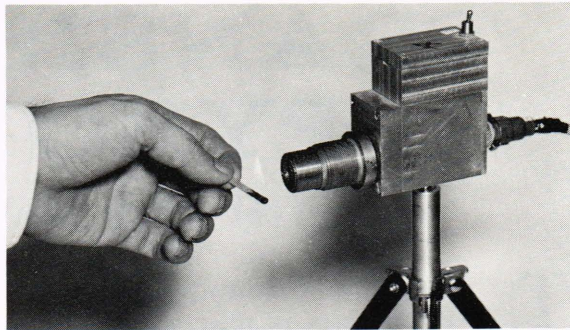


feedback is introduced in the form of an infrared light signal. A subminiature tungsten bulb acting as an electro-optical transducer re-introduces into the window of the phototransistor an optical signal proportional to the electrical signal at the output of the amplifier. Base bias for the phototransistor is supplied by the DC component of the light from the lamp, which is run at a steady 12-ma current.

The photofeedback version of the pyrometer gives greater precision as well as greater calibration stability. The voltage calibration is reproducible to better than 0.1%, giving a temperature that is reproducible to better than $\pm 1^\circ\text{C}$ at 1000°K and $\pm 4^\circ\text{C}$ at 2000°K . Even greater precision could be achieved by redesigning for a larger amount of feedback, but stability of the feedback lamp characteristics may impose a practical limit. The threshold temperature of this version is $\approx 840^\circ\text{K}$.

The most important advantage of the feedback version of the pyrometer, as previously noted, is that after an initial absolute calibration, it needs no further optical calibration and is therefore ready for field use under any conditions. Another advantage is that feedback improves the linearity of the phototransistor response.

An accompanying figure shows how the pyrometer is being used currently to measure throat-



Recording pyrometer designed for use by the Flight Research Group.

surface temperature in a rocket motor. By mounting the pyrometer directly to the rocket-nozzle wall (a capability made possible by its small size and weight), optical alignment errors due to thermal expansion can be avoided. An optical pyrometer is preferable to a thermocouple in this application since it has no thermal lag or lead conduction loss.

Other groups in the Laboratory are finding uses for the transistorized pyrometer. A conveniently sized unit using the same basic optical and electronic design, which has been adapted by J. M. Akridge for use by the Flight Research Group, is illustrated.

SURVIVAL

in

Metropolitan-Area Nuclear Attacks

R. J. Vicars

On May 25, 1961, in his message to Congress on "Urgent National Needs," the President called for a new and revitalized civil defense program to protect the civilian population of the United States from the hazards of nuclear war. Since that time, many pamphlets, books, and articles have appeared urging the population to begin providing the means for shelter-

ing itself from the residual radioactivity ("fallout") that would result from a nuclear attack.

It is agreed* that "fallout shelters" will provide useful protection only

*The author acknowledges that the factual data upon which this study is based were derived from U. S. Government and other publications listed at the conclusion of this paper. The statements herein do not con-

stitute a specific set of recommendations, but are an aggregation of facts from which the reader may determine his own course of action.

tants plus the residents of small cities and towns) from nearly any form of nuclear attack, and for nearly all of the population, urban and rural, from *some* likely attacks (on SAC bases or missile launching sites, for example). However, the appeal of the fallout shelter alone understandably vanishes for the 40 million residents of our 60 largest cities when they consider the cities themselves as potential targets. Despite many seemingly persuasive arguments to the contrary, there is little reassurance for city dwellers in predictions that an enemy may be bold enough to strike remote parts of our country but will be too timid to assault our cities.

Neglect of adequate shelter preparations by the urban population repre-

sents a gamble that there will be no nuclear war, that if cities are targets in a nuclear war, adequate shelter is impossible, or that if successful shelter is possible in a target city during a nuclear strike, the post-attack world will not be worth living in. The uncertainties in these conclusions are huge and the stakes in the wager immense: survival for the individual, his family, his community, and his nation.

This paper considers the feasibility of providing adequate shelter within an urban area that is the scene of a direct attack. An estimate is made of the immediate lethal effects of such an attack. Shelter design criteria, as influenced by the environment thus created, are developed. Comparison is made of casualties among an un-

sheltered population and of expected survivors among a sheltered population.

Lethal Characteristics of Thermonuclear Explosions

The explosion of a thermonuclear weapon near the surface of the earth releases a tremendous amount of energy in a number of ways potentially lethal to a city and its inhabitants. The weapon explodes with a brilliant flash of light, and the air in the immediate vicinity of the explosion is heated very rapidly to extremely high temperatures. A "fireball," which may persist for more than a minute, is formed. During the period of time when the major part of the thermal energy is being emitted, the apparent

