a shelter, it was necessary to make a space-time analysis of the human uses of a typical shelter unit. The graph on this page illustrates the study of a normal day's occupancy for a typical shelter area, based on the assumption that the men will continue to work and that children will continue to go to school during the refuge period. "Clean up" would consist of activities such as the erection or dismantling of 'family trees' and 'versibeds,' and the clearance of gymnasium and other areas for daytime use. Feeding operations would run on a sustained schedule, based on the number of persons who could be served during a given period. Recreation could include closed-circuit T-V, table games, reading, and movies from a permanent film reserve.

"The vertical bars show the degree of occupancy by men, women, and children at given times of day in this typical unit, such occupancies being based on the capacity of the nearest feeding station. Note that congestion is greatest during early evening hours, at which time it would probably be necessary to organize activities.

COMMUNITY ELEMENTS

"It should be remembered that in spite of the ominous and urgent rationale for this community, it is, above all, the habitation of human beings. As planners, our goal was, in addition to answering the pragmatic considerations, a matter of conceiving a setting desirable for a great variety of human wants and needs. Consequently, we strived to instill that ideal in all of our thinking relative to the town planning aspect of the project. The town plan concepts varied in the early design phases, and it was not until the shelter network had been adopted that a specific plan approach took shape. This network, as previously noted, established definite limitations on the size and shape of the community, and on the relationship of elements therein.

"The needs for access to this network also suggested the nature of the individual neighborhoods. We divided the city into three segments of roughly 3000 people, each segment capable of supporting an elementary school. The idea of utilizing a school as a shelter has been in existence for quite some time, so that our decision to do so was not without precedent. Laying out each neighborhood with internal 'greenbelts' radiating from the school focus brought about a scheme which would enable pedestrains to approach the schoolshelter by crossing a minimum of streets.

"This turned out to be one of those rare, fortunate instances in which hard, practical needs worked very well with a purely esthetic amenity. The greenbelt, which penetrates the interior of each block with what might be called a 'park artery' is often difficult to justify expensewise in an average-income town. But in this case, the functional need for just such a pattern would have made it meaningless to apply a conventional street system. The conflict of auto and pedestrian movement in an emergency could create a disastrous jam without a system that funnels movements to the shelter accordingly.

Neighborhood Community Centers and Shelters

"At the center of each residential area would be a community center, in which would appear an elementary school, local shops, social center, churches, and recreation facilities. Besides serving as the social-recreational hub of the neighborhood during normal times, this complex could also function as such in the disaster situation.

"Each element of the center would have supplementary hardened spaces beneath, which would be usable at all times. For example, the storage spaces beneath the shops would be food reserves for shelter operations, while Sunday school areas beneath the churches, recreational facilities under the social center, and the school's subsurface gym-cafeteria would similarly function for disaster needs.

"Normally, these underground elements would be closed off from one another, except that the school would be connected with the seatway tunnel for the benefit of school children and adults traveling via the seatway. In the neighborhood center there would also be an exterior access to the Seatway, and this would constitute the major entrance to the neighborhood shelter complex in an emergency. At that time, all of the subsurface areas would become interconnected and would function as the 'neighborhood in miniature.'

Central Business District and the Central Shelter

"A major focal point of the plan is the central business district. With an eye toward the intimate atmosphere that one might expect in a town of 9,000, this business-civic center was conceived as a pedestrian plaza. Most major businesses and community functions were laid out near the edge of the area, while parking and service elements were located at the periphery, so that no traffic penetrates the center. Small shops and businesses located within the complex would be served by small delivery vehicles.

"In order to establish a physical separation between the business district and adjacent residential areas, a park area surrounds the complex. This park belt includes public recreation facilities, an athletic stadium, high school, and an elementary school serving one of the three neighborhoods. The high school was designated as the site of the downtown shelter, such shelter serving as the hub of the entire subterranean network and the location of the civil defense control center under emergency conditions. (See Fig. 6.)

"The downtown plaza is on two levels, conforming to the general slope of the land—the eastern half of the complex is elevated about five feet above the western half, and both parts are slightly above the level of the adjacent parking areas. In the center of the upper level is a 'memorial court' on which rises a 120-foot pylon, the visual focus for the downtown plaza and the community. Beneath this court one finds the central interchange of the seatway, whose transit arms radiate to the plant and the various residential areas.

"The central shelter operates integrally with the central business district and the high school-elementary school complex, being the refuge for occupants of both areas in time of emergency. The municipal office building at the northeastern end of the plaza contains hardened subsurface office space which converts to the C.D. control center in a disaster period. In addition, the primary downtown entrance to the central shelter is through this building, with auxiliary access at Seatway entrances.

"Beneath the school complex one would find complete gymnasium, library, auditorium, cafeteria, and storage facilities for the schools. This entire area would be convertible to shelter uses in a disaster situation. Feeding, recreation and living facilities for personnel of the C.D. control center and residents of the adjacent residential area are maintained here. In addition, this central shelter is equipped to provide primary clinical facilities for the community in both normal and disaster times. With its library, museum, and auditorium, this hardened central complex is also the town's cultural center, and would provide such cultural and entertainment activities as could be expected during the refuge period. As in the case of the Seatway, continued normal use of these facilities by the townspeople is expected to reduce the psychological reactions that one might encounter in entering them as disaster shelters for the first time. All police and fire personnel and equipment is placed in hardened facilities adjacent to the municipal offices, and thus would be available and intact for service at all times, either for surface or shelter emergencies.

Industry

"Having determined the space, functional, and circulation needs of the electronics manufacturing facility, the major remaining obstacle was the positioning of the facility in the Onondaga limestone. It was necessary to pay particular attention to accessibility for personnel and services, and to the relationship of the installation to the townsite itself.

"Access problems were intensified by the all-important need to provide blast and radiation protection at the entrances. Consequently, the long entrance tunnels to the plant were designed not only with a number of turns to dissipate direct blast and radiation effects, but with substantial closure devices which could be sealed either manually or mechanically. One can better understand the concern given the treatment of these entrances when it is realized that they constitute the weakest link in the insulation of the shelters and hardened facilities from outside blast.

"Excavation in the limestone would be similar to that of a comparable mining operation, except that within the cavity there would be erected mill-type structures detached from the ground and completely shock-mounted to withstand the concussion of a nearby nuclear blast. This last consideration is of vast significance to the maintenance of sensitive machinery. In addition, there is never less than 100 feet of earth and stone between the plant excavation and the outside, thus providing additional protection from both shock and radiation.

"Proximity of the E.M.F. plant to the town center is important not only to expedite movements in case of disaster, but to reduce the expense of the tunnel connection between the two. As a result, the plant and town had to be planned and located as a single element. Certainly, by virtue of its subterranean character, the plant inflicts no objectionable atmosphere upon adjacent residential areas, so that usual difficulties in industry-residence relationships should not arise.

"Beside linkage with the rest of the community via the Seatway, there is parking for 1,000 employee cars on the surface above the plant. Personnel entrances at three points along the extended parking area disperse circulation in and out of the facility, and thus reduce the hazards of congestion at a single entry.

UTILITIES

"The development of an effective utilities system for a hardened community entails numerous interesting problems. Our foremost obstacle lay in the fact that there must be complete isolation from external elements in operating a utilities network during a critical shelter period of two weeks.

Water Supply

"A breakdown of quantitative water needs for a community of 9,000 persons in per capita consumption:

Domestic	70 gallons per day
Commercial & industrial	40 gallons per day
Public	10 gallons per day
Unaccounted for	20 gallons per day
TOTAL	140 gallons per day

"On the basis of the above per capita figure, the maximum daily water demands of the community were estimated at approximately 1,930,000 gallons. Two sources were considered capable of meeting this demand—well fields west of the townsite, or Schoharie Creek plus a supplemental reservoir.

"Wells drilled in the flood plain of Schoharie Creek indicate that approximately 200 feet of Pleistocene gravel overlies the bedrock. An existing well drilled to bedrock in the area yielded 150 gallons per minute, and when pumped, the water level stabilized at a depth of 60 feet. This was outwardly indicative of a source sufficient to meet our demands, but if it proved not to be so, then Schoharie Creek would be adequate at least for the non-summer months. Schoharie Creek carries a very small volume of water during the summer months, and it would be necessary to erect a supplementary reservoir to insure a sufficient water supply in these months.

"Utilization of wells, however, was considered a substantially preferable source. In addition to their being a less expensive means of obtaining water, wells could be a distinct asset to our efforts in designing a totally hardened community. Specifically, the 200-foot depth of ground water is such that radiologically contaminated water or particles would require a period far in excess of the two weeks to penetrate into our water source.

"The water would be pumped from the well field to a treatment plant located in rock above the electronics manufacturing facility, along with a million-gallon subterranean storage reservoir—this elevation creates adequate pressure to serve the entire community. The primary water distribution system would then tie in with the shelter network in such manner that, in case of an attack situation, valves from these conduits to secondary areas could be closed to conserve water and prevent cross-contamination. In this way, the water system is easily converted to serve only the 'buttoned-up' town and plant.

"Three other subterranean storage reservoirs, each with a million-gallon capacity, would be located in strategic areas relative to the shelter network to insure an emergency source in the event of physical or radiological damage to the well field or supply main. If the well fields remained intact, we could anticipate completely normal water usage even during a disaster situation. However, the four hardened reservoirs would insure at least 25 gallons per capita per day if well sources could not be depended upon during an emergency. As normal water usage entails a great deal of wastage, this 25 gallon per day figure does not constitute an unreasonable amount if prudently used. These auxiliary reservoirs could prove valuable in the event of any crisis affecting the water source, and so would not be superfluous, even if thermonuclear disaster were discounted.

"The proposed hardened filtration plant would be designed to treat two million gallons of water daily, and would consist of mixing basins, coagulating basins, and filter tanks. Aeration equipment and suitable filters for removing radioactivity would also be provided. Although the inherent protective aspect of the ground water source negates the probability of radioactive penetration, conservative design dictates the inclusion of these filters. Ground water from existing wells in the region has indicated the presence of hydrogen sulphide, hence chemical treatment for the needs of our community would consist of alum, lime, activated charcoal, and chlorine.

