FEMA 126/ June 1987
(Supersedes CPG 2-1A2 dated May 1982, which may not be used.)

ATTACK ENVIRONMENT MANUAL

Chapter 2

What the planner needs to know about blast and shock

FEDERAL EMERGENCY
MANAGEMENT AGENCY

FOREWORD

WHAT THE EMERGENCY PLANNER NEEDS TO KNOW ABOUT THE NATURE OF NUCLEAR WAR

No one has gone through a nuclear war. This means there isn't any practical experience upon which to build. However, emergency management officials are responsible for preparing for the possibility of nuclear war. Intelligent preparations should be based on a good understanding of what operating conditions may be like in a war that has never occurred. If the planner lacks such understanding, the emergency operations plans produced probably won't make sense if they ever have to be used.

The Attack Environment Manual has been prepared to help the emergency planner understand what such a war could be like. It contains information gathered from over four decades of study of the effects of nuclear weapons and the feasibility of nuclear defense actions, numerous operational studies and exercises, nuclear tests experience, and limited experience in wartime and peacetime disasters that approximate some of the operating situations that may be experienced in a nuclear attack. In short, it summarizes what is known about the nuclear attack environment as it could affect operational readiness at the local level.

The data on the effects of nuclear weapons used in this manual have been taken from the 1977 edition of "The Effects of Nuclear Weapons" (ENW), compiled and edited by S. Glasstone and P. J. Dolan and prepared and published by the United States Department of Defense and the United States Department of Energy. Copies are available for purchase from the U.S. Government Printing Office. The ENW is the most widely available authoritative source of weapon effects and is in many public libraries across the country. For these reasons it was chosen as the source data in this manual.

This Attack Environment Manual supersedes CPG 2-1A1 through 2-1A9.

LIST OF CHAPTER TITLES

*Chapter 3 will be published at a later date.

PREFACE TO CHAPTER 2

This description of the blast and shock effects of nuclear attack is intended to provide the basic information needed to plan realistic actions to be taken in damaged areas. It does not assume knowledge of the material in subsequent chapters of the manual. It does presume that the reader is familiar with the material in chapter 1--Introduction to Nuclear Emergency Operations.

Until the advent of nuclear weapons, a ton of explosives delivered in a single bomb was considered to be a sort of superbomb. A thousand ton (one kiloton) bomb was unthinkable. Now we commonly speak of weapons with yields of 500 to 1,000 kilotons (one megaton). The blast damage potential from a single such weapon is enormous. The blast wave is capable of engulfing, crushing, and transporting the resultant debris of many city blocks simultaneously. The blast effects have been studied intensively and much information is available to enable the planner to anticipate the effects and to plan accordingly.

Information is presented in the form of "panels" each consisting of a page of text and an associated sketch, photograph, chart or other visual image. Each panel covers a topic. This preface is like a panel with the list of topics in chapter 2 shown opposite. If the graphic portion is converted into slides or vugraphs, the chapter or any part can be used in an illustrated lecture or briefing, if so desired.

The chapter begins with introductory material to acquaint the readers with the phenomena of blast, blast waves, and the winds that accompany the passage of a shock front. It then turns to the effects of blast on people and on various types of structures in which people might be located. The effects of ground transmitted shock, the blast wind, and the production of debris are described. A short section on protection of industrial equipment follows. The chapter closes with a description of damage to vehicles, utility systems, and urban areas in general. There is a list of suggested additional reading for those who are interested in further information on the general subject.

CONTENTS OF CHAPTER 2

WHAT THE PLANNER NEEDS TO KNOW ABOUT BLAST AND SHOCK

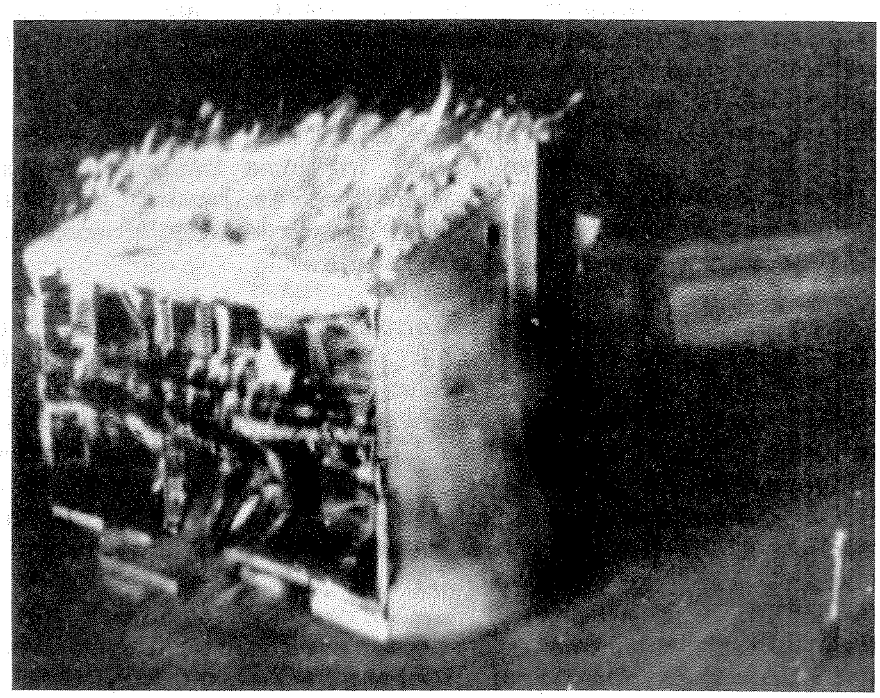
GENERAL EFFECTS OF BLAST

The blast or shock wave created by an exploding nuclear weapon is responsible for much more of the immediate physical damage to buildings in the path of the blast wave. The photograph shows a conventional two-story house just as the shock front has arrived. Before the arrival of the shock front, the house is subjected to only the normal ambient atmospheric pressure of about 14.7 pounds per square inch (psi). In this view, the house is suddenly immersed in an additional pressure within the shock wave of 5 psi (the overpressure). The sudden outside pressure begins to crush the house and the weakened structure is then blown down by the winds behind the moving shock front.

At about one-half minute following the detonation of a 500 KT air burst (5,873 feet or 1.1 miles above the surface of the earth), the blast wave has traveled outward to about 9 miles from ground zero. Its overpressure has decreased to about 1 pound per square inch, and it is now capable only of window breakage and other minor damage. Closer in, however, it has left a region of increasing destruction toward ground zero. Buildings are damaged or destroyed, utilities disrupted, and debris hurled into the streets. People with insufficient protection have been killed or injured. This height of burst maximizes the range, 2.1 miles, to which 10 psi overpressure extends for a 500 KT burst.

The destructive potential of the blast wave will generate most of the need for structural and equipment repair and rehabilitation following attack. The character of this damage will be described later in this chapter. But first, we will concentrate on the survival of people, since the most important part of the nuclear defense mission is the saving of lives.

PANEL 1



PANEL 1

SURVIVAL IN ORDINARY BUILDINGS

The planner will be concerned primarily with the use of ordinary buildings, such as those identified in the National Facility Survey (NFS), and residences as shelter for the population. The best available protection should be used to shelter the population in a particular community.

In areas potentially subject to direct effects, more than just fallout protection should govern the selection of "best available shelter space." A first approximation of the relative protection afforded by buildings is shown here. Blast survival is better in most basements (belowground) than it is aboveground. In particular, people are expected to survive closer in to the detonation (at a higher overpressure) in home basements than in the aboveground floors of NFS buildings identified as having adequate fallout shelter. Where home basements exist, they deserve special consideration in the development of community shelter use plans.

An indication of the life-saving potential of intensive use of basements for shelter was referred to in chapter 1. It will be recalled that a series of attacks on the Detroit urban area was described. For the heaviest attack--nine 5-MT ground bursts--somewhat less than 35 percent of the population survived the blast effects. The calculation was based on an median lethal overpressure (MLOP) of 6.5 psi, generally typical of aboveground locations. When the calculation was repeated, assuming that all the people were sheltered in the best basements, the blast survivors increased to 56 percent.

The information shown here is approximate. Some basements offer no more blast protection than aboveground space. To see why this is so, we need to understand some key characteristics of the blast wave and how it damages buildings and people. We will be concerned with the "lower overpressure" region of the blast area where overpressures do not exceed, say, 20 psi. Closer in to a detonation, (say the 100's of psi region) the blast characteristics are more complex than described here, but they are of primary interest to the designers of high performance, blast hardened structures (e.g., missile silos) and not to emergency planners.

PANEL 2

BLAST PROTECTION IN CONVENTIONAL BUILDINGS

	Median Lethal Overpressure*	
Location	Residences	NFS Buildings
Aboveground	5 psi	5-8 psi
Belowground	10 psi	5-10 psi

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*The median lethal overpressure is that blast overpressure at which 50 percent of the occupants may be expected to be fatally injured.

PANEL 2

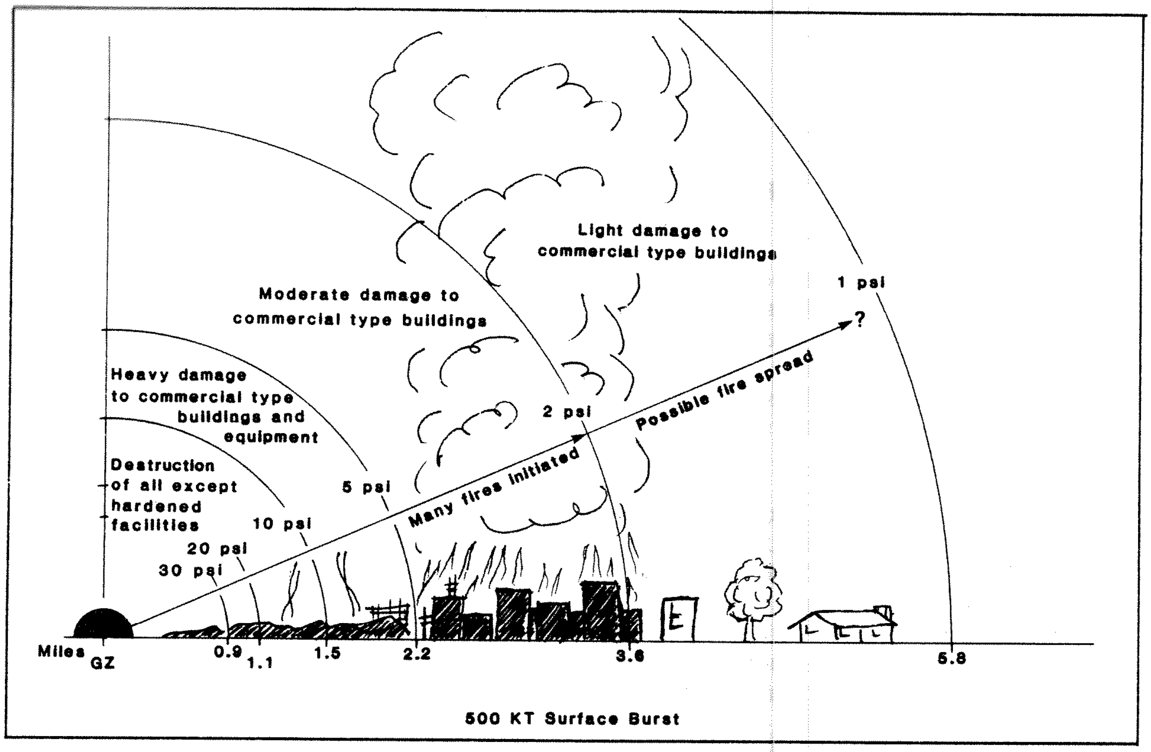
THE IMPORTANCE OF "LOW" OVERPRESSURE

The fact that nuclear defense planning is largely concerned with the low overpressure region of the direct effects area should not be interpreted as concern for only a small part of the area affected by blast. Quite the contrary, most of the direct effects area is subject to "low" overpressures.

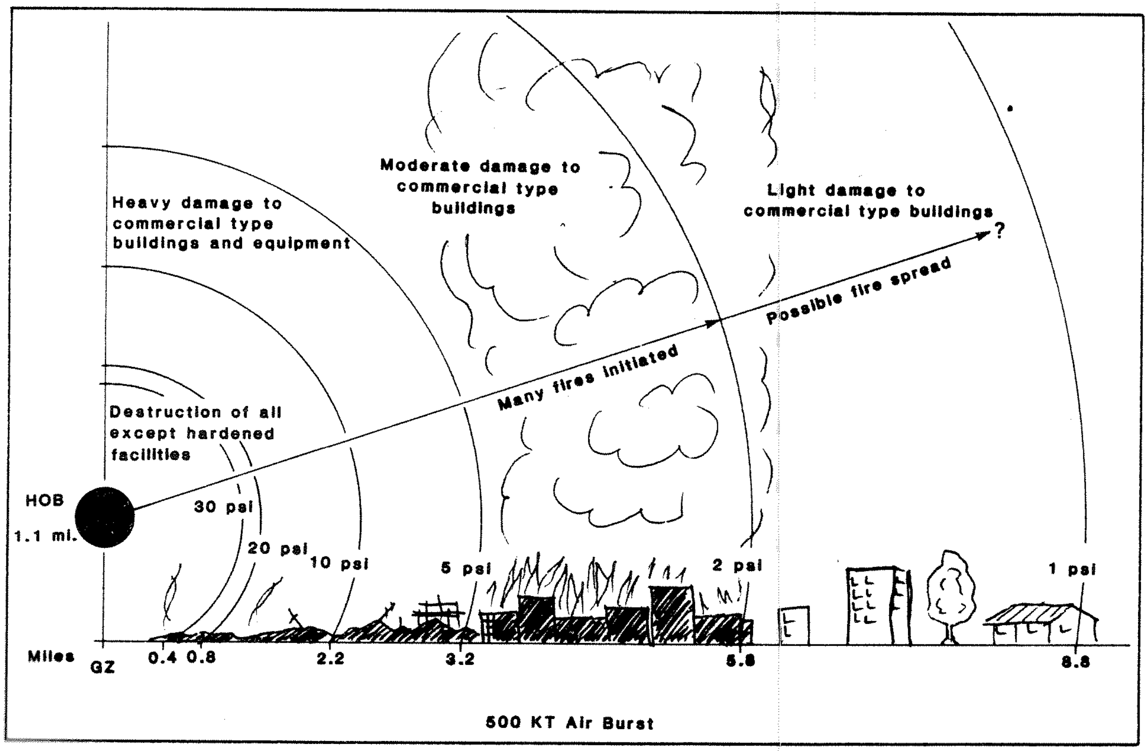
The sketch shows the various levels of damage to be expected at different distances from a 500 KT air burst. The height of burst (HOB) is 1.1 miles. This HOB is such as to maximize the ground range at which 10 psi overpressure occurs and is called the optimum height of burst (OHOB) for 10 psi. While light damage to commercial buildings extends out to 8.8 miles from ground zero (GZ) where the overpressure is only one psi, heavy damage on the verge of total destruction extends only to 2.2 miles. It is known that there were many survivors in Hiroshima and Nagasaki even in regions where heavy damage occurred. Furthermore, in this region lying between 1 and 10 psi, survival was considerably enhanced for people in the stronger buildings and the stronger parts of the buildings. Since this region comprises nearly 95% of the total area significantly affected by the blast, it is clear that nuclear defense measures can be very effective in improving survival in the "low" overpressure regions.