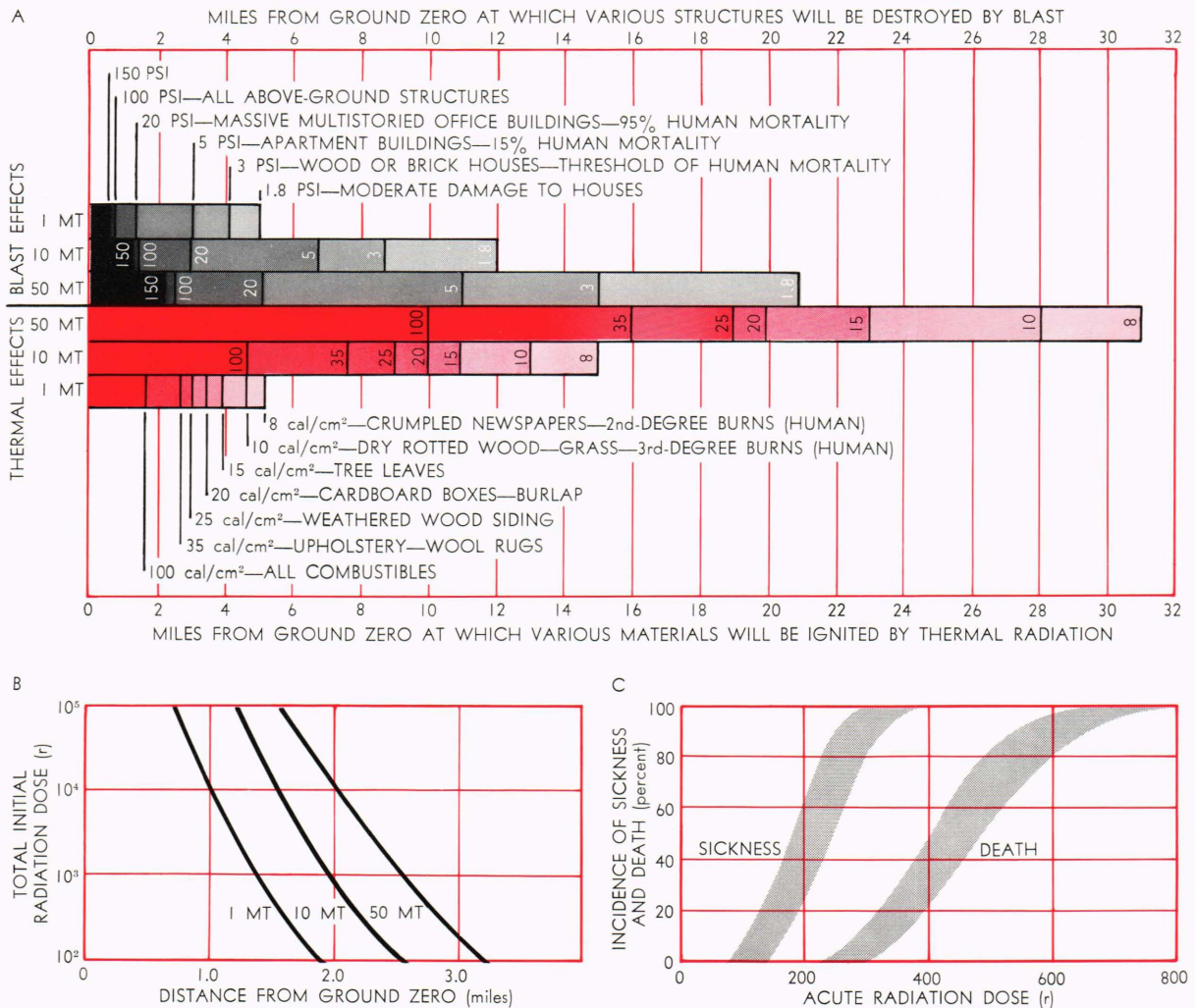


Fig. 1—Lethal effects of nuclear weapons: (A) thermal and blast effects on structures and materials at various radii; (B) radii of radiation effects for 1-, 10-, and 50-MT yields; (C) physiological effects of radiation for increasing doses.

surface temperature of the fireball reaches a maximum of about 15,000°F. The almost instantaneous burst of nuclear radiation issuing from the detonation point is followed by an intense blast wave that generates a violent wind.

When the burst is close to the surface of the earth, a crater is formed. The soil and/or rock structure adjacent to the crater is ruptured or permanently deformed by the intense blast. The shock transmitted through the earth beyond this deformed area is relatively weak, so damage by the direct ground shock to buried structures outside this zone will be small. The vaporized mixture of radioactive debris from the bomb and the surface material from the crater is lifted high into the sky by the vertical winds generated by the explosion. Upon cooling, this mixture solidifies in small particles, thereby trapping some of the radioactive debris. The contaminated material may return rapidly to earth in the form of heavy particles with much radioactive contamination. The smaller and lighter particles descend more slowly and thus their activity will have had more time in which to decay before they reach the earth's surface.

The regions over which the immediately hazardous radioactive material from a surface burst may be deposited depend almost entirely upon the unpredictable wind currents through which such material will pass during its rise and fall. Patterns observed in tests undertaken to date indicate a wide variation of activity as a function of distance from the detonation. Hot spots of severe activity have been noted at points moderately distant from ground zero.

The thermal radiation, the initial nuclear radiation, the air shock (and associated induced ground shock), and the "residual" radioactive contamination ("fallout") are the effects of most concern in the design of protective shelters (see Fig. 1A and B).

The shock wave will travel at great speed and will reach distances as great as 15 miles in less than a minute. This is probably the upper limit of time available for effective action by those whose survival depends on the action taken. This emphasizes the fact that, over the entire area of interest in any direct city attack,

TABLE I
NUCLEAR ATTACK PATTERNS STUDIED FOR THE WASHINGTON, D. C. AREA

Case Number	Number and Yield of Bombs	Aim Point	Total Yield of Attack (megatons)
I	1 at 50 MT	City center	50
II	1 at 10 MT	City center	10
III	3 at 10 MT	Chosen to maximize area of coverage	30
IV	1 at 10 MT and 5 at 1 MT	Chosen to maximize area of coverage	15

shelter must be immediately available for most of those who will survive.†

The Dimensions of Destruction in an Urban Area

In order to maintain a perspective in this grim assessment, it is important to understand that the destruction will not be as uniformly distributed as the following generalized discussion portrays. In particular, the enemy tactics of attack, and the ensuing location, yield, and number of bomb detonations, while reasonable in terms of future capability, are completely speculative. However, it is clear that some areas remote from ground zero will be substantially unaffected, in the immediate sense, by weapon detonations; some others closer to the burst will be physically untouched but will be threatened by fallout; closer to ground zero, fallout, fire, and blast damage will increase; very near ground zero there will be complete devastation. It should be noted that much of the evidence concerning overall effects of nuclear detonations has been drawn directly from controlled situations during actual tests of nuclear devices.