Sewage System

"The accommodation of a gravity flow of sewage was an important factor in townsite selection, and in the arrangement of connecting tunnels in the shelter network. The sewer mains would run, insofar as possible, within these tunnels—thus effecting the same economies as were considered in running the water mains similarly. But, more significantly, both utilities could then serve the needs of the town even during a period of subterranean refuge. Valves would be located at points where laterals connect with the mains in the shelter tunnel, and in event of emergency, would be closed to prevent the inflow of radioactive material from basement drains or infiltration. This shut-off operation would then provide a closed sewage system limited to the confines of the plant, reactor, and shelter network. A further safeguard would exist by designing the system to bypass the sewage treatment plant in a disaster situation, with suitable traps downgrade from the hardened areas providing sufficient attenuation of radioactive materials from the outside.

"The sewage treatment plant, located west of the townsite near Schoharie Creek, would consist of a protected comminutor, grit chamber, primary settling tank, sludge digestors, and sludge drying beds. Refuse disposal would be best facilitated by incineration or sanitary land fill. Radioactive waste from the reactor could be stored in a subterranean chamber until such time as it could be disposed of at sea.

Power Source

"The primary criterion in determining the town's power source lies in the need for this facility to remain operative in spite of radical external developments—which, in our case, would be the nearby explosion of a 20-megaton bomb. One such bomb, for instance, could easily divert the path of a river, so we immediately ruled out the possibility of a hydroelectric power source. In the same light, it was obvious that we could not consider any source dependent upon a constant supply of external material. Further, we determined that the space limitations of the hardened community would deem questionable any inordinately large area designated for fuel storage. And, since power generation from coal or oil would entail a prohibitively large storage installation, this possibility was discounted.

"Of the few uncommon means of generation that our criterion of independence would allow, a nuclear reactor was thought the most feasible. Reactors are available which answer the need for independence of environment and another important consideration—'fail-safeness.' More explicitly, in addition to the potential hazards presented by a reactor, there exist the stresses which a nearby thermonuclear explosion could place upon one. If these are so extreme as to prevent its functioning, then it must at least do no damage of its own to the community. It should be possible to confine any damage or danger to the reactor housing, itself.

"The fuel used must not be exotic. Although fuel sufficient for several years can be stored in a relatively small space, we found it advisable to use a common, readily available fuel requiring little processing, thus making it possible to borrow or lend fuel to other surviving areas in case of damage to supply sources.

"Similarly, it was determined that the coolant should not be exotic. In the event of damage to the reactor, the coolant, being liquid, could readily escape. Consequently, ordinary water, the least difficult element to supply and replace, was selected. The water is recirculated in a subterranean cooling receptacle called an 'expansion tank' in order to conserve the coolant, should water supply be cut off.

"It is, of course, all-important that the reactor be of a type which can operate for extended periods without fuel changes. Fuel changing generally lowers the available power, and entails a period of 'abnormal' operation. Since community operation during a prolonged disaster situation must be devoid of any abnormality in power generation, the frequency of change should necessarily be reduced. The reactor which was found most satisfactory in the light of our needs is not unlike those that appear in nuclear-powered submarines, on a substantially greater scale. This reactor would yield some 25,000 watts, and would require an excavated cylindrical space 85 feet high and 45 feet in diameter, while auxiliary equipment would require an additional 80,000 cubic feet.

"The primary distribution lines and transformers would utilize the shelter network tunnels, just as would the other utilities. Just as the other utilities, they would operate strictly within the shelter confines in an emergency situation, for all secondary lines and transformers radiating beyond these main conduits would automatically be cut off.

Air Conditioning

"The heat released in an underground installation of the kind proposed would reach highly uncomfortable proportions if left by itself. Electronic equipment, lights, motors, personnel, and other sources contribute to a heat problem which is intensified by the lack of natural ventilation in these subterranean areas. Studies of existing subsurface facilities have indicated that rates of heat gain vary from four to 15 million B. T. U. per hours, based on a multitude of individual considerations. The computation of the exact heat gain in our installation would be beyond the scope of this problem since there are numerous indeterminate factors which could be pin-pointed only in a specific and exacting solution. Nonetheless, it was readily obvious that heat gain would be sufficient to necessitate removal in both winter and summer.

"An additional complication arose in the fact that if conditioned air was introduced at a temperature low enough to remove all excess heat, drafts and a generally uncomfortable air temperature would then ensue. Consequently, conditioned air input would have to be constant throughout the year—warming incoming air in the winter and cooling it in the summer, while a separate means of removing the remaining air would have to be devised. Experience gained in Swedish underground installations offered us some advanced thinking in dealing with those problems. In its most elemental terms, the system which would be used in this installation would consist of water circulating in ceiling panels to absorb excess heat not removed by air circulation. The heat transferred to these cooling coils would be removed by means of a heat pump which would also provide waste heat for warming incoming air in the winter, or divert it in summer through some means of exhaust. Ground water from the joints and fissures in the Onondaga Limestone would probably be utilized for these purposes, in order to conserve treated water for the community.

Air Intake Filters

"Obviously, the amount of fresh air required by 9,000 people for a period of two weeks or more is vastly greater than could be supplied by internal sources. The only reasonable means of obtaining air would be from the outside, provided, of course, that the means exist by which chemical, biological, or radiological contamination would be prevented from entering with the air. In this case, it might be well to note that radioactive fallout is the simplest hazard to detect and remove, and that the lives of 9,000 people could depend here upon our success in eliminating the more elusive chemical and biological dangers.

"Filtration devices developed and produced by the Army Chemical Corps have proved adequate to meet these dangers. These filters are comprised of two parts, one of which filters out particulate radioactive fallout materials and

> biological warfare agents, while the other retains and neutralizes chemical warfare agents. These filters would be located in such a manner that human activities would not be exposed to the potential hazards resulting from the entrapment of radioactive particles in the filter. We have estimated that it would take a month, at the least, to exhaust one of these filters, so that our critical refuge interval is well within the bounds of effectiveness and safety for these filters.
>
> Communcations
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> "Telephone, radio, and television facilities would not entail the quality of complete isolation that we have found necessary in the other utilities, and consequently require no unique solutions. As all of the major elements of the community—the plant, central business district, schools, hospital, etc.—are interconnected by the shelter network, all of the main communication lines would follow this network. Closed-circuit television, for instance, designed to serve the school system, could be readily converted to use for entertainment and education during the period of subsurface isolation. Thus, there are no apparent problems concerning communications in this 'buttoned-up' period."

There is understandable pessimism today concerning the future of our cities. They have been diseased for too long a time, and the prognosis for cure through surgery is poor. Then, too, our cities and our civilization are threatened, really for the first time, with massive destruction. It is apparent that these pressures have combined to inspire new city forms. These will be mutations from the old ones, and we can expect radical departures. These new cities will be the exciting, constructive, and creative expressions of the Nuclear Age, and will evidence man's mastery of his new knowledge.

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Open Forum Discussion

Moderator—Milo D. Folley, Partner in Charge of Design & Research
Sargent-Webster-Crenshaw & Folley, Architects

Panel Members—Messrs. Achenbach, Albright, Baker, Greene and Welch

Robert S. Van Keuren, Syracuse University: Where can information on the risk studies relating to radiation intensities and overpressure criteria for various localities be obtained? Can an interested architect or engineer obtain this information for design purposes?

Mr. Greene: Requests for this kind of information must be submitted through organized civil defense groups. It is not being made available to individuals because of the security connotations, so I would recommend that you contact your local civil defense or State civil defense groups.

Arthur Dimer, Union Carbide Corp.: Is there any literature available which outlines the requirements necessary to select and develop "managers" for sheltered personnel?

Mr. Baker: The experiment by AIR which I described did produce some literature; they did do some training of their leaders. So I would say in answer to your question - yes, there is.

Haratio Bond, Natl. Fire Protection Assn.: Should not shelter requirements include water supply for fighting fires in shelters?

Mr. Welch: I think this is a very valuable consideration. The pressure-type fire extinguisher would be a useful item to have in a shelter.

J. C. Horton, Carrier Air Conditioning Co.: Do you believe a person can survive in an underground shelter with 5 cfm/person ventilating air with average outdoor air temperature at 85° F over a period of one week? Also 90° F average temperature? How about 10 cfm/person?

Mr. Achenbach: I believe you could survive at 5 cfm at 85° F air temperature for one week. At 90° F it might be questionable. It would then depend largely on the earth temperature surrounding the shelter and the heat conduction to the surrounding medium. There aren't adequate physiological data on the endurance of the human being for as long as a week under conditions of 90° F effective temperature or 90° F saturated air.

The data we have indicate that somewhere around 85° F, plus or minus a few degrees, is about the limit for periods of a week or two.

Leo Goldstein, City of Phila. Dept. of Licenses & Inspections: Does a surface curved in three dimensions provide more protection than a plane surface? Does a reflective surface material provide best protection?

Mr. Albright: Are you referring to radiation protection or blast protection?

Mr. Goldstein: Either one.

Mr. Albright: In other words, you are asking whether a load on a curved surface is less and therefore the resistance required for that surface is less. It's impossible to give a specific answer to the question from the blast standpoint. The question relative to the radiation protection of course depends on the position of the fallout particles on that surface, and the distance from the particles on the surface to spaces in the protected area. Therefore it is impossible, I feel, to give general answers for each of these two questions.

Ken Simmons, Atomic Energy Commission: You referred to use of upper stories of buildings as relief areas for overcrowded conditions. Does your reference apply to fallout shelter design only, or do you include blast design also?

Mr. Welch: The statement in my paper was related to fallout protection. It is not inconceivable that a degree of blast protection could be afforded in an upper story shelter, but my experience would lead me to believe that it would be far more expensive to do it this way.

T. W. Glynn, American-St. Gobain: What would you suggest as minimum levels of illumination in shelters?

Mr. Welch: In our studies we worked with approximately 10 foot candles in administrative areas and not more than 3 foot candles in areas of low use. We tried to keep 3 foot candles even in sleeping areas, for purposes of administrative efficiency.