The implication for emergency planning is that intelligent use of best available shelter can ensure improved chances for survival.

EFFECTS OF 500 KT BURSTS



500 KT Surface Burst



500 KT Air Burst

PANEL 3

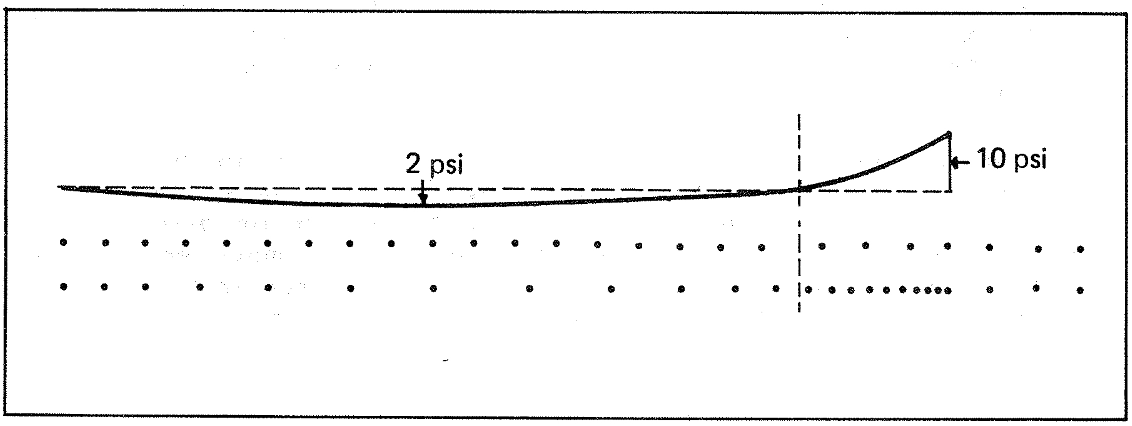
WHAT THE BLAST WAVE IS

When a nuclear weapon explodes in the atmosphere, the air surrounding the detonation point is rapidly compressed and forced outward, initially at speeds much higher than the speed of sound. A blast or shock wave is created whenever air is suddenly forced to move very rapidly. Commonly observed but very weak shock waves are those created when the end of a whip is snapped to supersonic velocities or when a supersonic jet aircraft creates a "sonic boom."

As the blast wave expands, it encompasses an ever greater volume of space. The peak pressure at the leading edge of the wave (commonly called the shock front) continuously decreases as it expands outward and the speed of expansion slows down. (The amount by which this pressure exceeds normal atmospheric pressure is known as the overpressure.) At great distances from a nuclear detonation, the shock front velocity slows to the speed of sound (about 1,100 feet per second or 750 miles per hour). At this point, the shock front disappears and the disturbances become an ordinary sound wave--a "boom."

A schematic illustration of the blast wave is shown here. The upper row of dots represents a row of undisturbed air molecules. As undisturbed air is overtaken by the shock front, the air molecules are jammed up into the leading edge of the wave and carried along for a bit, as shown by the lower row of dots. It is this compression of the air in the shock wave that produces the overpressure. The jammed-up air molecules never reach the speed with which the blast wave is expanding and gradually fall behind the shock front. Because of the violent outward movement, however, at some distance behind the wave front, the air becomes thinner than normal; and the pressure is less than atmospheric, indicted by the vertical dashed line in the sketch. The overpressure behind the shock front in the low to moderate overpressure region falls off to an "underpressure" about one-fifth the overpressure at the shock front. The air behind the shock front eventually begins to flow back into the low-pressure region to restore the normal atmospheric pressure.

The overpressure part of the blast wave is called the "positive phase"; the underpressure part, the "negative phase". Since the negative phase contributes little to casualties and destruction, the planner need not be concerned with it.



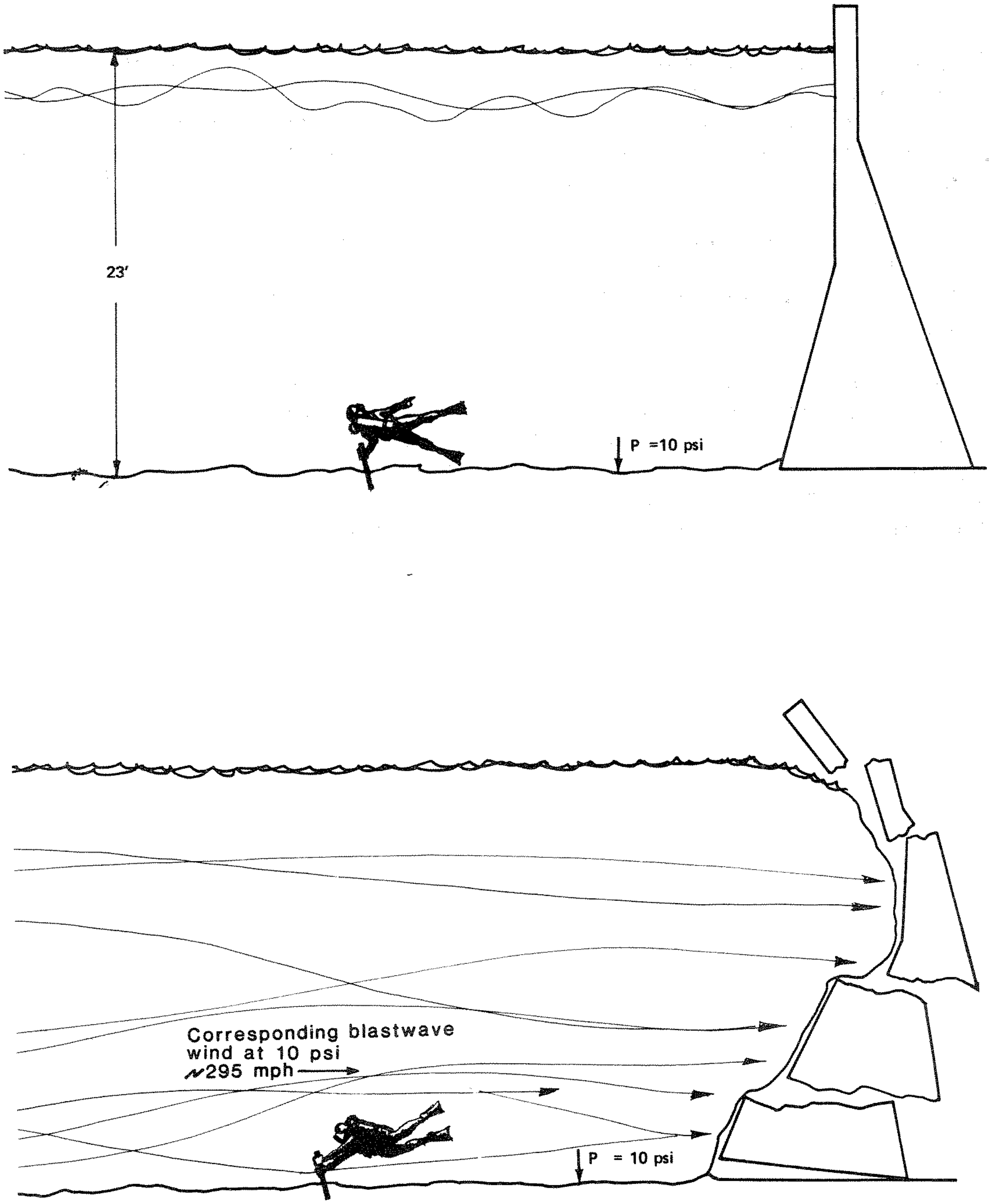
PANEL 4

A DAM ANALOGY

People are so accustomed to the world around them that they are not aware that they are being pressed in by the weight of the atmosphere, about 15 pounds per square inch at sea level. Nevertheless, the pressure is real. In the upper picture, we see a diver holding to an anchor at the bottom of a reservoir 23 feet deep. At that depth, the weight of water above him exerts an overpressure of about 10 psi above atmospheric pressure and he would be aware of it. Obviously, the sudden onset of a 10 psi pressure from a blast wave is much more critical than the gradual acclimitation to the 10 psi pressure the diver experiences when he dives to the depth of 23 feet.

If the dam were suddenly to fail, as in the lower figure, he remains under the pressure of 23 feet of water, but now the water begins to move and tends to tear him from his anchor point. In an air blast wave, this "tearing force" is a wind produced by the outward movement of the air molecules. At an overpressure of 10 psi, the momentary wind velocity accompanying the shock front is about 295 miles an hour.

PANEL 5


23′
P =10 psi
Corresponding blastwave
wind at 10 psi
~295 mph
P = 10 psi

PANEL 5

RELATIONSHIP OF BLAST WIND TO OVERPRESSURE

It will be seen that both the overpressure in the blast wave and the blast wind are important causes of damage and casualties. This table shows the relationship between the two. All buildings will suffer light damage at about 1 psi peak overpressure--shattered windows, doors damaged or blown off hinges, and interior partitions cracked. The maximum blast wind velocity would be about 35 miles per hour. As the overpressure increases, so does the blast wind, exceeding hurricane velocities above about 2 psi.

The most significant difference between the blast effects of kiloton-yield weapons and megaton-yield weapons is the length of time that the overpressure and blast wind persist. For low kiloton-yield detonations, such as those at Hiroshima, Nagasaki, and many at the Nevada Test site, the duration in the low overpressure, say 5 psi, region is about 1 second. For detonations in the one-half megaton-yield range, the duration is about 3 seconds. (Actually, the duration of the positive phase varies as the cube root of the yield; the blast wave for a 1-MT detonation lasts about four times as long as that for a 20 KT explosion.)

This change in duration is most significant for the blast wind gust. To get an idea of the significance, clap your hands twice, 1 second apart. Then, using the 1001, 1002 procedure for counting at 1 second intervals, clap your hands 3 seconds apart. Imagine the sort of winds shown on this chart persisting for several seconds. Of course, as the overpressure behind the shock front falls off, the blast wind lessens accordingly.

PANEL 6

BLAST WAVE CHARACTERISTICS

(Surface Burst)

Peak Overpressure (psi)	Wind Velocity (mph)	Wind Duration for 500 KT Burst (sec)
1	35	4.4
2	70	3.9
5	165	3.2
10	295	2.8
20	500	2.7
30	670	1.6

PANEL 6

EFFECTS ON PEOPLE IN THE OPEN

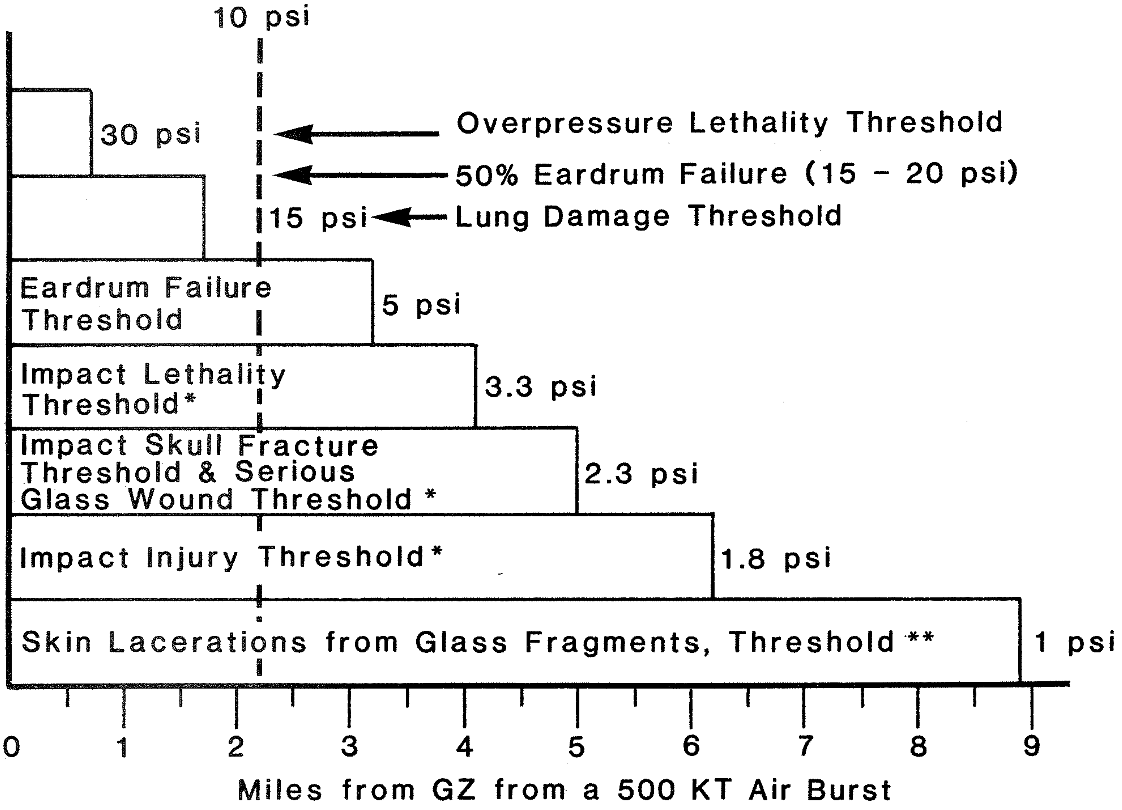
Consider a man standing in the open at a distance of two and one-fifth miles from the detonation of a 500 KT air burst. The shock wave would arrive at his location about 8 seconds after the detonation. He would first feel the sharp "air slap" as the shock front strikes. He would be enveloped in less than a thousandth of a second. He would then feel a 10 psi overpressure over his body. As can be seen from the chart, this pressure would be too low to cause death or lung damage. He might experience a perforated eardrum although 20 psi would be required to make this likely. Eardrum failure has been recorded, however, at overpressures as low as 5 psi.

In addition to overpressure, the man would experience a blast wind of about 295 miles per hour for about 3 seconds. This wind would blow him through the air for a considerable distance. When he struck the ground or another object, he would likely sustain injury and, possibly a fatal injury. If there were structures nearby, he might also be injured by flying fragments of glass or other debris.

The implication of the chart is that it is the bodily displacement and missile hazard created by the blast wind that causes most injury and death, not the overpressure itself. The overpressure, however, can break up buildings, creating the missiles that might cause injury. Ignoring for the moment, the other direct effects of a nuclear weapon explosion, very generally, people outside in the open in a residential area have about the same chance of surviving the blast wave as they would in a frame residence.