Discussion of the environment where shelters must function will clarify shelter design requirements and provide some guidance for the utility of shelters. The metropolitan Washington, D. C., area is used as a basis for discussion because it is a likely target if urban centers come under attack. The population and population density of the District of Columbia and its Maryland suburbs were derived from 1960 census data. (Data for the Virginia suburbs were not conven-

iently available and were not included in the analysis.) They are indicative of the nighttime or residence population distribution. However, they are the appropriate figures since they refer to population distribution under the only conditions in which passive defense will be effective. We presume that the preparation of shelters will have predisposed their owners to be in a position to use them should desperate need arise. Reconsideration of the lethality of the weapons should be sufficient encouragement to remain in or very near the shelters if nuclear attack appears imminent.

As a basis for study, the bomb patterns in Table I were superimposed upon the Washington area (guidance accuracy equivalent to a 1.0 nautical mile C.E.P.—circular error probable—is assumed as realistic).

The aim points for these sample attacks were selected arbitrarily.‡ For single bomb strikes, the Washington Monument was chosen because it is centrally located to the White House, Capitol, and Pentagon, and is at about the center of the population distribution of the metropolitan Washington area. For multiple bomb strikes, aim points were generally selected so as to maximize the area of the city over which there would be a high (0.9) probability of seriously damaging all except reinforced concrete or equivalent structures.

The extent of the blast destruction caused by the attack of Case IV in Table I is shown on the Washington-area map, Fig. 2. Here we see the region within which there is a high probability (0.9) that residential structures would be destroyed. In the vicinity of the aim points, even blast-

† For those interested in a much more detailed discussion of nuclear weapon effects, "The Effects of Nuclear Weapons," available from the U. S. Government Printing Office, is highly recommended.

‡ Aim points are selected for purposes of controlled studies and do not necessarily represent actual detonation points.

resistant, reinforced-concrete buildings will have a high probability of being completely destroyed. The total devastated area would extend to about 11 miles from the Washington Monument and would include such suburban communities as Bethesda, Silver Spring, Wheaton, College Park, Cheverly, and the environs of Andrews Air Force Base. Individuals within the devastated area would have a 9 out of 10 chance of being exposed to blast effects of *at least* 5 psi, and, without adequate protection, the casualty rate would be very high. The human body is surprisingly resistant to direct damage from blast, being able to withstand up to 35-psi overpressure before a significant number of fatalities occur. However, blast-induced injuries from being thrown

about and from impact against hard objects, and the injuries to be expected from blast-accelerated glass and other debris, assume importance at much lower overpressure levels. When added to the hazards of entrapment, injury, and death occasioned by collapsing buildings, high casualty rates can be expected in urban areas exposed to 5-psi overpressure.

It is clear that shelters cannot provide complete assurance of survival at any *particular* location within the metropolitan area; the laws of chance prevailing in such circumstances preclude efforts to predict actual locations of bomb detonation points (or the number or yield of bombs that might fall). However, there are very large areas where there exist high proba-

bilities of survival for even moderate-strength shelters, no matter which reasonable combination of bomb aim points, yields, and numbers is employed.

The effectiveness of shelters of various degrees of hardness (expressed in terms of the limiting overpressure which they are designed to withstand) is also illustrated in Fig. 2. The circular areas represent the limits of the regions about the arbitrarily chosen aim points of Attack Case IV within which there is 0.1 probability that the indicated overpressures will be exceeded. Anywhere beyond these circular regions there is a 9 out of 10 chance that a shelter possessing the strength shown will withstand the blast. While the probability of survival for a given shelter hardness does decrease within these circles as one approaches the aim point, there is still a better-than-even chance throughout the entire area that any particular 35-psi shelter will survive a burst of several megatons (MT).

The extent of the blast damage that would result from the other attack cases listed may be inferred from a transfer of the appropriate blast damage distances to the map of the Washington area. The need for making provision for survival of the immediate blast effects is not grossly affected by changes in the attack pattern. Even the smaller bombs would be vastly damaging to an unacceptably large fraction of an unprotected population.

Increasing the yield and/or the number of bombs dropped does not produce a proportionate increase in the percentage of the population affected. As an example, the area for a high probability of destruction for the 10-MT single air burst extends to a radius of about $8\frac{1}{4}$ miles from the Washington Monument and includes more than 70% of the metropolitan area population. Increasing the yield five times to a 50-MT air burst increases the radius to about 15 miles but increases the population included by only an additional 20%.

Figure 3 gives the proportion of the Washington area population that is vulnerable when unsheltered. Considering, for the time being, the overpressure criteria only, well over half of those vulnerable would have a very high probability of survival if they