Mr. Baker: In connection with an observation of ours to the effect that man can endure a lot, I am reminded here of the study of miners made in Nova Scotia. A group of miners, 19 in all, were trapped underground—a portion of them for 6-1/2 days and a portion for 8-1/2. During the majority of this period they were without any form of light whatsoever and when they emerged, as far as we know, this did not have any negative effect on them.

Carley Moncure, The Producers' Council, Inc.: Because the field of nuclear design is so new, I assume that we must now use conventional, already available materials when we design buildings to combat blast, nuclear radiation and thermal radiation. Will there be building products of the future, such as surface coatings especially designed for this use? Is research on such new products being done now, and will there be an expanding building market as a result of such new products and new designs for the Nuclear Age? If so, has its extent been predicted?

Mr. Albright: When we are speaking of protection against radiation from fallout, there is no magic material; it's simply a matter of the weight of our construction materials. When we are speaking of protection against dynamic loads, obviously the stress and strain characteristics of the materials that we use are very important. It's rather difficult to project what further developments will evolve in both these directions.

C. W. Griffin, Engineering News-Record: Is it scientifically valid to infer from the behavior of people following limited local disasters that survivors of a full-scale thermonuclear attack, which would bring nearly universal destruction and thus limit the hope of outside rescue, would behave as well as survivors of floods, tornadoes, etc.?

Mr. Baker: I wouldn't accept the assumption that thermonuclear attack would result in completely universal destruction. I would assume the targets might be a selected number of cities, or a selected number of bases in one given country, or a combination of given countries. The important point which I can offer here is that for the survivor, immediately after the disaster agent has come and gone, the environment is fairly limited. He isn't looking over in the other county or the other state, and I think we can generalize fairly satisfactorily from some of the data on floods, fires and hurricanes. The people in the mine disaster in Nova Scotia underwent a lot of stress. When they came out, they were interviewed by psychiatrists and none of them, with one exception, had any need for psychiatric referral after that. As a matter of fact, the people who were around the mine pithead outside did require psychiatric help during the course of the disaster. Not to be unreasonably optimistic, however, I would underscore again the need for considerably more work in this general area.

Walter Holt, Buffalo Forge Co.: Did your studies include any correlation of ventilation rates with cubic foot/person of shelter space?

Mr. Achenbach: No, they did not. We only had one size of space, and we varied the ventilation. The rates of ventilation used in such a small space amount to several air changes per hour and, in terms of conventional ventilation, are fairly high turnover rates. The study did not encompass changes in the amount of space per person. We did not use real people so we did not get a real reaction on space.

N. E. Hager, Jr., Armstrong Cork Co.: After initial period when radiation levels are high, people could go outdoors for measured periods for exercise and sunshine (accepting small additional doses). Why is it necessary to consider people imprisoned for two weeks?

Mr. Baker: I think this question bears on some policy decisions rather than human behavioral decisions. The two-week period has been used as a kind of planning figure. It may be that long; it may be less than that. It would be good to have enough food and other supplies available for that length of time.

Mr. Greene: This time length really represents the "worst case" situation. I agree that, in almost all circumstances, people could come out for short periods of time after the first two or three days, but whether they could come out long enough to find supplies, etc., is another question.

Horatio Bond, Natl. Fire Protection Assn.: Your list of requirements for shelters did not include fire protection. Do you expect no fire exposure of people in shelters?

Mr. Albright: Speaking of the structural system, I was not including the other items which we accept as a part of our normal day-to-day building requirements. I think we certainly will want to include fire protection of an appropriate amount in all of the buildings and equipment which we provide, whether it be shelter or other conventional building.

Ken Simmons, Atomic Energy Commission: How is the protection factor of upper floors affected by loss of windows and subsequent infiltration of fallout particles, assuming the blast leaves the building standing but removes windows?

Mr. Albright: I think a specific answer would depend upon analysis of a series of hypothetical buildings to see what the fallout distribution might be on the upper floors and, consequently, what change in protection factor would exist. It's important to recognize that in many cases the particle sizes, etc., are such that this would not be a great hazard. In other cases, it might reduce the protection factor somewhat. It's also important to recognize, when we are talking about protection in the upper stories of a building, that the principal contribution of radiation is coming from the ground through the floors underneath us. If fallout is deposited on adjacent surfaces of a floor, then that statement I made would no longer be true, and it may be the principal contribution would be from the fallout on an adjacent floor area.

Unsigned Question: Does it do any good to build a fallout shelter if you are close to any one of the recognized targets?

Mr. Greene: Your security would be improved a finite amount because in each of these attack situations, there is always some target area that isn't hit—they don't hit them all. But, if they hit the target, and if the fallout shelter is within the high blast risk area, then, obviously, it's not going to do any good.

Mr. Folley: You don't have sort of a scale, listing the areas, with the factors that we can use to rate this?

Mr. Greene: Perhaps I didn't make clear what happened to the other 50% of the bombs that didn't land within one CEP of target. Something like 74% of them land within 2 CEP's. If a CEP were two miles, about 74% of them would be within four miles, and perhaps 94% within two to six miles. They don't just fall all over the country; they are closely located around the target.

Mr. Folley: Do we have a problem of fallout from any source other than warfare, for example, an atomic power plant or atomic powered craft of some kind?

Mr. Greene: Well there could be, certainly. The chances are very low. The AEC probably should speak about this, but any power plant that is approved is designed with maximum safety. There has been a study of this done at the Brookhaven National Laboratory. Also, there is a handbook now being printed by a subcommittee of the National Committee on Radiation Protection which deals with this subject.

Mr. Folley: What effect would insulation have on the design of the mechanical systems? It is obvious from your data that walls, etc., have low temperature surfaces which would cause the accumulation of moisture. Is insulation a way to stop it and what effect would this have on the mechanical systems?

Mr. Achenbach: In situations where the shelter is colder than you wish, one approach, in a small shelter, at least, would be to drape aluminum foil over the walls. This would provide a reflective surface, would reduce the heat transfer, and would reduce the probability of condensation, in that the exposed surface would be nearer or even above the dew point of the air. Insulation would be of value in any situation where space was too cold. Of course, during the occupancy period of a week or two, your environment is continually getting warmer, so you would want portable or removable insulation in some cases. The ceiling is the most critical area, and I think some work should be done on preventing condensation on the ceiling by insulation or by doming the ceiling so that the condensation would drain off to the walls. Water forming on the walls could be drained down onto the floor and could be handled more adequately than water dripping from the ceiling.

J. A. Rorick, IBM: Did any bacterial growth such as mold or mildew appear on your simulated personnel or anywhere in the shelter? If so, is this a possibility that also exists for humans?

Mr. Achenbach: I don't believe we had any appreciable mold during the test period but, during the year or so since, things are fairly musty in the shelter. I think this is a real problem during the stand-by condition in any shelter that you might build underground—how to keep it habitable when you don't expect to use it, or aren't using it. This applies both to the matter of mold and to corrosion of metal parts, and things of that kind. While we all can think of ways to prevent it, it certainly seems like a considerable task and one that would need attention at frequent intervals. There is definitely the possibility of fungus growth if you had to live for a couple of weeks on a wet floor, and were not able to keep your clothing and your feet dry.

Mr. Folley: N. Y. State requires a 22" exit unit for each 100 people based on 10 sq. ft. per person. This seems to indicate that the openings would constitute not only a high cost but a hazard as well. What exit requirements would you suggest for shelters?

Mr. Welch: My own feeling about it is that every shelter should be provided with at least two exits. The real problem for me to assess, and I think for most people who plan for large group shelters, is the question of entrance time. In order to achieve rapid entrance to a shelter you may require more exit-entrance space than would be necessary at any other time during the shelter's use. Most of the exit requirements that we work with are predicated on an emergency which requires evacuation of the space. In the case of shelter, this is putting an emergency on top of an emergency and therefore, I think, is not a primary consideration.

Mr. Folley: Can water or fuel from an exposed area be a radiation hazard even though it were in a concealed state? In other words, can concealed liquids transmit radiation?

Mr. Albright: It's possible for particles of radioactive material to be deposited in fluid which would move into a sheltered space. Studies are currently being conducted to determine how critical this might be, and in what quantities it would have to occur. Generally, we do not consider it a major problem. If it is concealed or contained outside, there is no problem whatsoever—that fluid will not become radioactive.

Panel Discussion
Implementing the New Design

Moderator - Gifford H. Albright,
Associate Professor of Architectural
Engineering, and Director, Shelter
Research and Study Program
Pennsylvania State University

Department of Defense Policy

By Paul Visher*
Office of Civil Defense
Department of Defense

The problem with civil defense, and the problem with protective structures over the past several years, has been a lack of a specific focus. For the past three or four months, the task force which was put together by the Department of Defense in July 1961 has been trying to set up a specific target toward which to direct action. Unless a policy is capable of being implemented, it is not an effective policy, so this has been the goal of the DOD for the past few months.

One of the difficulties in deciding precisely on the goal which is to be your target is making a general analysis of the threat involved. Now the threat, as you know, in this particular age, is one which involves fallout, blast, fire, chemical warfare, bacteriological warfare and other as yet undefined threats beyond these. We have tried to evaluate each of these potential threats in the over-all determination of policy and at the present time, as stated by the President of the United States, the primary target is protection for the civilian population against general radiation from fallout.

The secondary targets, if we can achieve them economically, are protection against blast, fire, chemical warfare and bacteriological warfare. However, the primary focus of our action for the next year and a half will be on solving the fallout problem. Research and development activity is being undertaken in DOD to contain such threats as blast and fire with the Nike-Zeus program. We feel that there is possibly a more economical solution to blast and to fire protection through an effective anti-missile system. One of other major hurdles which we have had to overcome is the tendency upon the part of many people to think in what I classify as "black and white" terms. Their solution to the problem is either all community shelters, or all home shelters, and unless you can clearly define the difference between these two, you don't have a policy. I am afraid that we disagree with this approach.

We feel that a policy can encompass a variety of solutions. At the present time, and as stated by the President at his recent press conference, the primary action of the

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Federal Government is to direct itself towards providing a community shelter solution to the fallout threat. Now, this does not imply that we are not at the same time looking for ways of providing better and lower cost family shelters. In order to conserve resources at the DOD and Federal levels, we feel that there are certain types of actions which can best be implemented at the local level, and certainly, individual shelters come within this category.