The information shown here comprises a small part of the great amount of data that exists from animal experiments, accident statistics, and weapons tests for specific injuries and causes of death.

BLAST INJURY THRESHOLDS IN THE OPEN



*For impact injury or death to occur at stated overpressure, the body must be thrown at least 10 feet before impact. Otherwise, a higher overpressure is required to achieve necessary velocity.

**Glass fragments must also travel at least 10 feet.

Source: Reference 7

DAMAGE TO BUILDINGS

We have concluded that people are mainly affected by the winds accompanying the blast wave. People are so quickly engulfed by the shock front that there is little time for the overpressure to act on the near side before it is also acting on the far side. Being relatively noncrushable, people react mainly to the wind. There are structures, such as telephone poles, smoke stacks, and radio towers that behave the same way.

Buildings, however, are large enough that the overpressure acts on the facing side before it can act on the other sides. Buildings are therefore affected by both the overpressure and the blast wind. These views show the effects of blast from a 47 KT weapon on a brick test house, as seen from the rear. In the first picture, the blast front has just struck the far side of the house and is spilling around the structure. The overpressure in the shock front is about 3 psi, but the load on the building face at this time is about doubled because the blast wave is reflected and thus reinforced. Damage is occurring to roof panels.

The situation 0.6 of a second later is shown in the second picture. Light roofing panels are being hurled by the blast wind, which had a maximum velocity of about 100 miles per hour. The roof framing is lifted nearly vertically by the wind force. At 1 second after blast wave arrival (third picture), the positive phase is over, the roof rafters have moved back into place, and roof panels are falling to the ground.

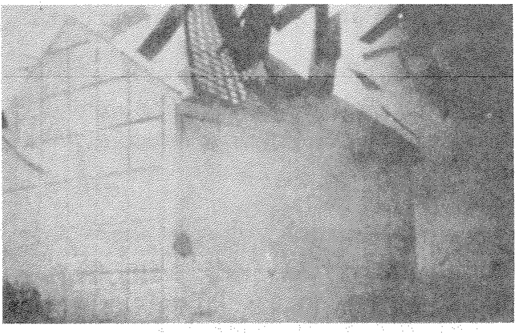
The final picture shows a front view of the house after the test. The roof has collapsed but the main brick structure appears to be in fair condition. It was estimated that this structure suffered 10 percent damage. It should be noted that this test structure represented a kind of masonry construction considerably stronger than ordinary U.S. houses.

Is this test representative of what we might expect at 3 psi from a 500 KT yield? The answer is no. For a 500 KT detonation, the positive phase of the blast wave lasts about twice as long as in this test. Not only would we expect the roof panels to be thrown farther but the entire roof structure would probably have been removed.

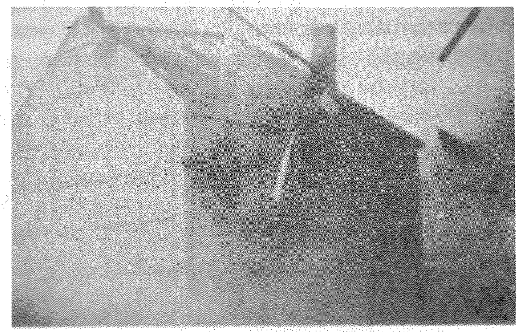
It is an unfortunate fact that past weapons test programs have yielded almost no direct data on blast damage to conventional buildings for explosions in the yield range of hundreds of kilotons. To remedy this lack of information, theoretical analyses have had to be supported by blast tests of a nonnuclear variety.

PANEL 8

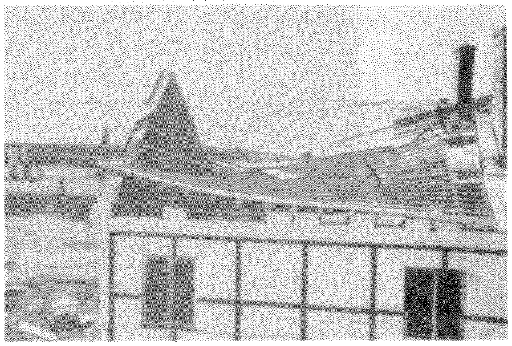
Impact



Impact + 0.6 second



Impact + 1.0 second



Afterward

PANEL 8

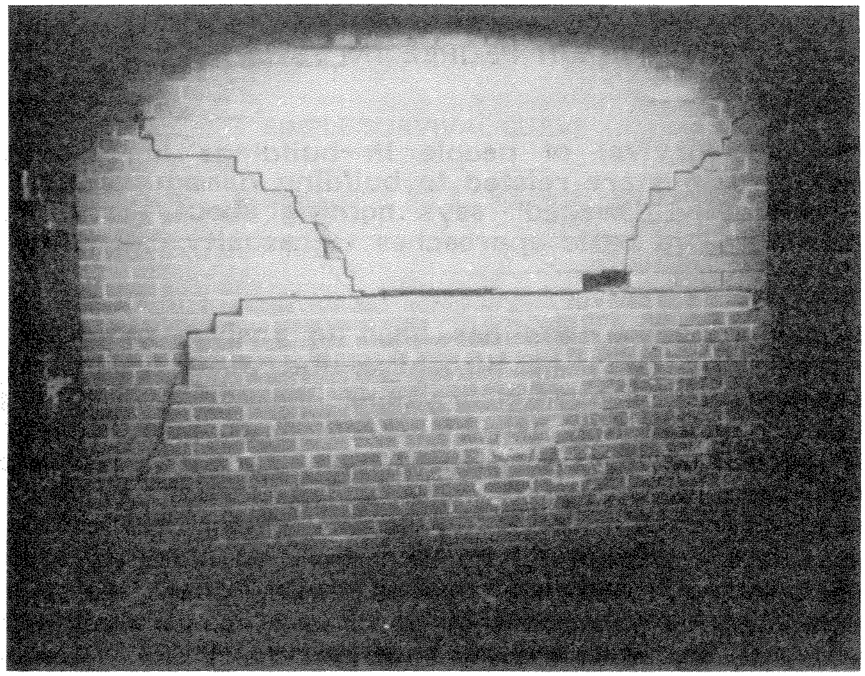
A TYPICAL BLAST EXPERIMENT

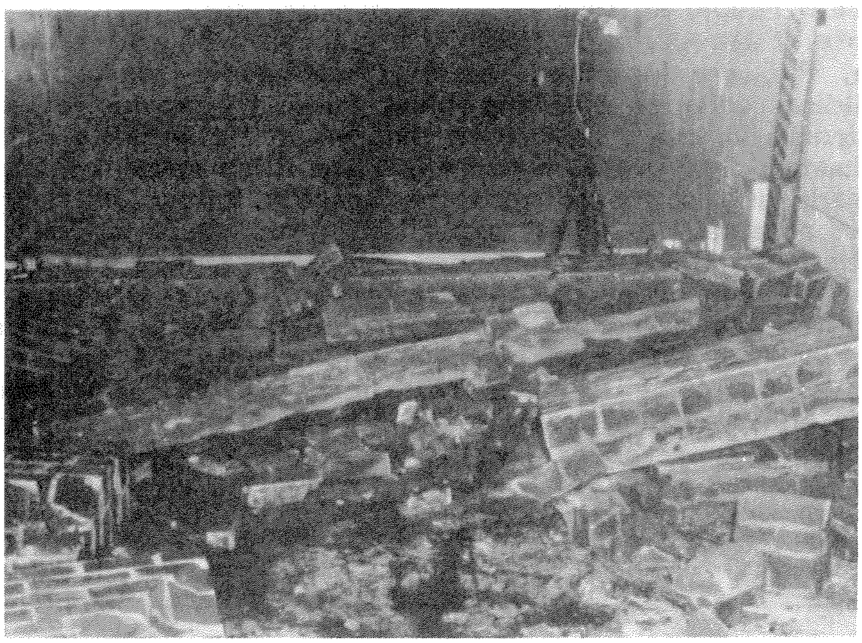
For over a decade and a half, FEMA and its predecessor agencies investigated the way walls fail under blast loading in a "blast tunnel" that permitted one to duplicate the long-duration peak overpressure load caused by nuclear detonations in the yield range of 100's of kilotons. Two typical results are shown here.

The upper figure shows a brick wall that is on the point of "incipient collapse" after blast loading. The wall failed horizontally near the middle of the wall. The peak overpressure in this test was about 1 1/2 psi.

The lower figure shows a similar brick wall after exposure to 3 psi overpressure. The wall has been thrown many yards down the tunnel, breaking into many small pieces in the process.

These tests have given good information on the overpressures required to cause various types of walls to fail and have shown how the size of the pieces vary with the incident overpressure. The particular walls tested here are typical of relatively weak masonry walls, often found in single-story commercial buildings and residences. Their weakness stems from the fact that they are not locked into a stronger frame at their edges. In some types of buildings (those having "arched" walls), the brick walls are held rigidly in a surrounding frame. Both full scale nuclear tests and tunnel tests have shown that, in many cases, these arching walls will withstand several times as much overpressure as will the nonarching types, even though they are no thicker than those shown here. The strength of both types of walls are also affected by the manner in which they are constructed. If, for example, an arching wall is not firmly mortared into the frame, its strength will be greatly reduced. It usually requires a person familiar with building construction and some special training to distinguish "weak" masonry walls from "strong" masonry walls.





PANEL 9

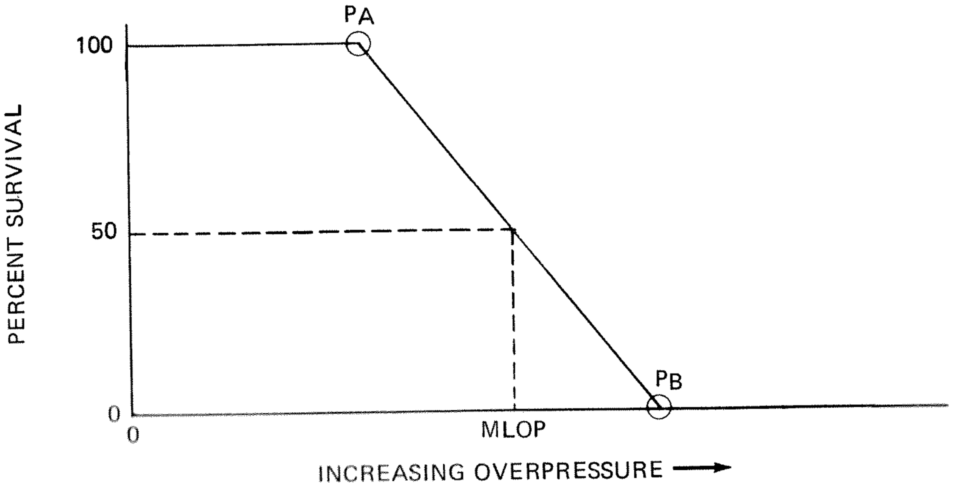
EFFECTS ON PEOPLE IN BUILDINGS

Estimating the survival of people in buildings has been a difficult problem. Blast casualties are related to building damage, but to describe a building as "moderately damaged" says nothing about the survivability of the people therein. Two basic approaches to casualty estimation have been tried.

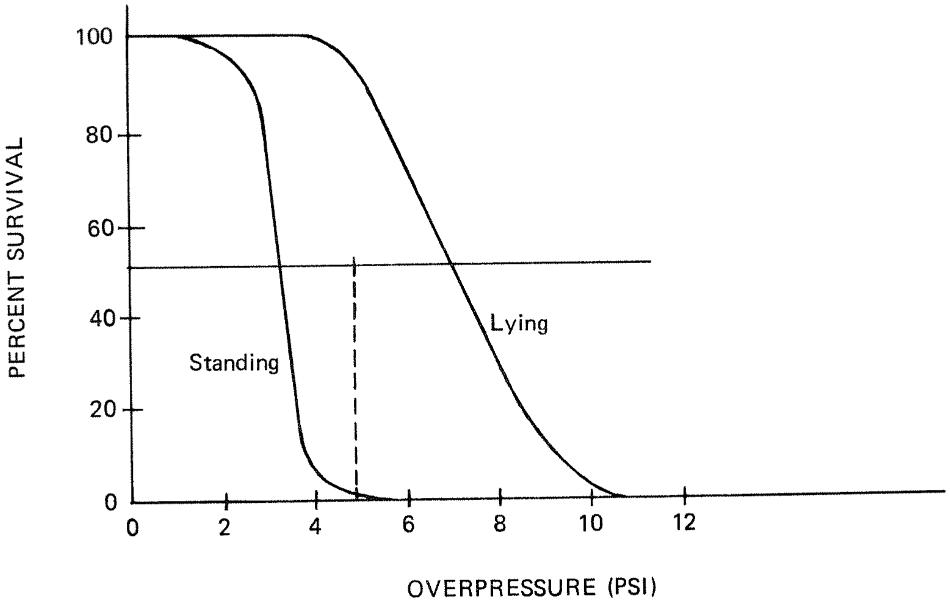
The first and oldest method has been to analyze carefully what happened to people in buildings at Hiroshima and Nagasaki in an attempt to estimate what would have happened to people in American buildings damaged by weapons with yields in the 100's of kilotons. Thousands of detailed case histories have been studied. One difficulty has been to separate the blast casualties from casualties due to other effects, such as fire and initial radiation (see chapter 3 and 5). A second and more difficult problem has been to extrapolate the results to the long-duration blast wave of the larger weapons. The first problem has proved easier than the second. The results are now suspect because they tend to give survival estimates that are inconsistent with the blast experiments just described. Longer duration loading not only propels debris farther but also acts on people for longer periods and, thus, creates a more severe environment.

The newer approach has been to break the casualty-producing mechanism into its constituent parts. The survival curve, in its simplest form, is shown here. People survive up to an overpressure, P_A, where the wall, for example, is at the point of "incipient collapse," shown in panel 9. The overpressure, P_B, on the other hand, is well above the overpressure for complete building collapse and the blast wind is capable of accelerating people and debris to impact velocities that would be lethal. To arrive at a survival estimate, careful calculations of the displacement of people and debris are made and compared with the specific injury and mortality data that has been obtained in animal experiments, at weapons tests, and from accident statistics. When we indicated in panel 2 that the median lethal overpressure (MLOP) for people in aboveground parts of residences was 5 psi, the estimate was based on this type of calculation. Note in the lower sketch that 5 psi represents an average vulnerability. People standing are more vulnerable; people lying down are less vulnerable. These curves were derived for a one megaton burst. The curves would be displaced toward somewhat higher overpressure for the lower weapon yields treated in this chapter.

SIMPLE SURVIVAL CURVE



SURVIVAL ABOVE GROUND IN WOOD FRAME HOUSE



PANEL 10

PROTECTIVE ACTIONS

The newer method of casualty estimation can show the value of protective positions on the part of people. For example, it requires about eight times the blast wind force to move a person who is lying down compared to a standing person. People crouched or lying down also offer a much poorer target to glass shards and debris missiles.