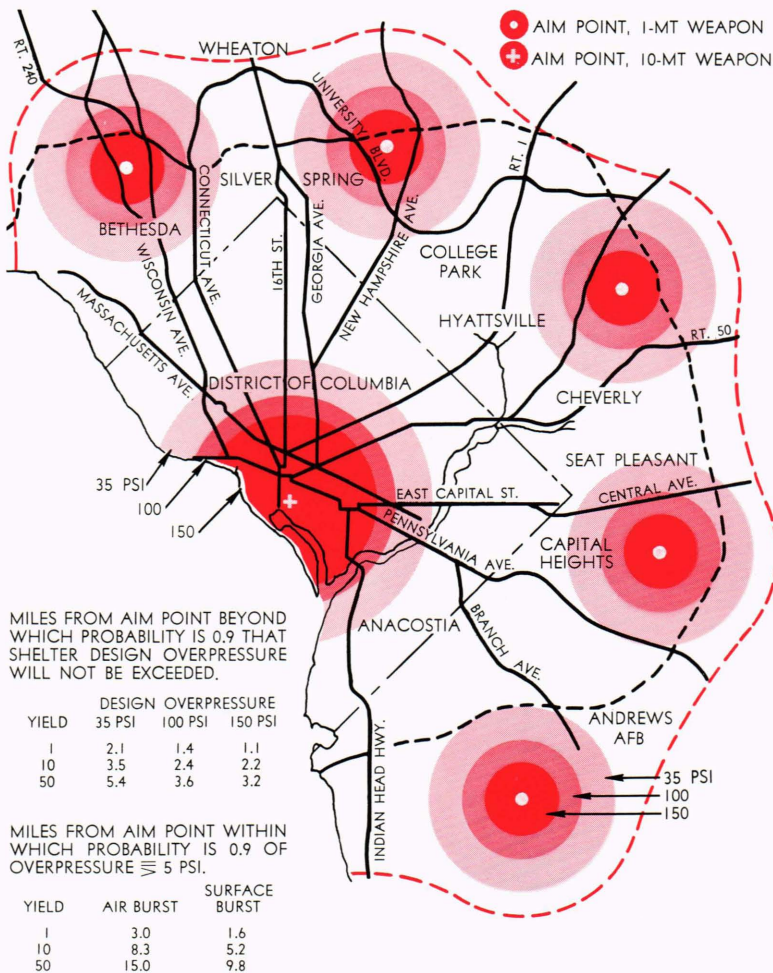


Fig. 2—Dimensions of destruction for Attack Case IV in the Washington, D. C. area. Inside the entire area shown, there is an 0.9 probability that overpressures will exceed 5 psi. Outside the circled areas, there is an 0.9 probability that overpressures will not exceed those shown on the circles.

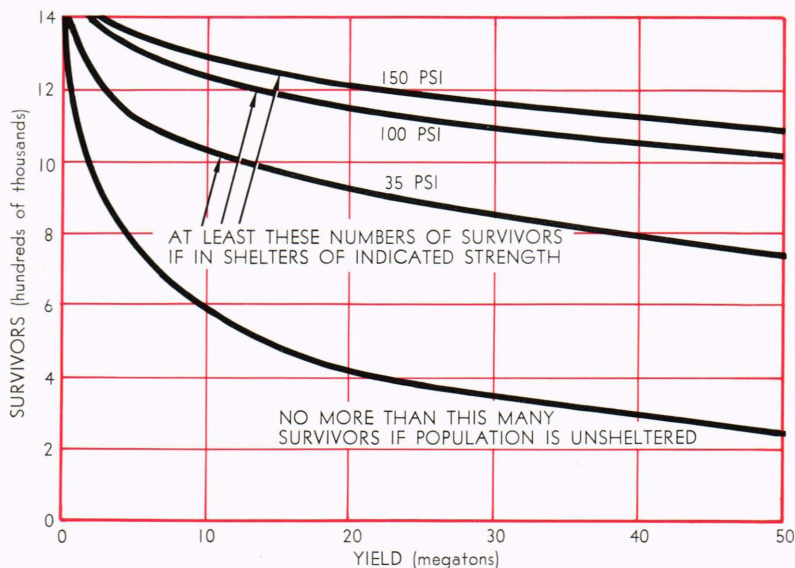


Fig. 3—Estimates of probable (0.9) nuclear-burst survivors among sheltered and unsheltered populations in Washington, D. C. (single-burst; aim point, Washington Monument; 1.0-nautical-mile C. E. P.).

were protected by even a minimum-strength (35-psi) blast shelter, and stronger shelters would reduce the casualties even more. It has become clear from examination of the various attacks, that no one combination of aim points and weapon yields is overwhelmingly more destructive to the city than any of the others. Throughout all of the District of Columbia and well into the Maryland suburbs, there is clear indication that the stronger the shelter, the higher the assurance of survival. However, since any protection will improve the chances of survival, the standards should not be set so high that shelter efforts are, in fact, discouraged.

Attack Case IV probably represents an upper limit to the number of weapons that would be expended on a single city. (It should be assumed that the Virginia suburbs, being as thickly populated as the Maryland areas, will receive equal attention from the attacker.) Thus, beyond about 15 miles from the city center, it appears that expected blast forces would be reduced to an extent that would permit survival in *fallout-type* shelters. However, the fires that result from the attack may necessitate much more elaborate precautions than are provided for in some of the designs described in the available literature.

The extent of thermal damage to

the Washington area resulting from these arbitrary strikes is heavily dependent upon a number of factors that cannot be predicted satisfactorily. Such physical factors as moisture content and reflectivity of exposed materials, transmittance of the atmosphere, presence or absence of clouds and snow cover, shadowing effect of foliage, structures, and topographic features, etc., all will substantially affect the radius of ignition of primary fires. However, the potential destruction under conditions favorable to the attacker may be estimated.

Figure 1A includes the approximate radiant exposure required for ignition of household materials and dry vegetation. Almost any thin, flammable, household material will ignite if exposed to thermal radiation of about 10–20 cal/cm². Dry vegetation will ignite at about the same exposure. The distances from the aim points at which these thermal radiation levels would probably be reached are indicated below. (These figures presume a reasonably clear atmosphere.)

Yield (single surface bursts)	Distance from Aim Point for 0.9 Probability of at Least 10–20 cal/cm ² (miles)
1 MT	2.0–3.3
10 MT	8.6–12.2
50 MT	19.0–27.2

It is evident that the regions within which there is a high probability of having incident thermal energy sufficient to cause ignitions (termed *primary ignitions*) in common materials extend to about the same or greater distances as those associated with blast damage. Conditions suitable to widespread *secondary ignitions* (those resulting from blast damage to heating elements, fuel lines, etc.) are also to be expected throughout the zones heavily damaged by blast, although these may be less widespread than the primary ignitions.