Community shelters, however, we believe to be susceptible to action at the national level, and I was therefore interested in the population projections made by previous speakers. I recall, back in 1932, that Dr. Owen Baker of the Department of Agriculture, who was the top population expert in the world, was firmly convinced that our population would settle out by 1975 at 175 million people, and this projection was the product of the best intelligence available at that time. Today, we hear that as of 2010 we will have up to 400 or 500 million people. This poses another difficult problem when you are trying to project a national program and decide what your target should be. We hope to have a fallout shelter program which will be completely adequate in four or five years. Whether or not we reach completion at that time depends a great deal upon the degree of cooperation which we get from individuals, and from state and local governments.

Specific implementation of this policy, at the present time, is directed towards providing shelter space in existing buildings. We have a very extensive program, utilizing the Army Corps of Engineers and the Navy's Bureau of Yards and Docks to provide and to put into operation approximately 50 million shelter spaces in the country's existing buildings. This will include providing food, water, medical supplies and other types of equipment to make these effective, operating shelters.

Another basic element of this year's program, in this long-term goal of providing community and dual-use shelters for the population of the country, is an inventory of the present space to determine in what specific areas of the country we need additional shelter space. At the present time we do not have sufficient information to allow us to make specific plans for the needs in the downtown areas, in the daytime working hours or in the nighttime. However, we have, from a series of preliminary surveys, a fairly firm degree of awareness that our major problem will lie with protecting the residential or nighttime population. We feel this is the area to which we need apply the most attention during the next four to six years, or however long it takes to solve the problem.

Another basic problem we've had in developing a firm national policy has been the lack of solid, definitive information on what the cost will be to achieve this program. We have worked with the General Services Administration this year and, as of the present time, we have developed approximately 27,000 shelter spaces for somewhat under $400,000. This is less than $20 a space. This, perhaps, is slightly low in contrast to national averages, but it does represent what can be done if we utilize and modify other buildings effectively for shelter purposes.

So, as a general summary of the program defined by the DOD, we are trying to focus our efforts on a realizable goal. We have, I believe, developed a policy which will achieve that goal. At the same time, we are trying to integrate the use of shelters, the need for shelters, into the over-all fabric of the country by utilizing a very comprehensive system of dual-use types of shelters. Furthermore, we are working with the Federal Government as the leader in the program, to include in each new Federal building to be constructed this year, as well as those built during approximately the last 10 years, shelter space for all Federal employees and people from the surrounding area. As the same time, the DOD is taking the lead in providing shelter space from its vast inventory of buildings and potential shelter areas for employees and members of the Department. We will use these two programs, the Federal program, which incidentally includes the DOD program, as a means of evaluating new and different types of construction techniques for getting better and lower cost solutions to this problem.

Office of Emergency Planning Policy

By Ralph E. Spear*
Director of Research, Policy and Review
Office of Emergency Planning

At the outset, I would like to disavow any suggestion that the Office of Emergency Planning has a policy separate and distinct from that of the Department of Defense. Obviously, we are dealing here with a matter of national policy with respect to protective construction, and not with separate agency policies, disappointing as this prospect may be to those of us who like to rub our hands over controversy and conflict. Instead, I would like, because I know many of you are aware of recent changes in responsibility and perhaps are not entirely clear as to what these changes have been, to outline very briefly what has happened to the former Office of Civil and Defense Mobilization.

Perhaps the most significant change has been the decision by the Administration to tap the vast resources of the DOD to get a program going, in lieu of a policy of just favoring fallout protection. The major responsibilities in civil defense have been transferred to the DOD, and the Office of Emergency Planning has become a Presidential Staff agency, much like the Bureau of the Budget as related to fiscal matters. It has the responsibility, largely, of advising and assisting the President with respect to our total non-military defense developments. There are certain specific mobilization responsibilities which remain with it, but in the field we are discussing here today, ours is largely an advisory and coordinating role.

I would also like to review very briefly some of the policy developments over the past several years, in order to make as much sense as we can out of the trends. Back in 1950, when we first began in the Federal Defense Administration seriously to address ourselves to the problems of civil defense in the nuclear age, we were confronted with two components of the problem. We were advised by our military colleagues, first, that we could not accept the Hiroshima bomb as the ultimate in nuclear weapons; that future bombs might be as much as 10 times more powerful than that weapon. We were told, next, that they could hold out no prospect of effective early warning; that if we wanted to assume five or 10 minutes for planning purposes, they would not object. Under these circumstances, we were unable to devise anything other than the "duck-and-cover" policy which characterized those early years.

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Along about 1952 or 1953, we saw the explosion of the first thermonuclear weapon. We had held out to us the prospect of the Dew Line, and the prospect of three to six hours of warning of air attack. Given these two ingredients, we began to study what might be done to move people into less vulnerable positions, and it was in this period that we saw the development of plans for the evacuation of cities. The prospective damage was much greater than we had earlier contemplated, and the time available for movement, for protective action, was considerably lengthened. Then came, in 1954, the shot in the Pacific, the accident that injured some of the Marshallese and some of our own people, and we began to get for the first time, from these tests, a reasonably good reading on the radiation threat of a thermonuclear weapon. This meant that perhaps there should be less movement and more protection, and at that time there began to evolve an increasing emphasis on shelter capability.

Finally, in about 1958 or 1959, we were able to formulate a national policy that conceded that radiation protection, fallout shelter, was a good thing; that the Federal Government should take a modest lead in setting an example—in showing how to construct prototype shelters. However, the basic policy was still that the responsibility for providing fallout protection remained with the property owner. In a home, it was the home owner's responsibility; in a factory, it was the management's; and in an apartment house, it was the owner's.

I am sure I violate no confidence when I say that this was not a conspicuously successful policy in terms of providing shelters throughout the country. The new ingredient is an undertaking on the part of the Federal Government to participate in providing fallout protection in the ways that Mr. Visher has described. This is how we reached the point we are at today, and we are all gratified to see a real awareness of the problem here and to note a bold forward approach.

Design of Above-Ground Protected Areas

By Darrel D. Rippeteau*, Partner
Sargent-Webster-Crenshaw & Folley
Architects and Engineers

Occupying the position of the transitionist in this group, I have chosen as a point of departure conventional buildings, as we all have come to recognize them (schools, hospitals, public, industrial and commercial buildings) and will tend in the direction of the transition of these conventional buildings to include design characteristics providing radioactive fallout shelter. Generally, conventional buildings are above grade, with service facilities and other minor areas located below grade in basement or boiler room areas. In the transition toward buildings provided with fallout shelter capabilities, certain areas and functions will be located below grade, or certain interior portions of conventional buildings will be specially designed and equipped to provide fallout shelter. No quarrel with this position of a transitionist is indicated; rather I have long been among those who believe that Venus did not actually arrive in her fully developed form, riding in a shell across the waves, but rather that she was a product of evolution.

Building design is truly evolving to incorporate considerations for radioactive fallout protection, and some of the present and future developments in various building types will be discussed. First, however, it is important to define that fact that multi-purpose use of the fallout shelter is almost mandatory in the context of shelter space in conventional buildings. The basic economics of building construction costs demand multi-purpose use of fallout shelter areas in conventional buildings as compared to separate, single use shelters or spaces. Many multi-purpose uses involving easily removable furniture are compatible with shelter space. Obviously other activities, such as storage of supplies and permanently located equipment, are not compatible with multi-use, as the space could not be made available for its intended purpose within a short enough time.

Examples of such protected spaces above grade are now familiar to all of us. These are generally areas in the central portion of multi-story buildings. These spaces can consist, for example in a typical office building, of a centrally located cafeteria and related areas provided with construction mass, including the contribution of the surrounding structure, giving the shelter protection required plus air conditioning, filtering, and ventilating, and the necessary sanitary facilities.

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However, the problem of additional construction cost for building mass to create the shelter facility above grade leads to locating these facilities in the earth under the structure. This location achieves considerably improved protection at lower construction cost, and also has several desirable by-products which are not immediately apparent. For example, in school construction, there appears to be general agreement that classrooms should be provided with natural light from windows located in the exterior walls. However, a school contains many other spaces which might be located below grade with no reduction in efficiency of use, or inconvenience to the pupils and staff. For instance, there could be space under the building, with all of the required shelter facilities, which is designed for and used on a daily basis as a cafeteria. Until the emergency requirement arises, the shelter area operates as a usual, everyday function of the school program, and is different from our present idea of a conventional school design only in that the cafeteria is located below grade, under the building, and is provided with total air treatment.

Many hospital spaces can also be located below grade in the building without interference with function. Operating rooms are frequently isolated entirely from outside atmospheric influences and totally air conditioned. Before the advent of residential air conditioning units, many residences in the Midwest provided sleeping quarters in the basement under the house, for comfort during the summer months. In residential design, living rooms, dining rooms, kitchens, and other rooms used during the daylight hours are no doubt best located above grade by almost any standard of design, but a critical look at sleeping requirements indicates that bedrooms have a function which suits them ideally to year-round use in below grade spaces under the residence, with temperature control, air filtering, and humidity control provided both for normal use throughout the life of the building and emergency use when the space is required for the family shelter. A minor by-product of such an arrangement would be the provision of quiet areas for sleeping, which is no small consideration as we learned at the BRI Conference on Noise Control in Buildings, held in 1959.

The next step in this evolution is to use an industrial plant as an example of a conventional structure which might be more underground than above, for reasons which are equally sound, whether we are considering day-to-day manufacturing processes or fallout shelter use. Many manufacturing processes require temperature and humidity control, and air filtering and, even in the case of processes which do not require such controls, the efficiency index of the personnel frequently dictates the use of air conditioning. These design requirements have already developed manufacturing plants which are windowless, or nearly so. Visualize, then, dropping this windowless factory vertically into the ground, with the roof flush with the surface of the ground, and with the roof construction converted to reinforced concrete to provide radioactive fallout protection and parking space simultaneously. A reduced cooling load in the summertime and a greatly reduced heating load in the wintertime, plus short travel time from automobile to production machine, are three fortunate by-products of this design concept. In a typical manufacturing plant, probably 30% of the floor area would remain above grade, involving receiving and shipping areas, and some administrative offices.