These people are practicing a good protective posture to improve blast survival. Lying down would be even better. Calculations show that the median lethal overpressure (MLOP) in aboveground areas can be increased by 2 or more psi by these protective actions. The planner should recognize that a change in vulnerability of this magnitude can save many lives.

For persons outside at the time of a nuclear explosion and at locations beyond the range of lethal initial nuclear radiation (chapter 5) or serious thermal pulse (chapter 3), fast action could reduce the hazards of damage from the overpressure (and to some extent thermal burns). A deep trench or properly oriented culvert can supply some protection from the overpressure as well as significant protection from blast winds. Avoid the inside of an automobile where the thermal pulse and flying glass could be hazards.

Photograph courtesy of The News-Virginian, Waynesboro, Virginia.

BLAST PROTECTION IN HOME BASEMENTS

Survival in residential basements is estimated to be much higher than aboveground. As shown in the upper sketch, the first floor will provide protection for basement occupants at low overpressures where windows, doors, and interior partitions will fail and present missile hazards from above. The blast wind would range up to 70 miles per hour.

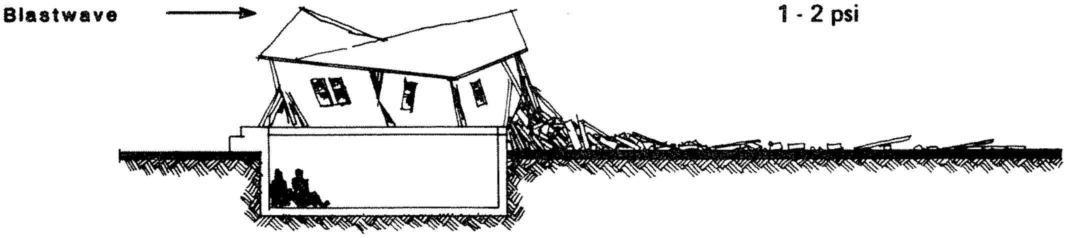
At higher overpressures, the first floor would be pushed down into the basement. As shown in the middle sketch, much of the debris formed by the house would be blown from above the basement. Voids would be formed by the broken first floor permitting survival along the walls. This intermediate condition might present the most hazard to people in the basement.

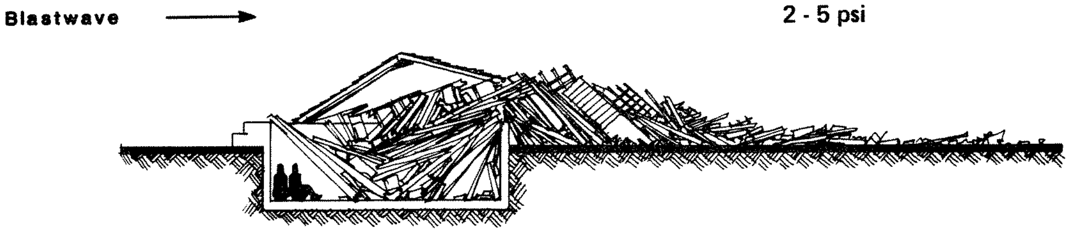
The lower sketch shows that, as the overpressure and blast wind increase, the whole house, including the first floor, would be blown clear of the basement. Survival might be higher than in the intermediate case. Debris from other buildings could fall into the open basement, and, as blast winds increased above 300 miles an hour, basement dwellers could be ejected from the basement. Our best guess is that the MLOP might be 10 psi under these circumstances, but there is no definite evidence. The estimate is probably low rather than high.

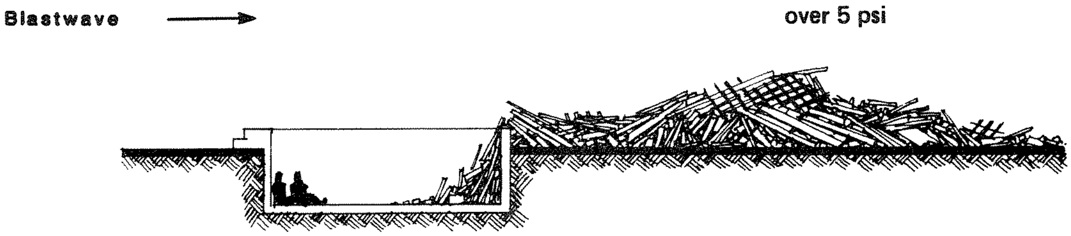
Those people who wish to do so have many options for improving their protection in their homes. These are described in FEMA publications, e.g., H-20, "Protection in the Nuclear Age," June 1985.

PANEL 12

HOME BASEMENT SHELTER







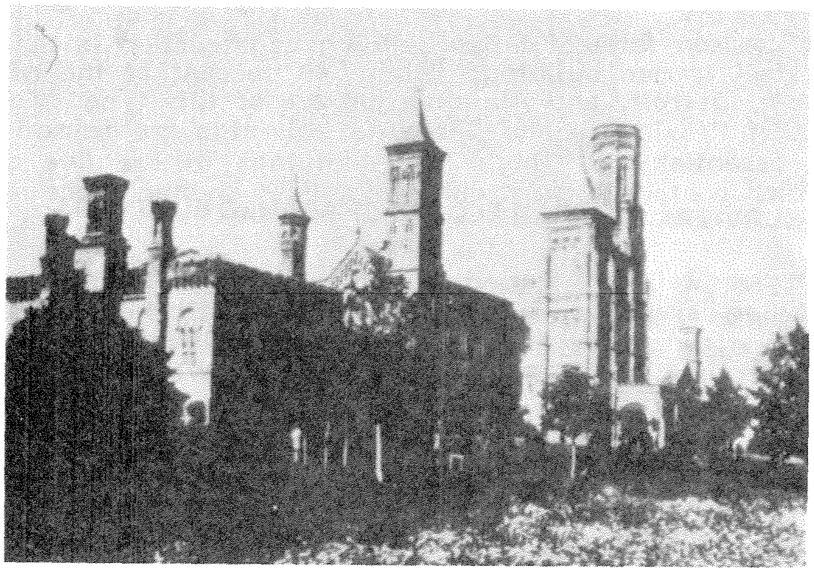
PANEL 12

SURVIVAL IN LOAD-BEARING WALL BUILDINGS

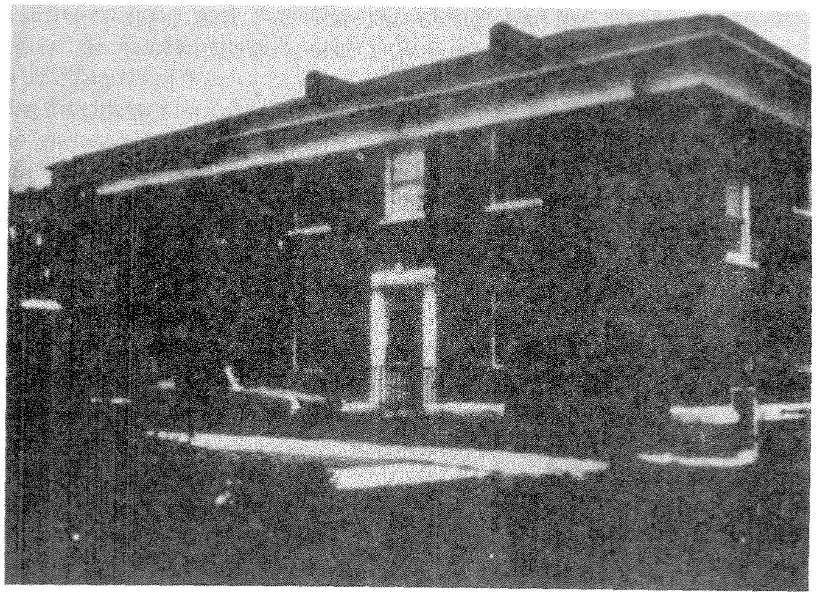
Although the National Facility Survey (NFS) was not directed toward protection against direct effects, considerable information was gained on the structural characteristics of most large buildings in the United States. Additionally, a special statistical sample of NFS buildings in five cities has been studied in great detail as part of a research program to develop an all-effects survey. The five cities--Providence (RI), New Orleans (LA), Detroit (MI), Albuquerque (NM), and San Jose (CA)--were chosen to exhibit a full range of regional and other urban characteristics.

Many NFS buildings have continuous masonry walls and partitions from the foundation to the roof. In these buildings, the floors are commonly supported by the walls that may resist overpressures of 10 psi or more. People lying near the exterior walls of the aboveground floors of such buildings would have better shelter than those in aboveground floors of most steel and concrete framed buildings. An example of a monumental-type structure is shown in the upper picture.

Most brick or masonry load-bearing wall buildings have little resistance to the lateral forces of overpressure and blast wind. The bearing walls tend to crack at about 2 psi, with collapse likely at 6 psi. The collapse of the exterior bearing walls results in collapse of most of the structure that is supporting them. Since the masonry debris is heavy, it is not thrown far by the blast wind gust. It is unlikely that the floor over the basement would be able to withstand the combined effects of the overpressure and the falling debris. Survival is about the same both aboveground and belowground in this type of building. Thus, except for monumental-type buildings, basements in load-bearing wall buildings are not much better than upper floors as protection against blast. A typical weak-walled brick apartment house is shown in the lower picture.



EXAMPLE OF MONUMENTAL MASONRY BUILDING



EXAMPLE OF WEAK LOAD-BEARING WALL BUILDING

PANEL 13

SURVIVAL ON UPPER FLOORS OF FRAMED BUILDINGS

Another common form of large building construction is the reinforced-concrete or steel framed building. About 40 percent of the NFS buildings in New Orleans, Detroit, and Albuquerque are of this type. Only about 20 to 25 percent of Providence and San Jose buildings are framed structures. Nonetheless, essentially all "high-rise" buildings in the five cities are of this type, which contain large amounts of fallout shelter space on the upper floors.

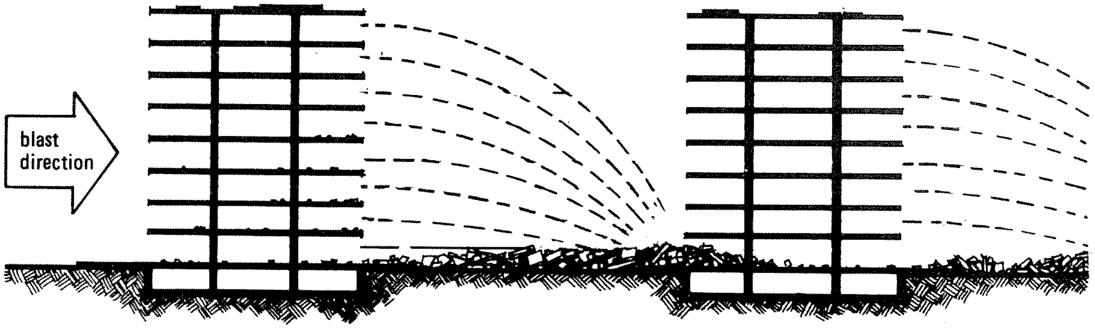
The exterior walls of framed buildings tend to be either very weak (2-3 psi), being simply mounted on supports attached to the building frame, or fairly strong (say 7-10 psi), actually built into the building frame to create an "arching" wall. In any event, at overpressures lower than those that would fracture the weaker walls, people lying near the exterior walls would likely escape both flying glass and the jet action of the blast wave as it pours through the windows.

Damage to interior partitions and suspended ceilings would progress until, at higher overpressures, the exterior walls would collapse. Depending on the size of the buildings and the strength of the blast wind, some or all of the contents of each floor would be ejected out the far side of the building and would fall to the street below. The upper sketch shows two 8-story framed buildings separated by a distance of 100 feet. At overpressures high enough to sweep out the aboveground stories (4 to 6 psi), the contents of each story would follow somewhat the paths shown. Survival would obviously depend on being below the fourth floor at the least.

At overpressures in excess of about 6 psi, the structural frame, which remains as a "drag-type" object, would be subject to collapse by the wind force. Failure would be as shown in the lower sketch. Note that, in a framed building, the basement does not receive a large debris load as is the case in the catastrophic collapse of a load-bearing wall building. Whether the basement suffers damage depends mainly on the ability of the first floor over the basement to withstand the blast overpressure.

For the stronger (arching) walled buildings the picture is not very clear. The overturning forces due to the blast winds are enormous if the exterior walls do not fail, so the failure is strongly dependent on the effective height of the building in relation to its width in the direction of blast travel. In general, the upper stories of strong walled buildings higher than three stories should be avoided as shelter from blast effects due to the uncertainty of their response to blast effects.

FRAMED BUILDING



PROTECTION IN BASEMENTS

As has been indicated, the basement areas of large buildings, particularly steel or reinforced-concrete framed structures, potentially offer significant protection against blast. The most important consideration in this respect is the strength of the ground floor directly above the basement. Other considerations are the nature of exterior openings into the basement (apertures), whether the basement walls extend above the ground level, and the location of nearby buildings.

The structural statistics shown indicate that from 40 to 70 percent of NFS buildings in the five city sample have no basement wall exposure. In other words, the floor above the basement is at ground level, a desirable situation. An even higher percentage, 60 to 90 percent, have no basement wall apertures. Entrances to the basement are internal to the buildings. This feature offers some advantages for blast protection but may complicate ventilation and access, particularly if the aboveground part of the building is damaged or demolished. About 40 to 70 percent of the buildings do not have common walls or immediately adjacent buildings. This means that these buildings are probably surrounded with streets, alleyways, or parking areas.

It goes without saying that a floor of wood or light steel framing above the basement offers little protection unless the structure above is wood frame or of other light construction. In that case, the protection is similar to that afforded by a home basement. Most ground floors are of reinforced concrete, supported by columns, pillars, or, occasionally, interior bearing walls. Typical live load limits on first floors range from 50 to 150 pounds per square foot. Most are less than 1 psi (144 pounds per square foot). Of course, large and usually unknown "factors of safety" enter into the floor design, which are intended to avoid any significant distortion. Major sagging, cracking, and distortion of the floor (generally described as heavy damage) on the other hand would not necessarily result in major casualties among building occupants.

Older buildings were generally built in ways that enhanced basement blast protection. Since World War II, however, flat slab construction has largely given way to flat plate construction--a construction technique that meets building codes but inherently exhibits considerably less blast resistance. It can be seen from the table that a majority of buildings in Providence, New Orleans, and Detroit were built before 1945. In the newer cities of the west, only about one-third are of prewar construction.

The main threat to basement occupants would be the collapse of the floor above due to the blast overpressure. Research shows that the slab can be made much more resistant to blast by spacing an array of posts in the basement between the floor and the slab over the basement as an expedient blast upgrading measure. However, the provision of adequate expedient blast closures, protection from initial nuclear radiation, and ventilation are technical problems for which adequate solutions have not yet been found.