Detonation of even a few megatons in the Washington area is capable of initiating fires over a great area while at the same time destroying or severely disrupting most ordinary means of fire fighting. The post-attack spread of fires may be expected to follow an expanding trend from the massive destruction and the great number of fires in the central area. If uncontrolled, ignitions even in the areas remote from ground zero might develop into building fires, block fires, or area fires. With the hazard of early fallout in the downwind direction, it does not appear possible to prevent widespread enlargement of the fire area. Surface winds would continue to drive the fires until a natural or artificial firebreak (a park, river, wide street, reservoir, etc.), where there is insufficient fuel to propagate the flames, is reached. Even their efficiency as firebreaks may be severely dependent upon the season, weather conditions, orientation with respect to the direction of fire travel, etc. It seems clear that destruction by fire of a very large part of the metropolitan area must be anticipated. No section can expect immunity.

A fire resulting from a nuclear explosion over a major metropolitan area will reach its peak and begin to die down after three hours. Generally, individual buildings will be destroyed in about one hour; collapsed buildings may continue to smolder and burn for days. Where fires develop into firestorms or conflagrations, they will continue to burn with great intensity until all the fuel has been consumed.

The lethal capacity of these massive fires is emphasized by data from cities burned by firebomb attacks during

World War II. A series of Allied attacks on Hamburg in 1943 destroyed 55 to 60% of the city, with damage extending to an area of 30 square miles; 12.5 square miles were completely burned out. Estimates of deaths ranged from 60,000 to 100,000, and 300,000 dwellings were destroyed.

During the second of the series of raids, within 90 minutes after the bombs had dropped, a full-grown firestorm developed. Available shelters proved inadequate, and they became death traps for their occupants. Carbon monoxide from the incomplete combustion of rubble became recognized as a major cause of death; in Hamburg, it was estimated that 70% of all deaths were caused by carbon monoxide poisoning.

Other cities, too, suffered the destruction of mass fires. Tokyo was attacked on March 9-10, 1945, and 16 square miles were destroyed by a moving conflagration, with a loss of over 130,000 people. Dresden was burned on February 13-14, 1945, and estimates of the dead reached 300,000.

The lessons that were learned from these facts are:

1. Effective control of large area fires in cities was not possible.
2. In some circumstances, heroic efforts preserved some sections.
3. Masses of hot rubble and debris from destroyed structures choked all passageways in the more densely built-up sections of the cities.
4. Communications within the cities, necessary for any coordinated attempt to fight fires, were completely destroyed.

5. Existing shelters were inadequate from the standpoint of resistance to high temperature and noxious gases. Many persons, who might have left the area before the fires spread, were trapped in the shelters.

Shelter Design Requirements

Hypothetical attacks against the Washington area have been examined, and the lethal nature of the resulting environment has been described. From such information, criteria for shelter designs may now be developed. Admittedly, while no advance preparations can guarantee survival, it seems possible for a very large number of the metropolitan-area residents to improve vastly their probabilities of survival. This improvement will

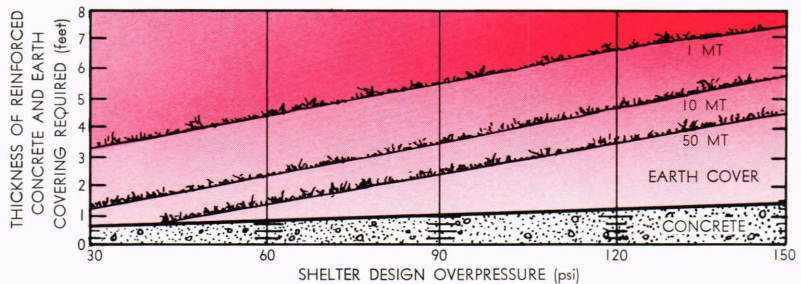
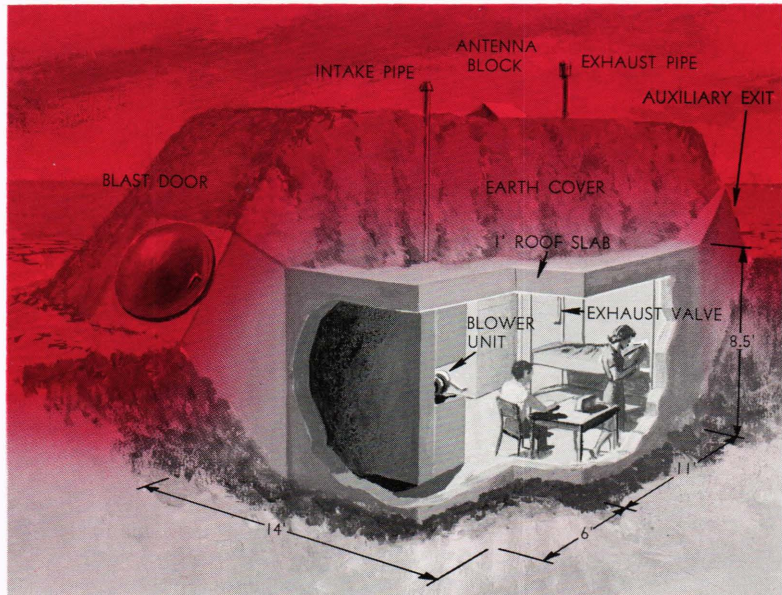


Fig. 4—(A) A representative family shelter that meets the minimum standards for austere accommodations and that will survive 65-psi overpressures; (B) thickness of combined concrete and earth cover required to attenuate the initial radiation of 100 r inside the shelter and to withstand the crushing forces associated with the indicated blast overpressures.

stem directly from the provision of "hard" shelters—and the harder the better. The minimum standards for such shelters are discussed in the sections that follow. Details of construction, cost, equipment, etc., are not included since meaningful definition is not possible in a study as broad in scope as this.