As a final point, it seems reasonable to mention that, with the atmosphere in some areas becoming increasingly polluted with all kinds of chemicals harmful to animal life and to manufacturing processes, the use of self-contained spaces has an advantage entirely separate from the radioactive fallout shelter aspect.

Design of Below-Ground Protected Areas

By John J. O'Sullivan*, Subdepartment Head
Dept. of Weapons Control and Sensor Systems
Mitre Corporation

I would like to invite you to consider some structures that are somewhat unusual, and I would like to take as one of my premises the fact that the cities themselves are targets, ignoring the related problems such as warning systems, etc. During the past 10 or 15 years our structural designs have not kept up with our weapons designs. No matter how hard we ran, we never did more than maintain our place, and I would suggest that perhaps, today, we are even farther behind the weapons designers than we were 10 years ago. This would imply that perhaps we might think of taking a great leap forward.

Buildings take many years to design, to finance, to construct, and when they are finished, we like them to have a certain economic life. Whether their economic life should be two, five, ten years or more, I am not prepared to state. However, when you count up the years of design and the life for those weapons, you are faced with some staggering engineering problems and perhaps more important, staggering costs.

The two types of underground shelter installations which we are considering are the cut-and-cover type, and the deep underground. The cut-and-cover are quite familiar to you. You dig a hole in the ground, you put a concrete box of a certain strength in it, and you bury it with a cover of from 0 to 50 feet. This affords a certain level of protection.

The other type, and the one I would like to discuss is the deep underground shelter. By definition, I suggest that deep underground means not hundreds of feet deep, but thousands of feet deep. These shelters have received a fair amount of investigation in the past, but in the last few years we've experienced a rapid increase in the knowledge concerning these installations. Over the past year, a number of non-classified papers have appeared to show that we are now getting a better idea of the problems which we will experience in designing these structures to resist a number of direct hits. This is a little bit of a misnomer, of course, because we really would not receive a direct

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hit. The shelter would be away from the direct hit, or the crater, by a certain vertical distance, these thousands of feet which I just mentioned.

In designing a deep underground installation, the first thing that occurs to us is the problem of the entrances—how do we get large numbers of people into these underground areas? As an example, we might take a mountain, and run a few tunnel shafts horizontally into it until we come to a point where we have sufficient rock cover over our heads. (We always assume that we will find rock cover or rock strata suitable for use in these mythical studies.) However, there are places where we might want to put deep underground installations where nature hasn't placed a mountain convenient to our cities. Therefore, we would have to enter the shelter by vertical shafts. Then, the problem of entrance of people becomes fantastically difficult.

We have to move these people into the shelter in a rather modest warning time, and close off the entrances. We probably would have to move these people through in a wave-like fashion, always protecting the underground installation so we do not have through-transmission of blast. Moving the people in groups, so that they are getting increased protection as we move them to the deep underground, hopefully we will get them to the bottom in time to escape any direct hits.

We expect the entrances through which we are moving these people to collapse, and also to collapse in a fairly safe manner. These will be grated in some cases, and we can't have the blast rushing into the underground installation and destroying the installation. Therefore, we have to have some sort of a seal at the outside. At the ends of the tunnels or shafts, we start hollowing out cavities, chambers which are laid out in some sort of geometrical pattern. The inside of the cavities will be prevented from falling, in some cases just by rock faulting. Then we run through all the other variations, until we get to the extreme where we have the reinforced concrete, very heavy line-up plates, compressible medians, etc., between the tunnel line-up plates and the rock cavities. Then we start thinking about some standard or different type of building. Perhaps we look into some new prefabrication techniques in which we could prefabricate these structures on the surface while we are doing the excavation, and then move the modular units into the underground areas and assemble them into buildings down there. Then, we hook up our underground utilities, and as I said before, shut the entrances.

I would like to point out a few of the problems we would run into in these designs. The first, of course, is the entrance problem. We have to move the people quickly, so this requires many entrances. We don't always have the rock layers where we want them. Therefore, we have to make many compromises. Water is a serious problem, because any study that I have seen to this date always shows that the water is over your head, just where you don't want it. Therefore, the design might resemble a submarine, to withstand hundreds or thousands of psi of water pressure.

Survival in these installations must be planned for some definite number of days, weeks, or months. When we have designed a fairly safe entrance, the next consideration is getting the people out. We can't have people from the outside dig these people out—they have to dig themselves out. This takes a great deal of planning. If you can envision a ladder several times the height of the Empire State Building, you get an idea of the problem of getting these people back to the surface. It requires new techniques, new machines, new designs, to enable them to move themselves out. The power for these perhaps should be electric power, but we don't have electric power because our connections to the surface for conventional power have been cut off. Therefore, a number of interesting power generation techniques have been proposed. Nuclear power itself seems to be the most interesting. We eliminate the adits for the combustion air and the engine exhausts, but we don't eliminate the problem of heat exchanging. We have to get rid of all the heat that would be generated down at these lower levels.

In site choice, we might also, while we are checking the layers of rock, try to find some water in the strata below the bottom of the installation, pump this up by wells, and create heat exchanges down to some other layers, perhaps below. Another method, of course, is the conventional heat sink. These are factors which must be considered in the over-all problems.

If you want to sustain a group of people for six months, you must have enormous reservoirs of supplies. This, of course, is a question of dollars and I might say the total of the dollars necessary would turn your hair gray.

Mechanical Facilities for Protected Areas

By Peter B. Gordon*, Vice President
Wolff & Munier, Inc.

My position on this panel is not as an expert with any great amount of know-how in this particular problem of shelter or containment, but simply as an engineer who has been engaged for some time in heating, ventilating and air conditioning, which is part of this problem of what to do about shelters. So, if I convey some of my concerns or worries, please understand.

My first concern is the problem of responsibility for decision; my second is the responsibility for determining criteria. In some of these decisions the costs can be staggering, just as the problems are staggering, but someone has to decide whether the funds can and should be expended, and whether all the obstacles must be overcome.

During the past 10 or 11 years, in our office, we have been faced on several occasions with requests to design shelters of one sort or another to accommodate 50 people, or up to 300 people. Until recently, we have sought out the most readily available information that could be acquired at that specific time. This consisted of a handful of reports, proceedings or bibliographies, a quantity of data, most of which was contradictory. Then came the problem of trying to evaluate the requirements, trying to decide how much protection should be built into the system or the facility.

What is needed is someone or some agency, and not at the lowest level, to dictate what the shelter requirements should be, what the criteria for design should be, and what decisions must be made. If there is a lack of protection and if the risk is valid, the need is obvious. If the risk is not valid, then we are embarking on a tremendous waste of the nation's resources, with a serious upset to the well-being of our citizens. So, again, this is not a problem for individual decision at the lowest levels, which means the man who is going to design a specific installation for a specific owner, or for a small local group, or even for a state government. This is a decision that must be made by qualified people who are knowledgeable about the total problem. Obviously, a rational national security policy is just as much a part of our nation's planning for defense as any

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of our offensive planning. The result will have an impact on our nation's economy and also on the well-being of the people.

As to criteria, we need some dictates. We need people to tell us in a definitive manner what the loading should be, what the occupancy should be, what quantities of air should be handled. Mr. Achenbach spoke of some further research that was required, and I agree with him. The equipment necessary to handle the air, the quantities of air, the kind of filter, whether or not chemicals must be absorbed, these are all considerations that affect costs and affect resources. Whatever is done in one place, when multiplied by thousands and tens of thousands of installations, becomes a serious drain on total resources, and might affect other parts of our nation's economy.

The problems of water supply and water storage are important. The problems of whether or not we require portable generators, fuel storage, are all things that we should be advised on in a realistic fashion, rather than have left to the ultimate and often unknowledgeable designer, because of the impact on costs and other considerations.

Design and Operation of Essential Facilities

By Donald A. Kalmbach*, Engineer
Building Engineering Group
American Telephone & Telegraph Co.

Because of the many changes in design problems today, there is nothing very specific we can say about designing essential facilities or their enclosing structures for the so-called nuclear age, particularly when we recognize probability as part of the problem. Data associated with probability that were hearsay a few years ago may be facts today, and completely outdated a year from now, as weapon sizes change and new test information becomes available.

Then how do we set the parameters for design of essential facilities? As I see it, we set an unusually high objective and build for it, if the requirements are of a single-project nature, and funds are available. However, if you are faced with construction of many such facilities, you are forced to take a look at what community demands for service are likely to be, and then design for something in excess of that demand.

By this approach, many buildings housing an essential facility will not need more than good quality masonry design that incorporates fallout shelter either as a part of the structure or in the entire building. There is some risk in this, but not much more than assuming a structure is adequate for a near-target area today, and then finding tomorrow that weapon size and the probability of its being a target have already put the stamp of obsolescence on your plans.

Statistics pertaining to probability of overpressure and fallout emanate almost exclusively from the Federal Government. Accordingly, all plans, designs and construction are correlated to data furnished by both military and non-military personnel in the Governmental agencies. We are wholly dependent upon them for up-to-date thinking. That is why it is beneficial to have them participate in our planning.

In the nuclear city, floor space properly protected to house the essential facilities would probably necessitate underground construction, with small above-ground enclosures at stairways and airshafts. Radiation shielding, both immediate and residual,

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would be a natural by-product of such design, with air in-takes, etc., properly filtered or closed during the actual emergency period. Pipe, cable, ducts, conduits and most machine components used in conventional structures today will be employed in new "blast" construction for some time to come. The major difference will be the way they are installed.

Structures designed to withstand low blast and overpressures usually will not warrant special mounting or connection details for internal apparatus, but must have some provision for emergency power. However, as the design strength goes up, more attention must be given to special design of gear, shock-mounting, flexible connections, blast valves, and alarms. Performance indicators on all apparatus are an absolute must. The enclosing envelope, when required, must be airtight.