SELECTED STATISTICS

Characteristics	Percentage of buildings with Characteristics				
	Providence	New Orleans	Detroit	Albuquerque	San Jose
Contains Basement	96	44	94	93	87
Framed Building	20	37	41	40	24
No Basement Wall Exposure	39	40	62	37	68
No Basement Wall Apertures	61	59	74	76	86
No Immediately Adjacent Buildings	72	44	37	73	47
Built Before 1945	51	73	82	27	36

PANEL 15

BEST BASEMENT SHELTERS

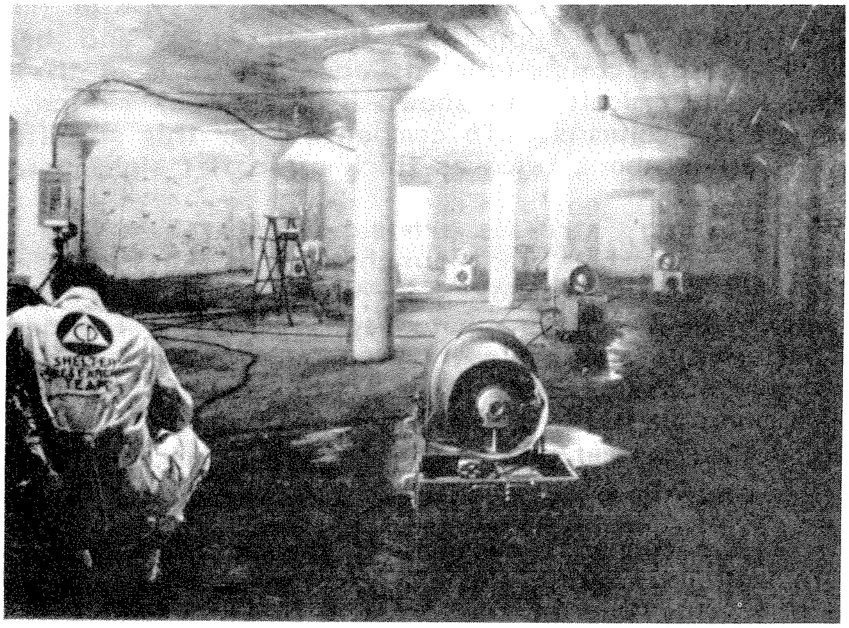
At the outset it should be stated that no conventional basements provide good blast shelter. However, some types are significantly better than others and, in the absence of blast shelters, offer the best chance for survival.

The strongest ground floors for blast survival in the basement were commonly used in framed buildings built between 1915 and 1950. One of the most readily recognizable of the better floors is shown in the upper photograph. In this type of construction generally called the "flat slab" type, the floor itself is 4 to 5 inches thick for a live load limit of 100 pounds per square foot. But the slab is thickened by 2 to 3 inches in the neighborhood of the supporting pillars to form a "drop panel." The top of each pillar or column is flared out into a "round capital."

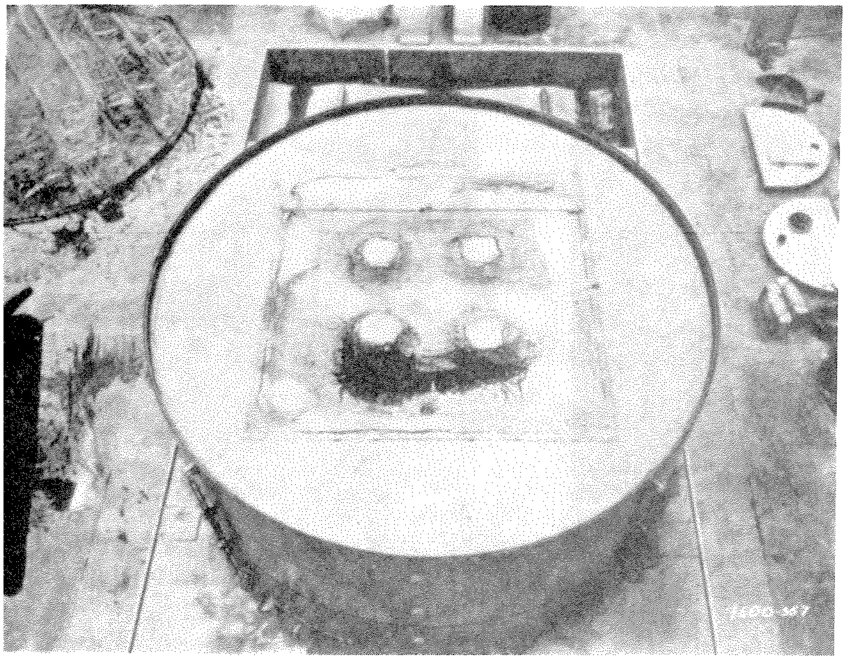
The merit of this type of construction is shown in the lower photograph. The slab undergoes a tremendous amount of deflection before breaking through. In general, the crushed concrete is held together by the reinforcing steel as it fails. The photograph shows the result of a test of this type of floor in the blast simulator at the U.S. Army Engineer Waterways Experiment Station. For the typical floor, this kind of failure might have occurred at about 10 psi. It can be seen that, although the floor is badly damaged, most of the people who might have been in the basement below would have survived.

Other types of flat slabs have columns with capitals but no drop panels or simple one- or two-way slabs spanning bearing walls or heavy girders. In general, basements under flat slabs offer the best shelter in conventional buildings.

FLAT SLAB FLOOR



UNDERSIDE OF FLAT SLAB



BLAST FAILURE OF FLAT SLAB

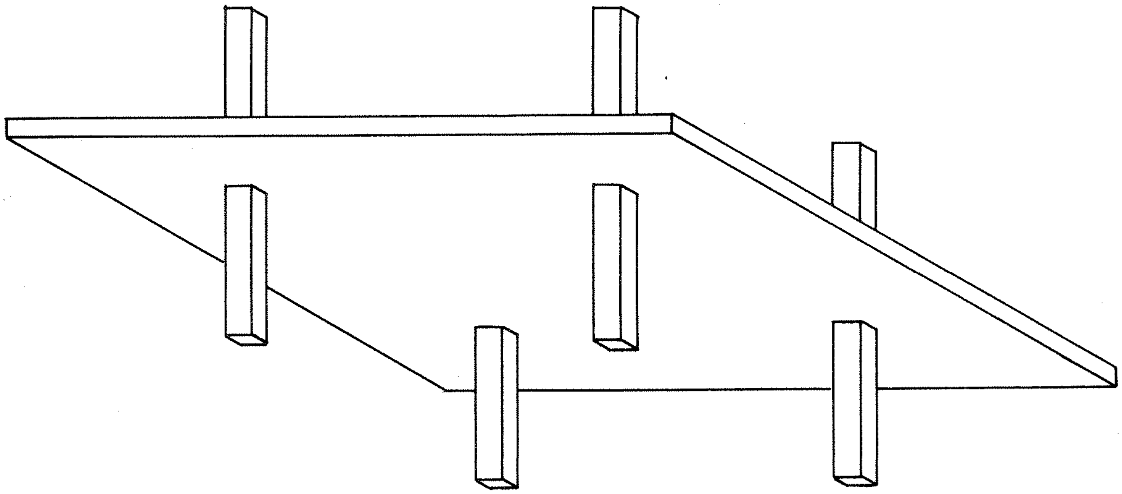
POOR BASEMENT SHELTERS

Since about 1950, and at an increasing rate, a type of floor construction called "flat plate" has supplanted the flat slab and beam types of construction. Flat plate construction is adequate to meet the design loads and is much more economical. As shown in the upper sketch, the floor is supported only at the columns. To compensate for this simplified construction, the floor itself is about as thick as in flat slab construction.

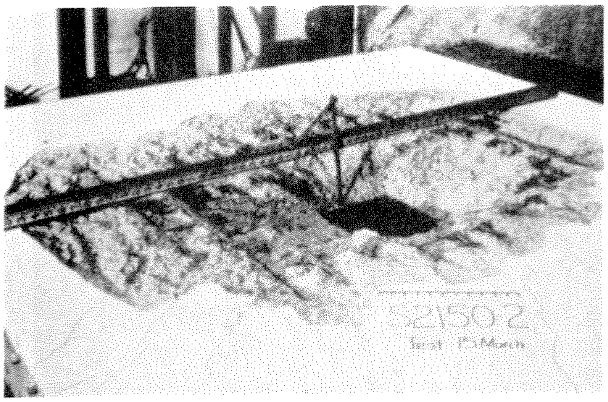
Under blast loading, stresses are set up that result in shear failure near the columns. The whole floor punches down into the basement, leaving a small portion at the top of the column. This catastrophic type of failure is shown in the two lower photographs. Failure is expected to occur at about 3-5 psi. While shelter in this type of basement is probably better than is most upper stories, this is one of the least blast-resistant types of basements. As poor as it is as protection from blast effects, it may have to be used since the thermal pulse must be avoided--even at overpressures as low as 3 psi.

Although only perhaps 10 percent of the basement space in the NFS inventory is in buildings using flat place construction, many of the newer buildings are built this way at the present time. Because they are new, your local building engineers probably have a good record of them.

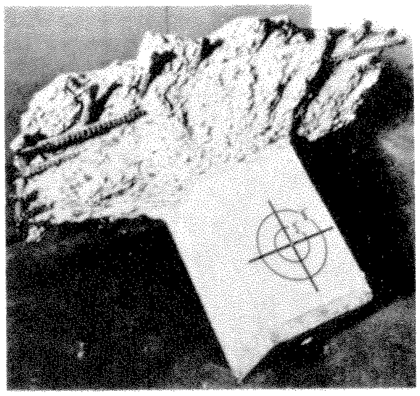
FLAT PLATE FLOOR



FLAT-PLATE SYSTEM



UPPERSIDE OF TEST FLOOR SHOWING FAILURE AREA



COLUMN AND FAILURE CONE

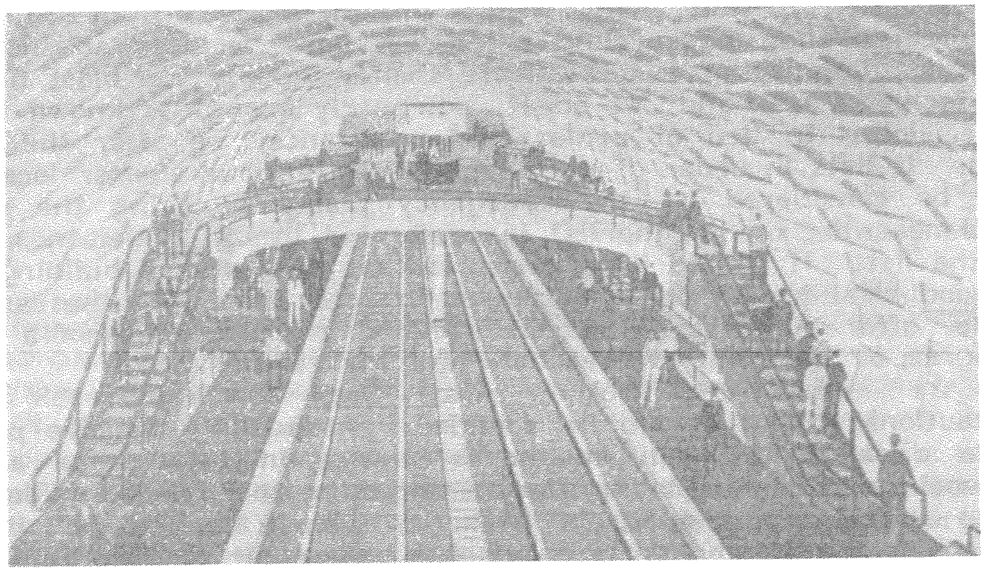
PANEL 17

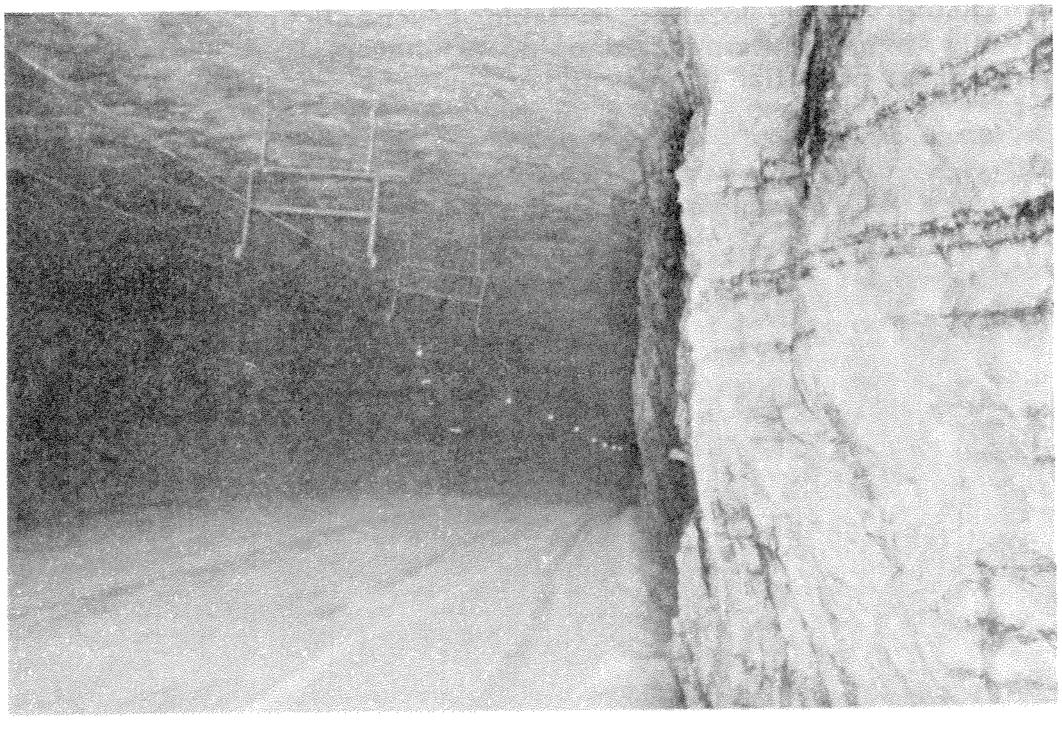
SUBWAYS, TUNNELS, MINES, AND CAVES

About 12 million fallout shelter spaces have been identified in underground areas other than buildings, both man-made and natural. Nearly all of these areas offer good blast protection as well. The Soviet Union has emphasized the use of subways as blast shelters in cities and has provided blast doors in the entrances to the subway station.

Most underground structures are stronger than building basements against blast loading. An analysis of a subway station built in Washington, D.C., indicated that structurally it could withstand an overpressure of 100 psi. However, the overpressure and dynamic pressure (blast wind) entering the shelter constituted a threat to the shelterees. It is estimated that the shelter as a whole is actually capable of providing only 30 to 40 psi protection. If blast doors and ventilation closures were provided, the subway shelter as a whole would be rated at 100 psi protection.