THE SHELTER MUST BE STRUCTURALLY STRONG ENOUGH TO WITHSTAND ANTICIPATED BLAST LOADS

A schematic example of an underground shelter is shown in Fig. 4. An estimate of the wall and ceiling thickness required to withstand the blast load, together with adequate earth cover for attenuation of the initial radiation, is also shown.

For the shelter design overpressures illustrated in Fig. 2, the following figures are appropriate (no factors of safety have been included in these

computations since estimates of survival should be based as nearly as possible on the true ultimate strength of the shelter):

Overpressure (psi)	Wall and Ceiling Thickness (in.)
35	8.0
100	13.0
150	16.0

These are preliminary figures in which only the gross strength of the structure has been estimated. It is to be expected that detailed design (see "Design of Structures to Resist the Effects of Atomic Weapons," for example) for a particular shelter will be based upon the individual needs of the builder.

THE SHELTER MUST BE THERMALLY INSULATED AND SEALED FROM THE EFFECTS OF FIRES RESULTING FROM THE BURST

It will be necessary to seal the

shelter to prevent ingress of carbon monoxide gas for the period that fires persist. This means sealing the shelter for as long as a day after the fire begins in the vicinity of the shelter. External air (filtered) may be usable after this time and can then be pumped into the shelter. If smoke and other noxious products remain in the atmosphere, the "sealed time" may need to be extended.

In a test that simulated the burning of a densely populated area of single-story buildings, a shelter buried under 3 ft of earth was instrumented to determine how much heat would register inside. The test indicated that negligible changes in environment occurred inside the shelter, showing the feasibility of satisfactory thermal insulation of the shelter with moderate depths of earth. Particular attention will have to be paid to the design of intake and exhaust ducts, antennas, and other projections.

THE SHELTER MUST ATTENUATE THE EXPECTED RADIATION TO AN ACCEPTABLE LEVEL

1. *Direct Radiation*—The direct radiation of concern in shelter design consists of neutrons and the immediate (less than a minute after detonation) gamma rays. Most of the dose received at a shelter will come from the direction of the detonation point, but due to scattering in the atmosphere, much will arrive from other directions.

From Fig. 1A and B, the estimated total initial radiation dose (neutrons plus gamma rays, unsheltered) at distances associated with various overpressure levels may be determined. Close to the burst points, at distances corresponding to the 150-psi overpressure, unsheltered initial radiation doses in the order of 10^5 roentgens (r) would be experienced. Much of the direct dose would be attenuated by the intervening earth; however, because of the uncertainty of the actual height at which the burst would occur, and of the great amount of scattered radiation, it is a conservative procedure to provide sufficient earth cover over the shelter to withstand the total radiation associated with the design overpressure. Figure 4 shows that about 6 ft of earth cover over the shelter provides sufficient attenuation to reduce the expected

initial radiation dose to less than 100 r in even the worst (150-psi, 1-MT) design case, and 3 ft of earth is sufficient to attenuate to doses of less than 100 r at design overpressures of 35 psi or less.

2. *Fallout or Residual Radiation*—Residual radiation dose rates greater than several thousand r/hr (at 1 hr after burst time) may exist at considerable distances (tens of miles) downwind from a multimegaton burst. At isolated points in the vicinity of ground zero, this one-hour reference dose rate may exceed 10,000 r/hr. These values seem to be reasonable design limits for estimating maximum attenuation requirements.

Utilizing the concept of an average wind speed to determine the rate of travel of the contaminated debris, it is possible to develop the factor for converting the one-hour reference dose rate to the total dose that would be accumulated at various downwind distances for various dwell times. This factor represents the integral of the product of the dose rate and exposure time from the time of arrival of the radioactive material until some time that might represent possible departure from the radiation field. For the distances from the burst that are of interest to this study, say 2 to 20 miles, factors of from 3 to 6 are appropriate. When multiplied by the design-dose-rate limits, total doses in the order of 10,000 to 60,000 r could result at unsheltered locations in the metropolitan area. Such doses, of course, are fatal (see Fig. 1C). Slabs designed to withstand 35-psi overpressure or more can secure an attenuation factor of 10,000 to residual radiation gamma rays with about 3 ft of earth cover. The depths of earth cover shown in Fig. 4 would reduce the total dose accumulated in the shelter by the end of the third week to only a few roentgens.

THE SHELTER MUST BE LARGE ENOUGH FOR THE EXPECTED INHABITANTS

While the dimensions of the shelter are subject to adjustment to suit the desires and needs of the owner, there are certain factors that can be used to determine the required shelter size, besides the obvious fact that price increases with increasing dimensions. As we have discussed, the shelter must be sealed during a firestorm.

The shelter dimensions may be established so that the sealed shelter will contain sufficient air to sustain the life of the inhabitants during the required dwell time, thus eliminating the need for storing air in high-pressure containers.

The amount of absolutely essential air space in the sealed shelter can be estimated by considering that one resting adult requires about 7 ft³/hr of air and that the minimum air requirement of one adult performing light tasks without discomfort is about 25 ft³/hr.

A number of measures may be taken to extend the safe dwell time within the sealed shelter. Auxiliary oxygen may be stored in tanks and released into the shelter as necessary. The use of individual oxygen masks permits the most efficient use of the oxygen. Excess CO₂ must be removed if habitation is prolonged; several methods of doing this are discussed in detail in "Shelter Habitability Studies—The Effect of Oxygen Depletion and Fire Gases on Occupants of the Shelters."