Mechanization should be used to the maximum possible, but allow for manual override wherever reasonable. Emergency electrical power and telephone service must be part of the facility. To guard against the effect of a close-in hit, some emergency back-up of power seems advisable for control systems, etc. This could be a storage battery such as used in the telephone equipment.

Connection with other structures in the city and to outside localities must be underground, with proper protection at the point of entry to prevent shearing near wall faces. Communication would be the only connection to conventional cities during an emergency. Sewer, gas and water would automatically be cut off to assure the safety of the nuclear city. Internal water supply would be from wells, protected storage tanks, or reclamation processes.

By-pass and grid systems of connection between structures would always be used, so that the unexpected failure of one part of the complex would not void the use of the balance of the city.

Maintenance and administration of essential facilities must be well planned and practiced in advance of an emergency. Special care must be given to protection of records vital to post-attack restoration, and to alternate operating centers to control apparatus and personnel. Alternate headquarters for properly delegated officials will also be a part of the over-all plan.

The essential service facilities must assure service equal to, or beyond, the utility objective of the city. In achieving this, maximum care must be given to blast, radiation protection (both immediate and residual), continuity of service arrangements, maintenance and administration.

Community Planning for the Nuclear Age

By Curtis E. Tuthill*, Associate Professor of Psychology
George Washington University

Having listened to these varying statements, I am even more impressed with the gap between the area which can be called physical engineering, and the area which can be called social engineering. By physical, we mean the actual planning of buildings, and by social, we mean handling of individuals or groups of people in an efficient manner.

This past spring and summer, a number of us were concerned with a particular study having to do with the analysis attitudes in a nearby community where underground prototype fallout shelters in classrooms were to be installed. Part of this study consisted of a public attitude survey, interviewing some 300 parents whose children will be going to these underground classes, and part consisted of a series of depth interviews with all local officials in any way concerned with this whole decision-making process. We were concerned, in all cases, with human factors, attitudes, beliefs, etc.

First of all we found that the parents themselves were in no sense apprehensive about having their children go to school in classrooms three feet underground. This, however, was in a situation where they had plenty of confidence in their elected officials and their school board. On the other hand, we also found that the parents, when asked specifically whether all children and all adults should have civil defense training, showed perfect willingness to have such training given. Another thing which came out, in interviewing parents, local school officials and others, was the fact that almost all these people had the belief, the hope, the assumption, the feeling, that somewhere, somehow, somebody was engaging in very detailed planning down to the very last detail in this whole area. When it came to considering certain problems in connection with the fallout shelter, they assumed that these plans were already in highly detailed form. This particular situation is one, in miniature, which I think exists all over America, namely, the awareness that at the present time we do not have fallout shelter protection for everybody, but only in very special cases, and that there is the problem of who will go in these shelters and who will not. This creates all kinds of attitude problems, quite apart from the fact that we hope some day, a few years from now, it will be possible to say that there will be adequate shelter protection for everyone.

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As I said, there was a basic belief that somewhere, somebody was engaging in very, very detailed planning and beyond the present stage. That is, they felt that there is a great deal of specific planning going on in terms of, let's say, the two weeks people would spend in an actual shelter; the problem of coming out of the shelter; the problem of contaminated food and the crops contaminated the next year; or the problem of the people who survive in the shelter; the problem of epidemic in terms of a number of bodies around that have no protection, etc. The impressive thing was the fact that everybody believed that somewhere, someone was planning for these situations.

We found also that on the part of the individual citizen, there was a tendency to put fallout shelters for the home very far down on the priority list. This was before the Berlin crisis, and the prevailing attitude can be summarized by quoting one person who said, "Afford a home fallout shelter? We can't even afford a recreation room in our basement." This was the system of values. We found also that the school authorities were saying much the same thing, "Build fallout shelters in the classrooms? We haven't enough money to build the classrooms themselves." The school people also had the feeling that somewhere, somebody in local government or some other department had the responsibility for doing this, and not they, themselves. There was a general tendency to assume that everyone should build his own fallout shelter and yet we can raise questions as to how much of this was really practical thinking when we consider the fact that the average individual thinks of police protection as a collective thing to protect everyone—he pays taxes for that. He thinks of fire protection in the same way, and to tell him that he must protect himself from fallout seems to him a little bit unique, a little bit strange. This is also especially true because of the very complicated technical problems in determining what is good or inadequate shelter.

Actually, the biggest single point is just this question of the social engineering, and whether the plans are short-range or long-range, inasmuch as we are dealing with something which is, in a sense, a unique kind of phenomenon. The human being or the social system is able to adjust, and to adapt quite remarkably to small changes, if they take place over a long period of time. The individual of a social system, however, is not readily able to adapt to sudden changes or to project and extrapolate into some particular new situation. The British, for instance, during World War II could learn, from one bombing to another, what was required. The Japanese did not have time to learn from Hiroshima what they should do in the case of Nagasaki. This was too massive a social event, and the system could not adjust itself. Now we find ourselves trying to think, plan, project and extrapolate into the future, considering all kinds of problems: the physical problems, the human organizational problems, problems of evacuation, problems of putting people in shelters, the problem of who is going to decide, the problem of who are the authorities, etc. This is a very difficult thing to do and it requires a more advanced type of long-range thinking and long-range planning on the policy-making levels.

For two years I was a Fulbright professor in Nationalist China, and I was impressed by the fact that the government there, made up largely of scholars, was also a government which was dedicated to a very, very long-range plan. Americans on the other hand, tend to think, on a national basis, in terms of planning ahead for a few months, or over the next crisis, or up to the next election. The problem we face today, however, will require much more long-range planning than we've done in the past.

Military Planning

By Wayne J. Christensen*, Director, Office of Research
Bureau of Yards & Docks, Department of the Navy

Ever since military organizations came into existence, they've had two primary missions: either to win or prevent wars and to protect their leaders, themselves, and the populace from their enemies. Each time a new weapon is developed and placed in the enemy arsenal, an adjustment has to be made in military planning to provide protection against the new danger. The impact of the latest evolutionary step, which ushered in the nuclear age, has literally dwarfed any previous development along these lines. The stunning impact of the nuclear bombs used on Japan was ample proof of their military effectiveness. It also provided ample warning that mankind must now adapt to a new potential threat.

Almost immediately, upon cessation of World War II and the hostilities in the Pacific, a group of specialists, including a number of military engineers, went to Japan to survey the damage created by these explosions. The information obtained in these surveys provided the first quantitative information on future requirements for planning, design and construction of facilities needed to minimize the losses from possible future nuclear attack.

With these Japanese surveys as a beginning, our current state of knowledge is the culmination of extensive, coordinated research, development and tests conducted or sponsored by the military services: the Defense Atomic Support Agency and its predecessor; the Atomic Energy Commission; the various civil defense organizations that have existed during the past 10 years; and others. This work was commenced almost immediately after the war, and has been progressing at a relatively rapid pace ever since. Concurrent with the development of information on weapons effects and protective measures, passive defense and disaster control organizations have been established in all the services. These organizations are responsible for measures taken to reduce the probability and minimize the effects of damage caused by hostile action.

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For example, the Bureau of Yards and Docks of the Navy has disaster control responsibilities in the naval shore establishment for: atomic, biological and chemical warfare defense; protective construction; and technical aspects of training. In partial fulfillment of these responsibilities, disaster control plans are in effect at practically all naval shore establishments where personnel are trained for the roles they will have to assume in event of an emergency. Schools have been set up to train officer and key civilian personnel in nuclear effects and atomic defense engineering. Manuals have been developed which provide information on technical aspects of nuclear weapons phenomena and the basic guidance for design of structures to resist the various levels of weapons effects to protect both personnel and equipment.

Also, standardized designs have been developed to provide protection from fallout, initial radiation and air blast over-pressures ranging from 50 to 100 lbs. per sq. in.

In like manner, the Chief of Engineers, under authority of the Secretary of the Army, is the construction director of the Army, and performs a large part of the construction for the Department of the Air Force. In fulfilling this responsibility, the Chief of Engineers has conducted extensive investigations and tests to develop criteria for the design of protective construction. Manuals on design of structures to resist the effects of nuclear weapons, designs of underground installations in rock and guidance for protection against chemical agents, biological agents and radiological fallout have been published. These publications are available at nominal cost through the Government Printing Office.

The Army is now developing standard plans for providing basement fallout shelters in military barracks, schools and hospital facilities. Authorization and funding for such construction will provide an increment of shelter spaces at selected locations consistent with the Army construction program.

Military planning is aimed at measures to be incorporated in future facilities which will enhance the survivability of essential components and essential functions. Survivability may be enhanced by hardening, redundancy, mobility, dispersal and camouflage. The more of these elements that can be incorporated in the design, the higher will be the chances of survival for a given attack situation.

Military requirements for protective construction planning can be divided into several basic categories. The first involves special operational structures to resist specific assumed high level effects of nuclear weapons. Some of these facilities have been built; some are in the process. The second category includes measures necessary to provide radiation shielding and low levels of blast protection in new permanent structures, without reducing the efficiency of the structures. The Navy has referred to this type of construction as "slanting." Policies in this area have been in existence for almost 10 years. It involves avoiding or minimizing the use of brittle construction materials such as glass and other frangibles, strengthening the framing, and providing a protected core with relatively high radiation shielding capacity. These features have been incorporated into a number of facilities built during the past eight or ten years.

The third category, which has not yet been implemented, will probably take the form of shelter for military personnel, for their families, and for civil service people who work at various bases. This category, while always considered important, has been given new emphasis by a recent Dept. of Defense memorandum to service secretaries. This memorandum, in effect, requests the Armed Services to exercise Federal leadership in a national civil defense effort. Such leadership will be furthered by concrete, visible steps to provide protection for civilian employees, dependents and military personnel located in United States. As an initial step in implementing this policy, existing facilities will be surveyed to determine currently available shelter capacity. Those found to be available will then be stocked and designated for use. A by-product of this effort will probably be a planned program to correct any deficiencies which are noted in the survey.

It is interesting to note that military families face problems in civil defense which are in some ways quite unique. First of all, those who live on a station or in on-station housing are forced to wait for shelter to be designated or built by the Government. To make matters more critical, many of the installations where these families live are what you might call front-line points in any nuclear war that might break out.