Underground subways and tunnels usually contain a large volume of air. When the blast wave enters through relatively small openings into a large-volume space, the blast wave overhead will pass by before the chamber has time to fill. This means that the pressure rise is relatively slow, which increases survival chances, and the overpressure inside may never reach the outside peak overpressure.





PANEL 18

BEST AVAILABLE BLAST SHELTER

The discussion to this point should provide some insight into how existing buildings and underground areas can best be used to increase blast survival. Identifying best available shelter against the blast hazard is a fairly technical task and, we admit, not nearly enough is known to do it with precision. In lieu of professional assistance, we offer the table shown here. It lists in order of survivability the various shelter locations that could be considered by the emergency planner. Using the space represented near the top of the list is preferable to using that near the bottom of the list. It should be emphasized that conventional buildings do not offer <u>good</u> blast protection but, if used in accordance with the ranking in the table, offer the best chance for survival in the absence of a blast shelter program or the ability to evacuate high risk areas.

One cautionary note should be sounded. Attempting to move people considerable distances to gain shelter is unwise in blast-prone areas. There may not be enough warning time. Increasing the population density in downtown areas is also a questionable tactic, even if the better shelter is there. The ideal movement plan is one that moves people as little as necessary and, in general, in the direction of the more sparsely populated parts of an urban area. Unfortunately, there is no easy way to compare the value of better shelter with the value of a more widely distributed population. Since even the work force is at home about 70 percent of the time, emphasis should be on locating suitable basement space close to where people live. An implication for planning is that residential basement space could be of great potential value.

RELATIVE BLAST PROTECTION

Description

1. Special facilities (Mine, Cavern, Cave, Tunnel, Subway, etc.)

2. Basement(s) of large structures where the basement overhead floor system is other than wood, flat plate, or flat beam.

3. Basement(s) of wood frame and/or brick veneer structures. Includes residences.

4. First story, second and third story of "strong walled" structures and no single story has a "side" with 50% or more apertures. For buildings with three or less stories, the topmost story is automatically eliminated.

5. Basement(s) of structures where the basement overhead floor system is flat plate or slab supported by a flat beam.

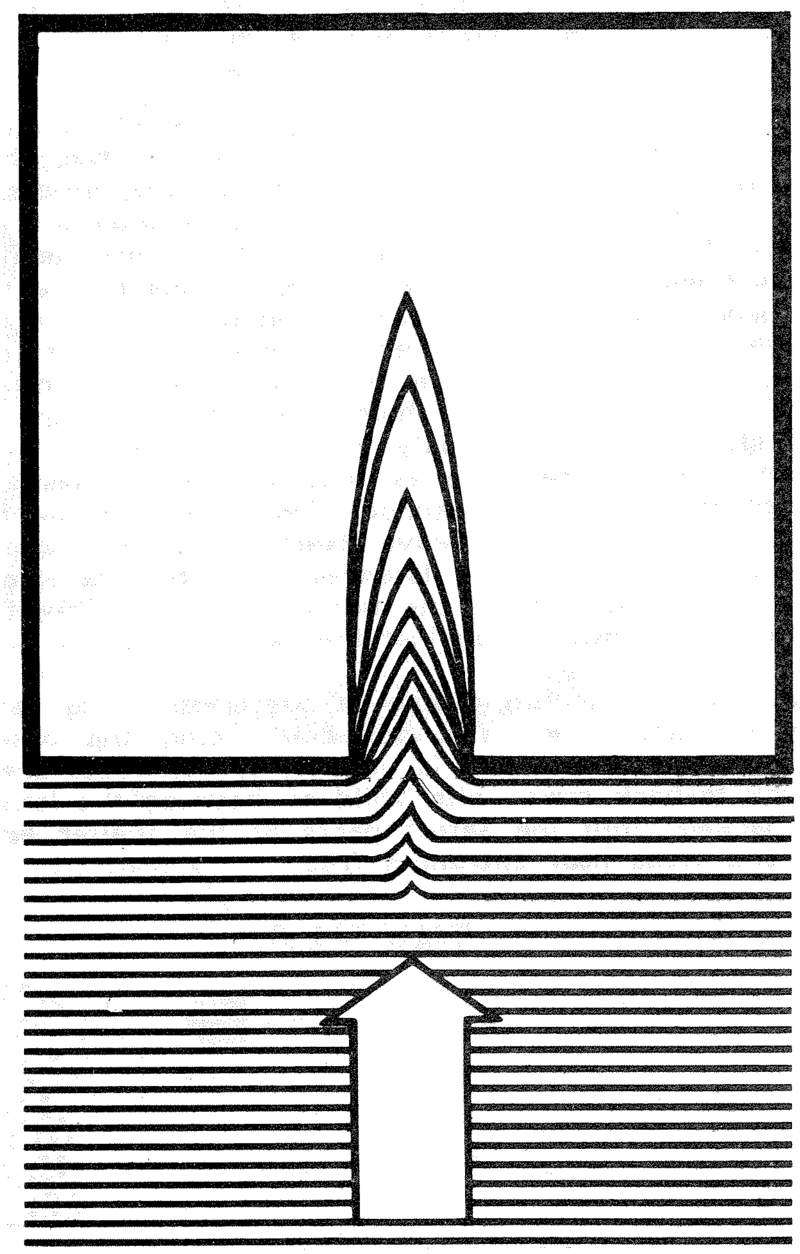
6. Upper stories of wood frame structure, or structures with weak exterior walls, or excessive apertures.

PROTECTIVE POSTURE FOR BLAST SURVIVAL

As noted previously, being thrown by the blast wind is the main source of injury and death in aboveground locations. Lying down rather than standing up is the preferred protective posture and would save many lives.

In basement areas, the hazard situation is somewhat different. People in basements will be subjected to severe wind forces only for as long as it takes the blast overpressure to fill the basement volume. The blast wave would enter through stairways, ventilation ducts, and other openings. In most basements, the filling process would be complete in several tenths of a second as compared to the several seconds of wind gust aboveground. In the vicinity of the major openings, however, the compressed air behind the shock front will rush into the shelter in the form of a high velocity air jet, as shown in the sketch.

The velocity in the jet can be sufficient to cause impact injury and death for a distance up to 10 times the width of the entranceway. Blast driven debris can also be very hazardous in this zone. In planning the use of basement areas, this hazard should be taken into account. The best location for people is near the exterior wall of the basement, out of the line of the entranceways. This location also takes advantage of the failure pattern of the ground floor over the basement. Since good basement space will usually be at a premium, people should be close-packed in a sitting position, with children sitting between the legs of adults. This protective posture can be maintained for several hours after the shelter is occupied. If people must be located in more hazardous areas, they should be encouraged to lie prone.



SHOCK WAVE

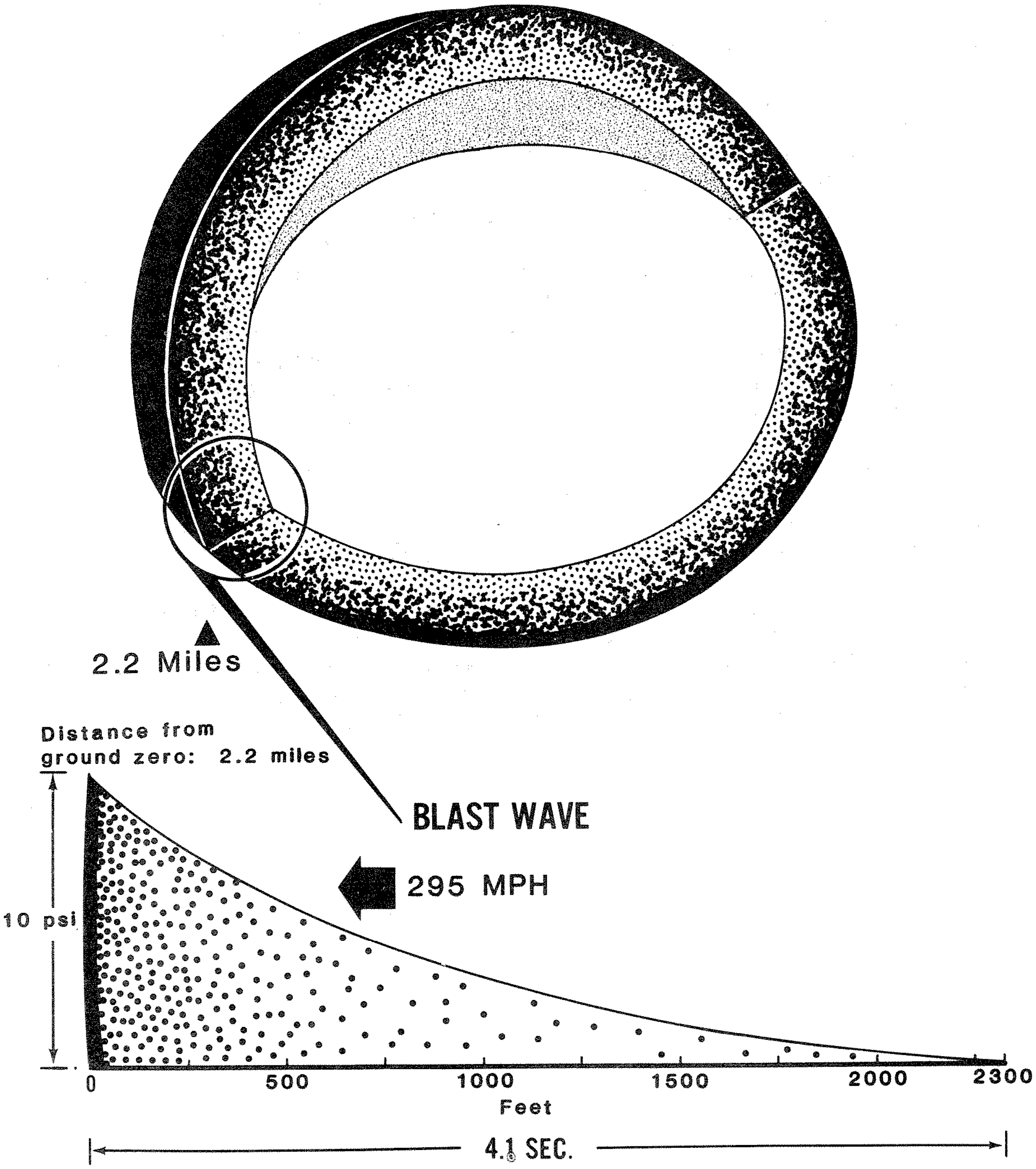
EFFECTS OF GROUND SHOCK ON PEOPLE

Up to now, we have ignored the pressure wave propagated through the earth by a nuclear detonation. The reason is that ground shock causes little damage in the "low overpressure" region with which emergency planners are concerned. However, the ground shock should be considered in positioning people in basements.

There are two sources of ground shock. Directly induced ground shock occurs only with a surface burst and derives from the fact that energy is transmitted directly into the ground in the process of crater formation. This direct shock decays rapidly as it expands outward into the ground. The second source of ground shock derives from the fact that the expanding air blast wave pushes down on the surface of the ground with great force and generates a ground pressure wave. This wave is generated by the blast wave regardless of whether it comes from a surface or an air burst. As shown in this sketch, the blast wave is pressing down on a circular band of ground nearly one half mile wide when the peak overpressure is 10 psi. It is continuously generating a wave in the ground that has a duration about the same as that of the air blast wave itself. This "air-induced" ground shock cannot affect aboveground portions of buildings as much as the air blast wave itself. But belowground portions can be moved suddenly for small distances, possibly causing injury to people if they are leaning against the basement wall. Therefore, people should be positioned near but not against the exterior wall.

A good plan for positioning people in basements is to have them sit back-to-back in a double row, with one row facing the basement wall. Injury through the soles of the feet is unlikely if the knees are bent. By using the two back-to-back rows, with children between the legs of adults, people can be "packed" into the safest parts of the shelter area, leaving the central area and areas near entrances free.

500 KT AIR BURST



PANEL 21

DAMAGE FROM GROUND SHOCK

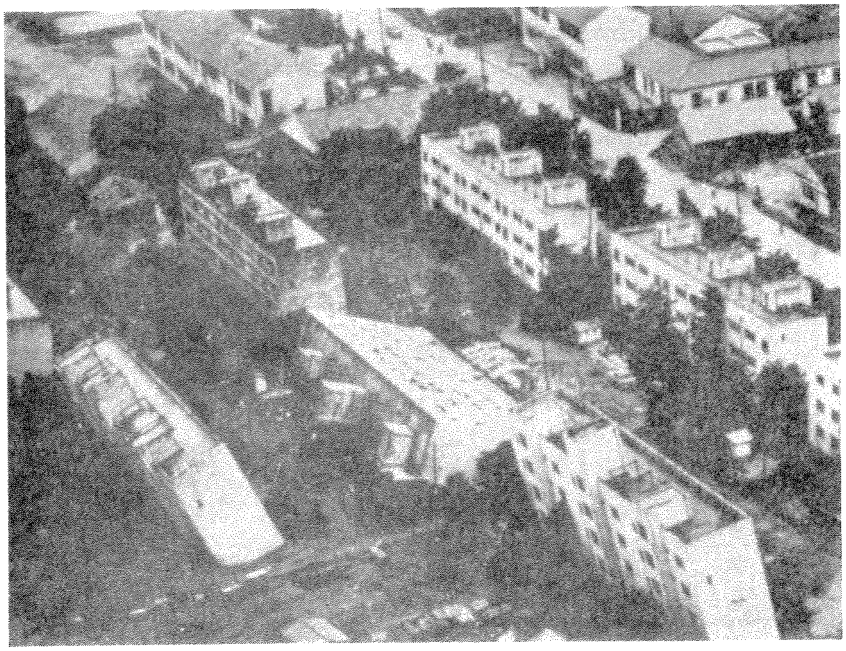
Air blast overpressure and the associated blast wind will cause most of the damage in the "low overpressure" region of interest to emergency planners. The ground motion produced by the passage of the blast wave will, however, have some consequences. The surface overpressure generates a compressive wave that travels through the soil. The differential motion of the soil can stress underground piping at joints and connections. The ground shock wave also compacts the soil. Differential settlement and soil "liquefaction" can occur in "poor" soils. Filled land and areas with a high water table are especially vulnerable.

Generally, underground piping will not be seriously disrupted below an overpressure of 10 to 15 psi. It must be remembered, however, that failure in buried piping occurs in peacetime from traffic loads and other causes, especially in older water, gas, and sewer systems. Therefore, sporadic failures are to be expected in lower overpressure areas. Breaks in water mains under streets can result from cave-ins as shown in the upper photograph. There is some similarity between earthquake damage and the air-induced ground shock of a nuclear detonation, although the mechanisms are different.