THE SHELTER MUST CONTAIN ESSENTIALS FOR SUPPORTING LIFE PROCESSES OF INHABITANTS DURING REQUIRED DWELL TIME

Many sources list items considered essential for life in a shelter. The quantities of items that must be stored or available are dependent upon the number of inhabitants and the required dwell time.

It would appear that there are at least two important time intervals to be considered for survival:

1. The time during which the shelter is sealed against intolerable combustion products;
2. The time during which the residual radiation environment in the shelter neighborhood presents a lethal barrier to exit from the shelter.

From Fig. 1C it can be seen that the tolerable dose for essentially no impairment of activities may be as high as 200 r. Assuming the dose accumulated while within a shelter to be no more than approximately 100 r, then a like dose may still be endured during immediate post-shelter activities. This does not mean that 200 r may be accumulated with complete impunity; the long-term effect of such doses of ionizing radi-

ation is very incompletely understood. However, it may be necessary to leave the shelter, at least for a time, in the face of other and more immediate threats to survival. Thus, it is essential to estimate the relationship between required shelter dwell time and the time available for evacuation or other activities in the reduced but still-dangerous radiation environment.

Assuming, for design purposes, the 10,000 r/hr reference dose rate, Table II shows the limit of exposure time for various exit times and accumulated exposure doses.

TABLE II
HOURS OF POST-SHELTER TIME TO ACCUMULATE SELECTED RADIATION DOSES

Shelter Exit Time (days after attack)	Accumulation (r)		
	150	100	50
	Period (hr)		
4	4	2¼	1¼
7	7	4½	2½
14	17	11	5½
21	28	18	9
28	40	26	13

Note: It must be emphasized that, while predictions of the radiation field are useful for estimating the required shelter dwell time for design purposes, actual emergence from a shelter must be based on measurements of the radiation activity at exit time.

Table II indicates that one who leaves the shelter after 21 days may expect to accumulate a dose of 100 r within 18 hr if he remains unsheltered in the area where the dose rate was 10,000 r/hr at one hour after detonation. It is evident that the radiation environment may still be severe, and only limited time will be available to evacuate to a more tolerable area. However, it is not expected that such severe "hot spots" of radiation as were assumed for design purposes will cover a very extensive area. It might be expected that relatively safe areas of much lower dose rates may be found, a few weeks after the explosion of a single bomb, within 10 to 20 miles up-wind or cross-wind of the shelter area. Distances of this order could be traveled on foot in a day or less. While even in these areas of relatively low dose rates some protection from radiation will be necessary, this phase most appropriately

falls in the realm of long-range survival planning and is beyond the scope of this paper. The shelters within the area can be expected to provide no more than the immediate necessary protection, with a margin of fitness sufficient to enable the inhabitants to enter the long-range survival and recovery phase without undue physical handicaps.

For design purposes, a shelter dwell time of 21 days should be assumed, with the expectation that for at least the first day of this time the shelter may need to be thermally sealed. During the remainder of the time, ventilation with filtered air will be required. The following list indicates the minimum supplies and equipment necessary for the occupants of the shelter.

AIR SUPPLY

Sealed Condition—equivalent of about 10 ft³/hr of air per occupant. This is near the limit of endurance for a resting adult, with a small margin of safety. More space or an auxiliary supply of oxygen, and provisions for removing CO₂ from the air, would be highly desirable.

Unsealed Condition—A manually operated ventilating system must be included, which is capable of providing at least 5 ft³/min of filtered air. This amount will provide for comfortable occupancy of the shelter for an indefinite period, and will permit more nearly normal physical activity.

WATER

One gallon per day per person is recommended, one-half gallon being for drinking, and one half for other purposes.

FOOD

While most healthy people can survive with no food for two weeks or more, their health and vitality will suffer and their morale can be seriously undermined. An adequate supply of palatable foods should be provided within the shelter to maintain the will and vigor essential for survival in the hostile post-shelter environment. Since detailed recommendations concerning family food stockpiles for shelters are readily available in such publications as "Family Food Stockpile for Survival," dis-

cussion of shelter food requirements is not included in this paper.

SANITATION

Provision must be made for the disposal of human waste, which can spread such diseases as typhoid, dysentery, and diarrhea. The simplest device is a tightly covered metal pail, together with a supply of plastic bags. Household bleach may be used (following the shelter-sealed condition) to decrease odors and prevent insect breeding. A larger can with a tight cover should be available to store the plastic bags after use. When the radiation field has decayed sufficiently to permit very brief exposure, this storage container may be placed outside the shelter.

LIGHT

A continuous dim light can be provided, using a 4-cell hot-shot battery connected to a flashlight bulb. Other methods of illumination can be used, of course, at the discretion of the occupants. Three or four fresh batteries should be on hand, together with spare bulbs. Simple hand generators might be utilized to supply electrical power for short intervals. Flashlights should also be available. A conventional electrical outlet should be installed in the shelter since it is possible that regular electrical service will not be interrupted by an attack.

THE SHELTER SHOULD CONTAIN MINIMUM ESSENTIAL EQUIPMENT TO ASSURE SAFE EMERGENCE FROM THE SHELTER AND EVACUATION OF THE SHELTER AREA

Instruments to detect and measure gamma rays are essential to determine activity of the radiation field in the area outside the shelter, and to determine the total dose accumulated by the shelter occupants during and after shelter. A rate meter will measure the intensity of the radiation and provide a basis for making estimates of the dose that will be experienced during excursions outside the shelter. A dosimeter will record the total amount of radiation (dose) to which it has been exposed. As we have said, pre-attack predictions of dose rate and dose cannot be relied upon to gauge exposure accurately in any specific instance. These instruments must be available to permit determination of the safe time of

exit from the shelter and to guide the evacuation to safe areas. An externally mounted instrument that can be read without exposure of the shelter occupants would be most desirable for monitoring external radiation.