Second, there are those who live in off-station housing. They are very often renters. They, therefore, are not able to build their own shelter on a landlord's property. Even if they own their houses, their tenancy is normally rather temporary, varying from one to three years. It becomes quite a difficult decision for one of these military families, with such a transient situation, to invest its own funds and build a shelter. I think some acceptable solution to such problems will have to be determined.

In summary, the military services have, for the past 15 or 16 years, been engaged in intensive programs of research, development and testing, in order to obtain sufficient information to proceed with rational design of structures to resist the various effects of nuclear weapons. Sufficient progress has been made to permit design and construction to proceed against all nuclear weapons effects, except the very high level blast.

Open Forum Discussion

Moderator—Gifford H. Albright

Panel Members—Messrs. Christensen, Gordon, Kalmbach, O'Sullivan, Rippeteau, Spear, Tuthill and Visher

W. R. Dickson, Massachusetts Institute of Technology: Is it not possible that the development of the neutron bomb will make monies spent on fallout shelters essentially wasted by the time the program can be substantially completed?

Mr. Visher: It's unrealistic to have anyone at any point in time state in a positive manner that something in the future might not negate something he is doing today. This is almost a truism. We are all playing a game of statistics, of probabilities, and we are playing the probability that we think is best justified by the evidence we have at hand. We picked a program which has been carefully evaluated by the Secretary of Defense, by the President, by every measure of intelligence that we can apply to the problem, and we think it is a sound program. It would be ridiculous for me to state that this program is not susceptible to possible change, but we think we have a program which will provide protection for the American public during a time when it needs that protection.

W. A. Keene, Buffalo Tank Div., Bethlehem Steel Co.: What yield weapon should be used as a design basis for underground blast shelters? Should one design to the yield point of material of construction?

Mr. O'Sullivan: In reply to the first question, I don't know. On the deep underground installations, there are some non-classified papers that use 100 megaton weapons for illustrative purposes. I think if you run a probability analysis on some of the other units, by using a cut-and-dried method, you will come up with the number of points to which you are designing. I am not talking about single targets now; I am talking about a number. You could get some sort of a probability of survival versus the size of weapons, the number of weapons, and the cost. I'm not quite sure how we plot these four things, but it can definitely be done. We have some of these problems set up on the computers. If these are single targets, then you have to choose a dollar amount that you wish to spend. You can work the problem back from that, running through the probability of survival versus dollars, and come out with a certain number of weapons, sizes, etc. It's more or less a matter of pick-and-choose from that point on. I don't think you can really put a probability of survival, as it concerns a human being, into any sort of a mathematical formula.

The answer to the second question is spelled out in the manuals. We do this all the time.

R. D. Courtright, IBM Corp.: You and others have mentioned cafeterias as likely space for locating underground shelters. Would you necessarily recommend that such action be taken in a manufacturing plant, if the primary purpose of a new cafeteria were to improve employee participation and reduce company losses from a cafeteria?

Mr. Rippeteau: The reason that a room like a cafeteria is used as an example (similar rooms would be meeting rooms, conference rooms, widened corridor spaces, etc.) is because they are usually equipped with loose furniture and are readily convertible into shelter activity space or subdivided dormitory space. In the particular case of the cafeteria, it has ancillary food preparation and food storage facilities, and has sanitary facilities which could have dual use. In thinking the problem through in your own imagination, you will come up with other similar spaces that fit that same general characteristic. The other part of the question I believe relates to employee relations or employee participation, and I would think that might be a by-product of creating such facilities, provided it was underground or flush with the ground in a manufacturing building.

R. W. Crawford, Monsanto Chemical Co.: Please describe in more detail a typical multi-purpose residence fallout shelter.

Mr. Rippeteau: The data that have been generally issued have indicated almost entirely, as far as I know, a shelter constructed in a certain manner, depending upon whose data are being used. That shelter is envisioned as an area in which you would retire and spend the necessary hours or days during the period of high radioactivity in your neighborhood. The further development of that concept is what I hope to stimulate. Rather than to make a single-use shelter, whether it be in a residence or elsewhere, we should create space which is used on a day-to-day basis, consistently and normally, which has the construction, ventilation, and air conditioning characteristics necessary for shelter space. Then the home owner or the occupant can use this facility which he has paid for once, and get dual use out of it. I purposely threw into the picture the idea that bedrooms might be made suitable shelter areas, totally air conditioned, totally treated environmental areas. One of the earlier conceptions of this has been that the recreation room or rumpus room in a residence could be multi-purpose, dual-use shelter space. Just offhand, that doesn't seem quite as logical as using a place to sleep. The whole point of this is to get dual use out of the space; to use it during the life of the building for whatever its primary use is, and simultaneously have fallout shelter capability built into it.

Unsigned Question: Would you care to project the impact that design for the nuclear age will have on transportation systems and movements of persons in our cities?

Mr. Tuthill: Our present transportation system is a good example of what I have been talking about, namely, that there is no problem whatsoever in the physical construction of the highways. There is simply the problem of adding to the formula various human factors, such as overload, the way these highways are being used, etc., and also the factor of different local jurisdictions which have charge of the highways. This is the sort of problem that we have in this case.

Unsigned Question: To what degree is CBR protection required or considered in the design of essential facilities?

Mr. Kalmbach: Today, in most essential facilities, it probably isn't being used as much as it should be. We are all faced with the money problem, and the problem of changing criteria. In our own business, when we know we have a structure that is going to be very important to our switching system, we will do something to provide protection adequate for the service demands that are going to be made on the system. In a few instances, we are even going underground, where this seems to be the real need. We are still studying the over-all problem.

C. M. Sanders, Minneapolis-Honeywell: In large fallout shelters, should there be consideration for protection against minor blast damage?

Mr. Visher: This gets down to the question of what is considered minor. Certainly, whatever blast protection you can achieve within the conventional building designs, slightly reinforced, makes some sense. Look at the 5 psi over-pressure line, and you'll find it covers a considerable area. It's unreasonable not to take advantage of building characteristics to cover the other threats which are recognized at the present time, to the degree that you can do so without significantly changing the price.

T. W. Henderson, United Steel Fabricators: Are the protective structure designs that you spoke of available to the public?

Mr. Christensen: I anticipated this question, but I am not prepared to answer it. A year ago, we didn't anticipate major public interest in this area. Our design manuals have only recently been put into the Government Printing Office service, so that they can be made available to the general public. I think it will be better for us to do a little homework in this general area, to go back and perhaps prepare a bibliography of the publications which are currently available and those that are currently in the planning stages. It would appear that this would be a major public service. As far as the Navy is concerned, during the past few years we have been sending our unclassified documents to the Office of Technical Services of the Department of Commerce. These, then, become available for purchase by anyone who desires to have them. I don't have in my briefcase a bibliography of publications available, but since the civil defense effort took on new impetus, we have taken steps to have all of our unclassified publications sent to the Government Printing Office for sale. And, as I mentioned, the Corps of Engineers' publications are likewise going to the Government Printing Office.

Unsigned Question: What problems do you envision in the installation of CBR protection that might be required in future buildings?

Mr. Gordon: This would depend on the size of the space involved. Assuming a space that would serve 200 to 300 people, there would obviously have to be some particulate filters, such as the absolute filter with a pre-filter before it, for the minimum quantity of fresh air, supplemented by activated carbon equipment. Whether or not there should be any chemical treatment is questionable. Special provisions would also have to be made for handling and disposing of the filter media and the activated carbon.

R. H. Avery, Cambridge Filters: To what degree is CBR protection required: 1) in family shelters; 2) in community shelters; 3) in civil defense facilities; 4) in essential facilities, for example, telephone buildings?

Mr. Visher: Any attempt to divorce the cost of doing something from a requirement is unrealistic. There is a tendency to state requirements and not relate these requirements to the cost of meeting them. We expect that our military deterrent policy will prevent a nuclear war from ever occurring. We are building deterrent forces by other means, not by a fallout shelter program. So, this is essentially an insurance program to take care of the unlikely situation of the primary deterrents failing. When you are buying insurance, you relate very closely what you're doing to the cost of doing it.

To effectively incorporate CBR in one of the Federal buildings on the GSA program would have cost approximately $130 per person sheltered. To provide fallout protection in that particular building required less than $13 per person sheltered. It's this type of evaluation that makes it very difficult to give a precise answer. If one can provide chemical and biological protection at a very nominal increase in price, then one should certainly do it. One should not provide chemical and biological protection if in so doing, you are making the total problem of the radiological, biological and chemical protection an unachievable goal economically.

Saul Uhr, Public Housing Administration: If the people survive the shelter stay, what will they do about food after they come out? Will not the animals, plants and water be contaminated?

Mr. Spear: There is a good deal of misinformation and some rather distorted impressions of devastation as a result of radioactivity, thanks to some of the more vivid writers in this field. In the first place, without discounting the threat in the least, I'd like to point out that, as far as food is concerned, food in ordinary tight containers, whether cardboard or tin or glass, is not harmed by radiation exposure. We have had several tests out in the proving grounds that have indicated there is nothing to fear as long as the radioactive particles themselves are washed off the containers. Hard grains can be similarly cleaned; they have not suffered by radiation exposure. We have, in this country, a vast surplus of foods which are a source of considerable comfort to planners in this area.

We've had estimates of from one to three years of food supplies being available. I might also mention that the physical damage that results from nuclear attack is damage inflicted by blast and by fire. When we think of coming out into a desolate environment, such as the motion picture "On the Beach" presented, this simply does not square with the facts.

On the question of animals that have been exposed, research available to us indicates that if animals which may have ingested radioactive particles in fodder can be slaughtered fairly soon, the flesh can be eaten with impunity, except for liver, kidneys, or other organs, where the particles might collect. This is not a rosy picture of nothing to worry about, but there are many factors in the situation which offer resources to deal with the food problem.

David Countryman, Douglas Fir Plywood Assn.: Does the Defense Department have, or propose to provide, approved plans for community shelters on a basis similar to that already existing for family shelters? How do you suggest community shelters be financed?