Differential settlement of the ground and liquefaction can adversely affect the foundations of large buildings. Loss of bearing support can contribute to the tendency of relatively strong-walled buildings to overturn under the pressure of the air blast wave and wind loading. An earthquake example of this type of damage is shown in the lower photograph.

There is also some evidence that long-range ground motion can cause window breakage and other minor damage beyond the area of breakage from air blast.

STREET CAVE-IN, ANCHORAGE ALASKA EARTHQUAKE, 1964



TILTED APARTMENT HOUSE AFTER EARTHQUAKE IN NIIGATA, JAPAN

DAMAGE FROM BLAST WIND

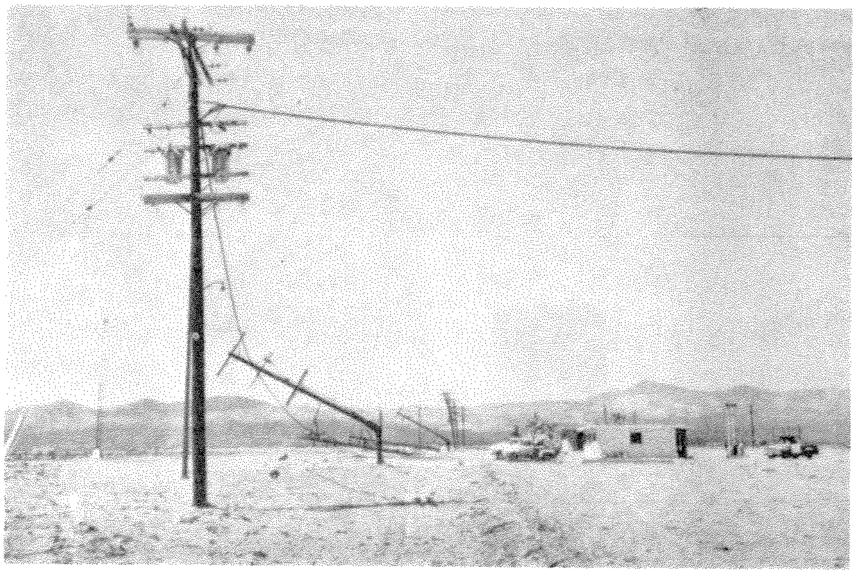
Trees, utility poles, and radio antenna towers are "drag-type" structures, principally damaged by the blast wind. Trees are less vulnerable in winter than when in full leaf. The 70 miles per hour wind associated with 2 psi overpressure will tear off many branches. At 3 psi (100 mph wind) shallow-rooted trees and those in cities with constricted roots will be blown down. The upper photograph shows wind damage to trees resulting from a megaton weapon's test. Few trees will be standing above 5 psi overpressure.

Utility poles and transmission towers with lines transverse to the blast will collapse at about 3 psi. Lines radial to the blast will be brought down above 4 to 5 psi. Well-anchored antenna towers can resist the blast wind about as well as steel building frame, failing at 4 to 6 psi.

The lower photograph shows damage to a pole-mounted transformer in Nevada at 5 psi. This sort of damage can be expected at about 3 psi for the longer-duration blast wind from weapons with yields in the 100's of kilotons. Trees, poles, and signboards can add appreciably to debris clogging access routes for emergency operations. For comparison, the following are wind speeds which are often associated with strong wind phenomena: thunderstorms, 50-100 mph; winterstorms, gusts up to 75 mph; hurricanes, 74-125 mph; tornadoes, 125-300 mph.

BLAST WIND DAMAGE

DECIDUOUS FOREST SUBJECTED TO 2.4 PSI FROM A MEGATON -RANGE WEAPON. NOTE EXTENSIVE CROWN BREAKAGE



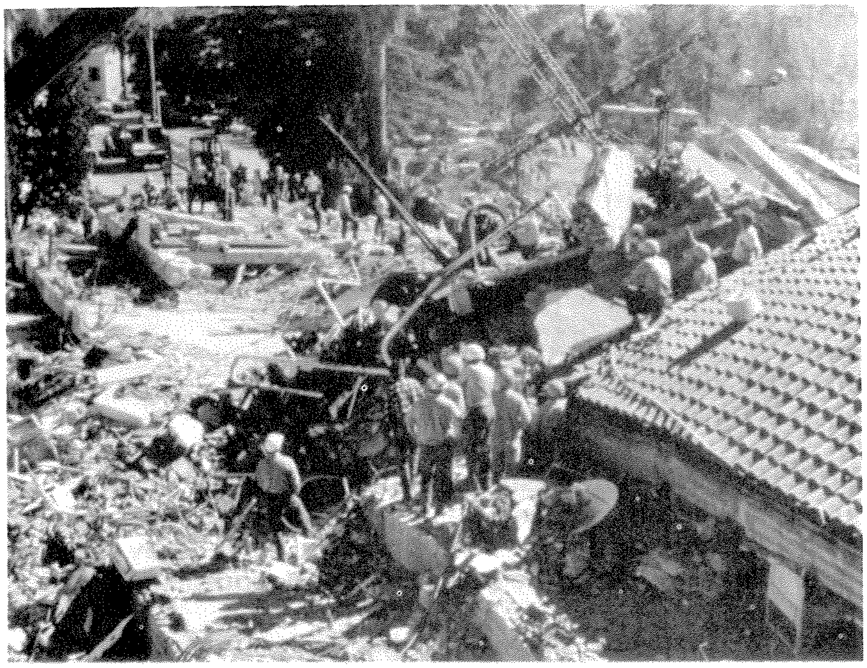
UTILITY POLE DAMAGE AT 5PSI AT NEVADA PROVING GROUNDS

DEBRIS FROM NUCLEAR BLAST

This chapter has emphasized the importance of the long-duration blast wave from half-megaton yield nuclear detonations. In particular, the persistence of the blast wind associated with the overpressure will distribute debris to large distances from the initial site. As a result, the debris from damaged buildings can be expected to be "off-site" rather than "on-site."

The upper photograph is of debris caused by the California earthquake of February 9, 1971. Parts of the building have collapsed directly onto the building site. This is not the situation to be expected as the result of a nuclear detonation.

The lower photograph shows debris near the water front at Pass Christian, Mississippi, following Hurricane Camille, August 1969. The floor slab of a building near the street at lower left is nearly clear of debris. Much debris is seen behind the original site, with the building roof several hundred feet further on. This example is more nearly like the action of the blast wind.



PANEL 24

INDUSTRIAL HARDENING

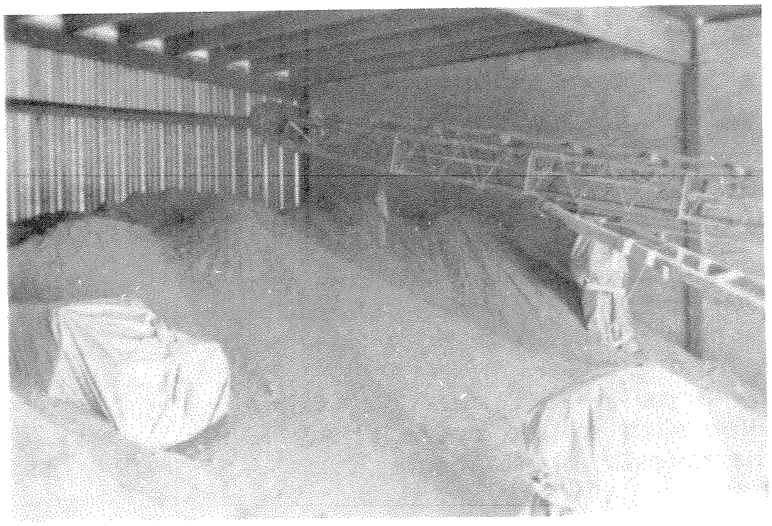
Clearly, debris can be a major source of damage not only to people but also to equipment. Simple, crude, but very effective measures can be taken to protect equipment from nuclear weapons effects.

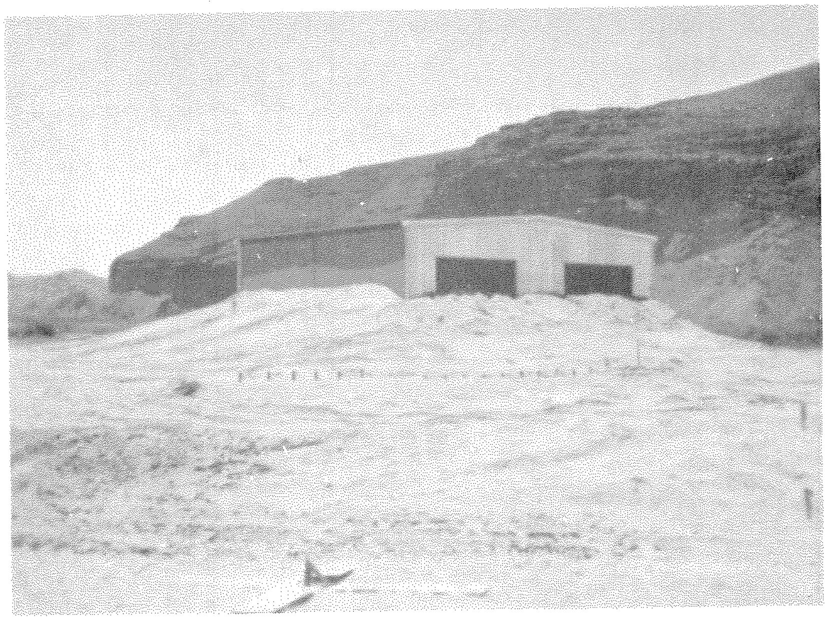
The upper photograph shows equipment wrapped in plastic (dense fabrics could also be used) in the process of being buried under loose soil. Prior to wrapping, each piece of equipment was surrounded by some crushable material such as foamed plastic or aluminum shavings.

The lower photo shows the completed semiburial of the factory buildings including the sloping berms around the building up to a height slightly greater than the tallest piece of equipment.

This building was later subjected to a blast created by a stack of explosives in a simulated nuclear test (100 tons of TNT equivalent). The exposed portion of the building was violently torn away and driven "downstream" by the blast winds while the protected equipment was undamaged.

A number of tests of this type have demonstrated that these simple measures can provide equipment protection at overpressures of several hundreds psi.





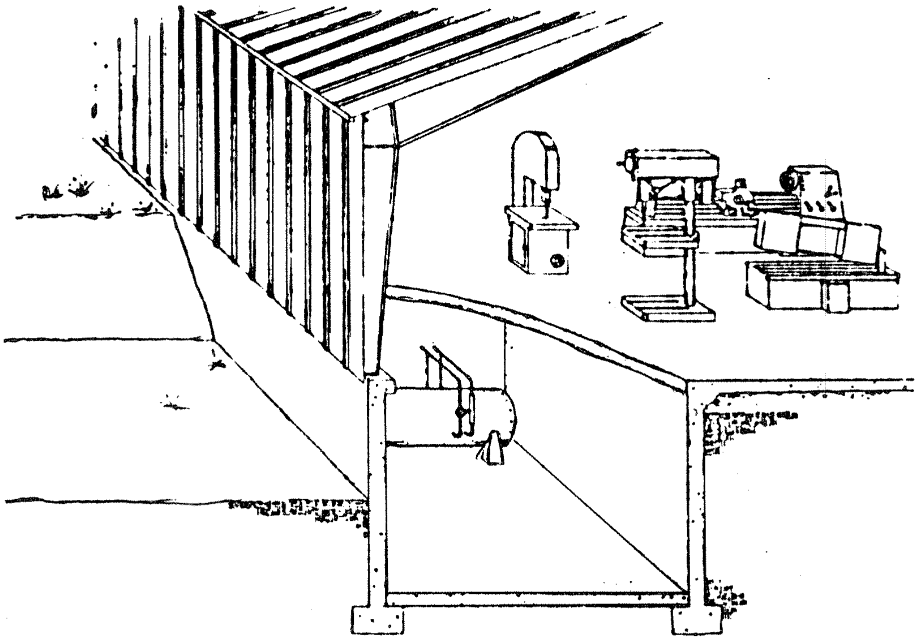
Photographs courtesy of Boeing Aerospace Co.

INDUSTRIAL PROTECTION ALTERNATIVES

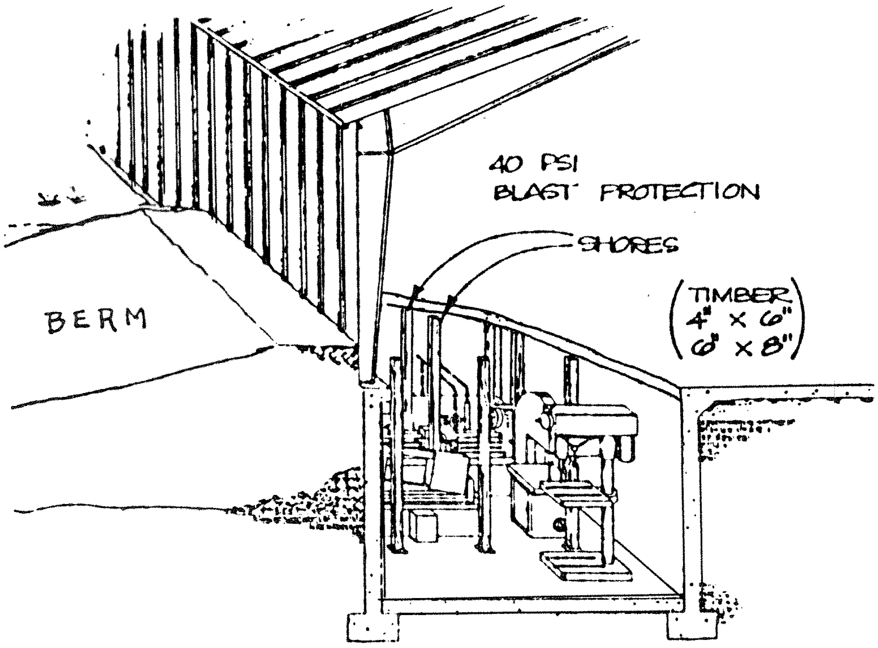
While the previous panel illustrated measures for protecting equipment against very high blast pressures close in to nuclear weapons detonations, other simple measures are available to protect widely scattered activities distributed throughout an area that may be subjected to direct effects.

The upper illustration shows an industrial activity in a factory building with a basement. In the lower illustration, the equipment has been relocated into the basement, and timber shores have been placed to lend additional support to the overhead slab. These measures can provide protection up to 40 psi or so. In this approach, stairways and elevator shafts can be filled with soil to prevent blast entry, and smaller openings can be protected by simple blast closures.

Other obvious measures include removal of the equipment from high hazard areas, housekeeping (i.e., removing obvious sources of debris), anchoring equipment in place with ropes and cables, and clustering and anchoring assorted movable equipment.