It is possible that debris in some form may block the exit from the shelter. Therefore, such tools as a shovel, crowbar, hack saw, wood saw, sledge hammer, chisel, hand ax, etc., should be provided within the shelter.

Instructions for evacuation, which may be received by radio from Civil Defense or other Government agencies, will most probably designate safe passageways and safe areas with reference to local area maps. For this reason it is essential to have detailed maps covering the area within at least 50 miles of the city so that this vital information can be charted. For guidance in unfamiliar areas, or where familiar landmarks have been destroyed, a reliable compass will be useful.

THE SHELTER SHOULD CONTAIN A MEANS OF RECEIVING COMMUNICATIONS FROM EXTERNAL SOURCES OF INFORMATION AND CONTROL

An operating battery radio is essential to receive CONELRAD broadcasts (640 kc and 1240 kc on the AM radio dial). Sufficient fresh spare batteries should be included to insure long-term operation. CONELRAD will probably be the only means for communication between Government sources and shelter occupants, and it will be the only effective channel for disseminating instructions pertaining to activities for post-shelter survival planning.

Since the materials used in the shelter construction may attenuate the radio signals, an adequate antenna for the radio (for example, see Fig. 4) should be a part of the shelter. Pre-attack testing of reception is recommended, to insure receiving vital information.

SUPPLEMENTARY SUPPLIES

Because the shelter is to be "home" to its occupants for the required dwell time, a number of items not generally included as mandatory on most survival lists, but which may be nearly so for many, should be stocked. These include: food preparation and serving

equipment; clothing and bedding; sanitation supplies, disinfectant and insecticide; infant care supplies; first aid kit, medical information, and special medicines that may be required for particular cases; such recreational equipment as books, games, toys, etc. for children and adults; tools that might be required for repair of equipment within the shelter; sources of information (books, magazines, maps, etc.) pertinent to survival in the post-attack environment; and spiritual or religious articles. This list of supplementary supplies should include whatever will best maintain the well-being and morale of the individuals.

Outside the shelter, but close to it and well protected, should be stored those items judged necessary and useful for evacuation from the shelter area and for long-range survival plans. These might include a larger and more elaborate supply of the items listed for the shelter, plus fuel for

transportation equipment, portable radio with spare batteries, complete camping equipment, materials for water purification, weapons and ammunition, etc.

Preparations for evacuation of the shelter area and long-range survival planning should be done with the constant realization that familiar sources of power, heat, light, water, transportation, food—in short, most of the things depended upon for the customary way of life—will have been destroyed or at least severely curtailed and will probably remain so for a considerable period of time. For the absolute necessities of life, *one can depend upon only those things which he has prepared in advance*, which can be transported, if need be, under his own power, defended by his own strength, and maintained through his own resourcefulness. Since individual capabilities are limited, the advance preparations must be thorough.

Bibliography*

- "AEC Group Shelter," CEX-58.7 (U. S. Atomic Energy Commission), Office of Technical Services, Dept. of Commerce, June 22, 1960.
- "Annual Report of the Office of Civil Defense for Fiscal Year 1962," Department of Defense, U. S. Government Printing Office, 1962.
- "Biological and Environmental Effects of Nuclear War," Hearings before the Special Subcommittee on Radiation of the Joint Congressional Committee on Atomic Energy, U. S. Government Printing Office, June 1959.
- "Building Code Requirements for Reinforced Concrete," report of ACI Committee 318, *J. Am. Concrete Inst.*, May 1956, 913-986.
- "Civil Defense: Part I, Shelter Policy; Part II, Post Attack Planning," Hearings before a Subcommittee of the Committee on Government Operations, U. S. Government Printing Office, Mar. 1960.
- "Civil Defense 1961," Hearings before a Subcommittee of the Committee on Government Operations, U. S. Government Printing Office, Aug. 1961.
- "Design of Structures to Resist the Effects of Atomic Weapons," Manuals numbered EM-1110-345-413 through 421, U. S. Army Corps of Engineers.
- "Fallout Protection. What to Know and Do about Nuclear Attack," Department of Defense, Office of Civil Defense, Dec. 1961.
- "Family Blast Shelters," OCDM Interim Technical Bulletin (draft), Office of Civil and Defense Mobilization, May 1958.
- "Family Food Stockpile for Survival," U. S. Department of Agriculture, Home and Garden Bull. 77, U. S. Government Printing Office, Aug. 1961.
- "Family Shelter Designs," Department of Defense, Office of Civil Defense, Jan. 1962.
- "Fire Effects of Big Nuclear Bombs," OCDM Information Bull. 273, Office of Civil and Defense Mobilization, Feb. 28, 1961.
- "Fire Effects of Bombing Attacks," OCDM Technical Manual TM-9-2 (rev.), Sept. 1955.
- "New Civil Defense Program," Ninth Report by the Committee on Government Operations, U. S. Government Printing Office, Sept. 21, 1961.
- "Operation Plumbbob—Shelters and Associated Tests," Federal Civil Defense Administration, July 1957.
- "Recommended OCDM Specifications for Blast Resistant Structural Design (Method "A")," TR-5-1, Office of Civil and Defense Mobilization, Nov. 1958.
- "Reinforced Concrete Design Handbook of the American Concrete Institute," (2nd ed.) American Concrete Institute, Detroit, 1955.
- "Shelter Habitability Studies—The Effect of Oxygen Depletion and Fire Gases on Occupants of the Shelters," Technical Report 144, U. S. Naval Engineering Laboratory, Port Hueneme, Calif., June 18, 1961.
- S. Glasstone (ed.), "The Effects of Nuclear Weapons" (rev.), U. S. Atomic Energy Commission, U. S. Government Printing Office, Apr. 1962.

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