Mr. Visher: Yes, we expect to have community shelter plans available for release by late December (1961). Parenthetically, we are now going to press with a series of somewhat lower cost shelter plans which will augment those plans presently out in NB-15. As to the question of financing community shelters, there is a variety of presently available financial resources. FHA has money which can be borrowed for this purpose, as has HHFA, and there are banks which have expressed a willingness to loan money for dual-purpose shelters. There are a variety of financial resources at the present time.

J. A. Rorick, IBM Corp.: What is the attenuation factor or factors utilized in establishing suitable shelter space in your program?

Mr. Visher: The Corps of Engineers is planning to mark space which meets a protective factor of 100. For purposes of the shelter survey, we are looking at all buildings which have a potential of 20 or more, because a part of this survey is to develop estimates on the cost of either increasing the protective factor of the building, or the capacity of the building. We are therefore looking for buildings that go beneath the 100, with the idea of developing information on how to improve these buildings. A protective factor of 100 is the present standard for the shelter inventory, however.

O. M. Hahn, U. S. Forest Service: Concerning underground blast shelters, have recommendations been developed which correlate building live loads with distance from target areas?

Mr. Christensen: Any answer I give to this question will be correct under certain assumed conditions, and can be extremely misleading under other assumed conditions. If the facility or structure which you are attempting to build is indeed a target, that is, the enemy knows exactly where it is and he has targeted it, the probability of survival can be computed using the formula presented by Mr. Greene. The better the enemy can aim at you with the proper sized weapon, the better is his chance of destroying you. As a matter of fact, if he thinks the target is sufficiently profitable, rest assured he will destroy it. On the other hand, we find that any structure which is not in itself a target, even a relatively short distance from the target, will have a high survivability if comparatively low blast protection is designed into it. For example, the distances at which various overpressures occur are well known. They are available in such publications as "The Effects of Nuclear Weapons," which, in the new edition to be printed within the next few months, will include many features not incorporated in the 1957 edition. I expect many millions of copies will be sold at a relatively low price. Using these documents, one can choose any weapon size he desires and predict at what distance the design and overpressure will occur. He can also make his own assumptions on the CEP of the weapon. He can then compute his own survival probability for any design overpressure he desires.

L. D. Sneary, Phillips Petroleum Co.: To what extent are the Russians protected from nuclear radiation and blast now, and what do we know of their present plans and programs in this area?

Mr. Spear: There is a good deal of controversy and disagreement on this point. We have some testimony from visitors to the Soviet Union that there is no evidence of any kind of meaningful civil defense program. On the other hand, Dr. Leon Gouré of the RAND Corporation, who has been a student of this subject for some time, recently has written a book on the subject of Soviet civil defense, in which he states that there is a great deal of protection built into their society. For a number of years, says Dr. Gouré, the Soviet Union has built in its apartment dwellings, which constitute most of the new residential construction over there, basement areas with a very heavily protective ceiling designed to withstand the collapse of the building on top of it, and with an escape hatch leading to an outside court. He has visited Russia, has observed these escape hatches, has matched them up with the designs recommended in the Soviet civil defense manuals. This evidence I find more persuasive than the negative evidence of the casual observer who, perhaps, doesn't know precisely what he is looking for. I might say that there is a fairly good coverage of this subject in the recent hearings before the House Subcommittee on Military Operations. Dr. Gouré testified before that Committee and there is an appendix which covers it quite thoroughly.

There is also a good deal of evidence that the boasts of the Soviet leaders in their various party congresses about accomplishments in this field have some real substance. Upwards of 20 million people are purported to be enrolled, and we've had some indication that perhaps some 80 million have taken substantial civil defense training.

Norman Giller, Norman Giller, Architects: What suggestion do you have for protection when there are no mountains nearby and when the water table is only three feet below grade and basements are not normally built?

Mr. O'Sullivan: There have been some studies concerning this situation in New Orleans and, as I recall, there were three solutions proposed. People have suggested that we put the population on barges and move them temporarily out of the area. Someone also ran a survey a few years ago and found they had ample space on the ships in the area to move the people out for a considerable period of time. I believe in that area that there also are salt domes which could be used. These are within a reasonable distance and are deep underground. So, if you want to go to the other extreme, the very deep underground, I believe you could employ these domes. According to statements, the salt acts like rock as a self-ceiling, and the water pressure doesn't go to that level.

The town of Concord, Mass., has been meeting the past few weeks on a basement shelter program which is similar to this. The water table in the area is about two or three feet below the surface. They are looking for a shelter program for the town, and they are considering mounding up, to get very low level overpressure resistance above ground. The problem here, again, is one of cost, based on calculations of the quantities of earth that they would have to haul into the area to build these little hills.

Mr. Christensen: In regard to this high water table problem, I had the opportunity, during the past year or so, to sit on a NATO ad hoc committee discussing problems associated with construction of facilities under adverse conditions. One of the panel members was a gentleman from The Netherlands, who discussed various problems approaching the worst protective construction situation anywhere in the world. At this point, I would like to add a warning for people who have this problem. Based on research and experimentation done in The Netherlands, utilizing high explosive tests, it has been found that appreciable artesian pressure is built up below the water table. This pressure lasts for approximately half an hour after the relatively short pressure pulse which you get from a high explosive shock. I've seen pictures of this occurring where there was a tremendous flow of water out of a six-inch standpipe for an appreciable period of time. Tests have also indicated, that, at least in sandy conditions, you lose practically all the shear strength in the sand. Whereas the sand will support the structure prior to the shock, a dynamic shock wave going through the soil practically eliminates all shear strength. This means that if your structure is less dense than the immediate surroundings, it's going to float; if it's more dense, it's going to sink. Don't try to build below the water table, if you can avoid it.

Mr. Albright: Would you care to comment on the building research needed to implement the initial shelter program?

Mr. Visher: This is one of the things we are doing right now in the Federal program to utilize existing buildings. The Corps of Engineers and the Bureau of Yards and Docks (Navy) presently have programs designed to test certain construction techniques. We've been asked to review this entire program in order to maximize the amount of intelligence which we can gain from a sizeable investment of money, and I am sure that we will gain a great deal of useful knowledge, particularly in the defense elements of the program, on finding better and lower cost ways of doing this work. There is a need for a lot of additional information.

L. E. Linn, Hercules Powder Co.: You passed over the hazard of fire as a secondary hazard. Do you have a "factual" guess as to the intensity and duration expected of a fire storm in case we have an all-out nuclear attack?

Mr. Visher: People who have looked at the fire problem recognize the very close correlation between the amount of fuel available for the fire, the burnability of the fuel, and the weather conditions—whether it has been wet or dry. Much of the test data we have was developed from the Nevada tests where you can look at a piece of paper and it will go up in flames. Correlation of such data with a wet day in New England is something that is still hypothetical. There is, however, a very serious need to develop additional information on the nature of fire spread, fire control techniques. I come from Southern California and I was watching the recent fire in the Bel Air area. This is not a fire storm; people can live within very close proximity to such a fire. The type of fire there did not deplete the oxygen resources, but it certainly is true that fire is something which should be a design consideration for all major dual-purpose construction. The major buildings we have right now are designed to minimize the fire hazard, but fire is still something that you want to think about very seriously.

Grosvenor Chapman, Brown, Chapman, Miller, Wright, Architects: I understand the fallout shelter program contemplates a $10 billion expense over a 10-year period. What would this same amount spent on preventing the missiles from reaching us accomplish?

Mr. Visher: The Nike-Zeus program is receiving on the order of $1 billion a year, and it has been receiving such sums for the past three or four years. At the present time, one of the major allocations in the budget is for protection against the arrival of blast and fire. Protection of population in metropolitan areas has been a goal of the Air Defense Command, a goal of nearly every defense weapons system, and it certainly is a goal of the Nike-Zeus program. We are presently allocating a very sizeable portion of the military budget for the solution of this particular blast and localized fire hazard as related to a given target.

W. A. Keene, Buffalo Tank Div., Bethlehem Steel Co.: Is there presently an approved blast check device for ventilating systems in shelters? Will DOD consider for approval a specifically designed item for this purpose?

Mr. Visher: Mr. Neil FitzSimmons in the Dept. of Defense has a group which has responsibility for looking at this type of article. I feel that the Federal name has been overused and also the words "accepted," "approved" or what have you. We want to establish standards, and people should design to those standards. I don't think we should be in the certification business. We will be very glad to work with people in assisting them to develop articles which will serve specialized purposes.

H. M. Priluck, G. A. Fuller Co.: What proportion of the space in a deep shelter would be needed for storage and equipment to allow the shelter to function autonomously in the period after attack, when it will be sealed off?

Mr. O'Sullivan: I have seen some studies of these underground installations where the equipment areas were greater than the few people we proposed to shelter. And, at the other extreme, I think the percentage was 10% of the area for the utilities and 90% for the people. This is a function of the number of people in the shelter. Usually, you have to take a lot of equipment down, and you have to equate the area with a certain number of people.

Robert A. Wilson, Ellerbe & Co.: Will there be an attempt to match the protection factors of shelters to the probable hazard anticipated, based on an educated guess as to the pattern of attack?

Mr. Visher: The question of the likely measure of attack is one which I find very interesting. I've yet to have a single person from any place in the country arrive in my office who is not thoroughly convinced that he and the area which he represents are of sufficient importance to be a primary target area. This conclusion is an unrealistic one. We have established a protective factor of 100 as being the best educated guess of a way of saving the largest number of lives, if that protective factor is reached on a nation-wide basis. Some people feel cities will be attacked; some people feel that military targets will be attacked. No one can say, with any degree of confidence, what the attack pattern will be. Even the best military planners can't state this. There is, however, under any attack condition, a very valid need for fallout shelter protection. Fallout shelters, under any attack condition, will save large numbers of lives, provided we have them, and our ability to get them depends on what they cost. The protective factor of 100 is the best compromise from our evaluation of these various variables.

ATTENDANCE AT THE BRI 1961 FALL CONFERENCE

The attendance list which follows includes all persons attending the BRI 1961 Fall Conferences, including the conferences on:

Performance of Plastics in Building
Prefinishing of Exterior Building Components
Mechanical Fasteners for Wood
Identification of Colors for Building
and
Design for the Nuclear Age

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