(a) BEFORE HARDENING



(B) AFTER HARDENING

Basement Hardening Concept

DAMAGE TO VEHICLES

Destruction of transportation vehicles, fire trucks, and earthmoving equipment can hamper emergency operations. Damaged vehicles can impede movement on streets and make debris removal more difficult.

Damage to mobile equipment located inside or adjacent to buildings is dependent almost totally on damage to the buildings. Fire stations and garages are usually lightly constructed and fail at low overpressures. Moderate damage requiring several hours of repair work will usually occur at 2 to 4 psi. Above 4 psi, mobile equipment will generally be inoperable and trapped in building debris.

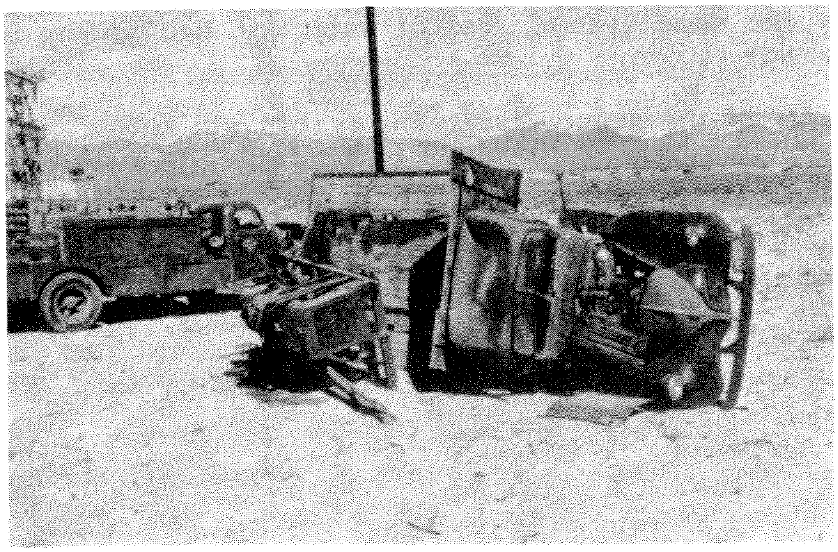
Vehicles parked in the open are significantly less vulnerable as shown on this chart. The amount of damage depends strongly on orientation to the blast. Vehicles broadside to the blast are likely to be overturned while vehicles end on are not. The photograph shows typical damage at 5 psi in a Nevada test. Both trucks were operable.

A case study made of a hypothetical 5 MT detonation in Albuquerque indicated that, with fire trucks parked in fire stations, 23 of 27 pieces of equipment were damaged, 11 of them beyond repair. Since the damage was due to the collapsing building (which is primarily caused by the overpressure in the blast wave), the same type of damage would be expected at the same overpressure but over a smaller area from a half-megaton weapon detonation. If parked in an open parking lot with random orientation, only 11 were damaged, 7 of which could have been repaired.

The concept of a "multi-purpose" staging area has developed from considerations of this kind. Fire trucks, utility repair trucks, and debris-removal equipment would be parked at, say, a large shopping center, with the operating personnel taking shelter in the building basements. Coordinated emergency operations could then be undertaken following attack, even in areas of substantial damage.

VEHICLE DAMAGE

Type	Moderate Damage (psi)	Inoperable (psi)
Automobiles	3 - 5	5 - 6
Buses	6 - 10	10 - 12
Fire Trucks	6 - 10	10 - 12
Repair Trucks	6 - 10	10 - 12
Earth and Debris Moving Equipment	20 - 30	30 - 35
Truck-Mounted Engineering Equipment	12 - 15	15 - 17
Railroad Cars	15	25
Locomotives	30	80



Vehicle damage at 5 psi, Nevada Test Site; both vehicles operable.

DAMAGE TO URBAN UTILITY SYSTEMS

As shown in this flow chart, an urban utility system consists of interdependent elements, so that damage to some facilities can cause larger disruptions throughout the system. This makes it difficult to describe simply the consequences of blast damage.

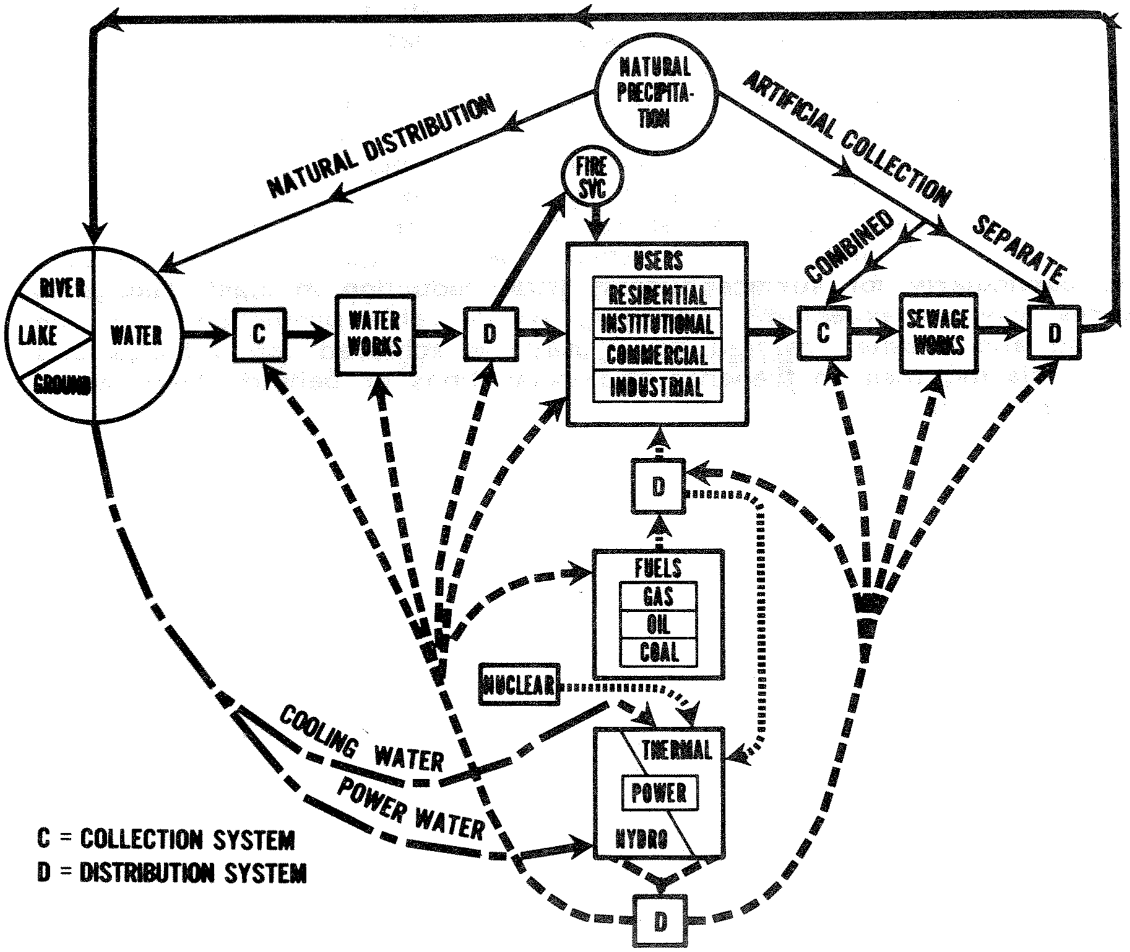
Electric power is needed not only to supply light, heat, and operate motors for the main users (residential, institutional, commercial, and industrial) but also to maintain the flow of water and treatment of sewage. In general, no power should be expected above 5 psi, because of extensive damage to substations and distribution lines. In the moderate damage region, 2 to 5 psi, availability would depend on specific circumstances, and early restoration of much of the service could be accomplished by isolation of damage and minor repairs. Outside of the 2 psi area, blast damage to the distribution system would be minimal and power could be available (however, see chapter 4 for possible EMP effects).

Water treatment plants and pumping stations should remain operable at overpressures less than 5 psi, but these facilities are totally dependent on electric power unless on-site emergency power generators with adequate fuel supplies have been provided. The most vulnerable part of the water system is the service connections and piping in buildings, which will suffer sporadic damage at 1 psi and general failure above 2 psi. If fire hydrants are serviced by the same system, loss of water for firefighting is likely in the moderate damage region.

Some elements of the sewage treatment system will suffer damage at low overpressures, but pumping stations will be operable up to at least 5 psi if electric power is available.

The supply of fuel is also dependent on electric power for pumping gas and oil and handling machinery for coal. Gas distribution is most vulnerable at the service connections and in buildings, much as is water piping.

PANEL 28

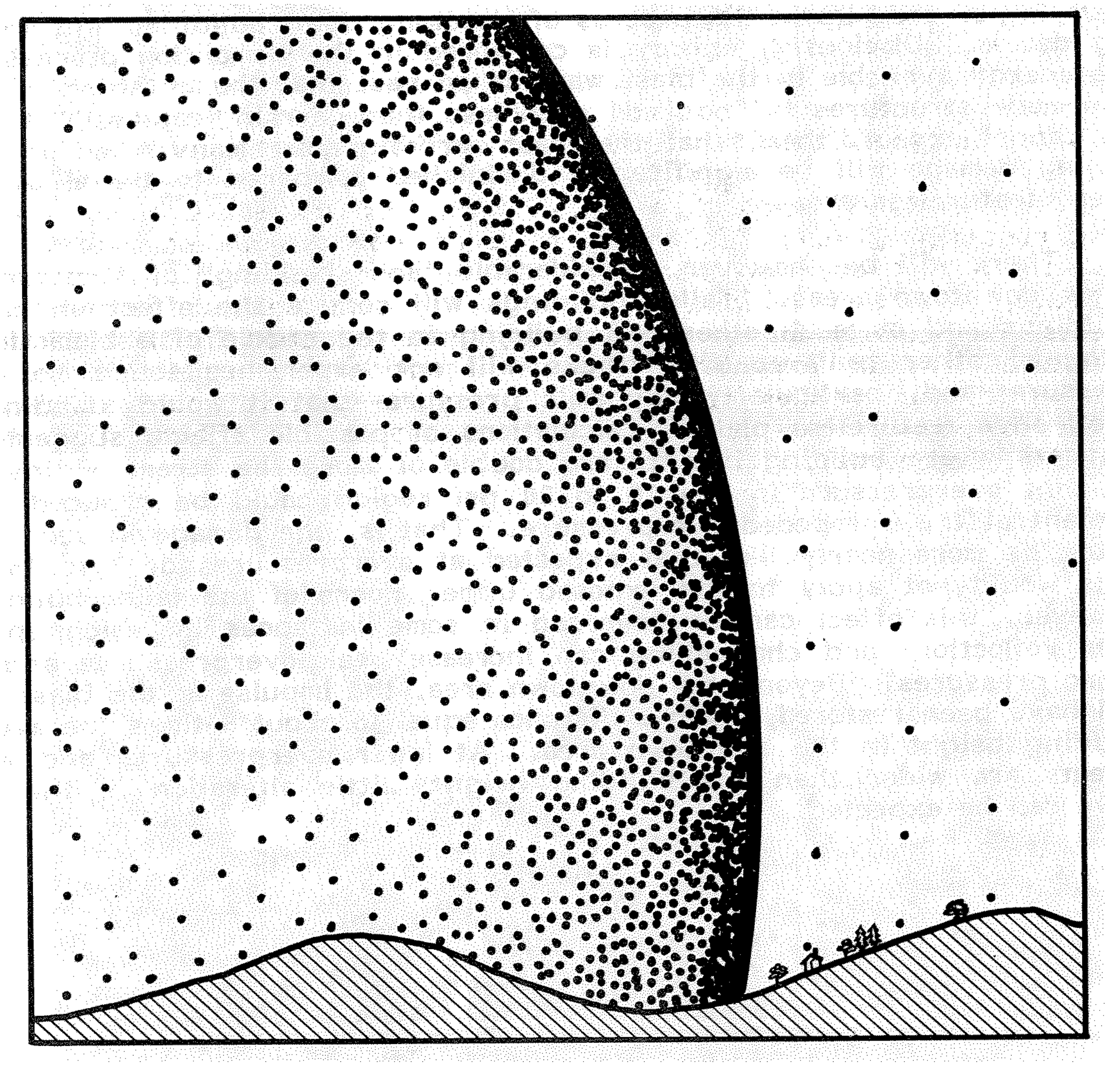

NATURAL PRECIPITATION
NATURAL DISTRIBUTION
ARTIFICIAL COLLECTION
COMBINED
SEPARATE
FIRE SVC
RIVER
LAKE
GROUND
WATER
C
WATER WORKS
D
USERS
RESIDENTIAL
INSTITUTIONAL
COMMERCIAL
INDUSTRIAL
C
SEWAGE WORKS
D
D
FUELS
GAS
OIL
COAL
NUCLEAR
COOLING WATER
POWER WATER
THERMAL
POWER
HYDRO
D
C = COLLECTION SYSTEM
D = DISTRIBUTION SYSTEM

PANEL 28

WHAT ABOUT HILLS?

The blast wave from a nuclear detonation is little affected by hills and other terrain features. The blast wave will exert force on the far side of a hill just as it does on the rear wall of a large building. There will be some reflection from the near side of a steep hill that could augment overpressures by perhaps 10 percent, with a corresponding reduction on the far side, but these minor changes will be of little consequence.

As the sketch shows, the blast wave from nuclear explosions in the yield range of 100's of kilotons is so large and extends so high into the atmosphere that even prominent terrain features are small in comparison. Although hills and buildings can shield people against other weapons effects, particularly for surface bursts, little reduction in blast damage to structures may be expected. However, considerable protection from the blast wind and missiles carried by it may be achieved for vehicles and people by placing them in trenches and excavations or behind steep earth-mounds (revetments).



PANEL 29

BUILT-UP AREAS

The question is often raised as to whether the energy in the blast wave is not used up in the process of knocking down buildings and spreading debris. Obviously, energy is consumed in the demolition process, but the energy available in the blast wave is so vast that the crushing of puny man-made structures is "noticed" even less than terrain features. A locality cannot expect, then, that the blast arriving after many miles of intervening damage will be significantly diminished compared to travel over an open, featureless area.

There will be, however, considerable "self-shielding" of structures in major downtown areas. Taller buildings will reduce the effect on smaller buildings and on each other. A building in the middle of a block in the midst of other built-up city blocks will not experience the same overpressure--and, particularly, dynamic pressure--that it would standing by itself on a featureless plain. Calculations of possible effects suggest that in areas where building heights are double or more the street widths, the incident overpressure in the 10 to 20 psi region could be reduced to 75 percent of the unimpeded overpressure. That is, the damage in such areas would be more nearly like that expected at overpressures of 7 to 15 psi. This would not apply to the exposed upper floors of the taller buildings. However, this effect can be reversed in some instances in which spilled-over reflections and channeling can increase peak overpressures and dynamic pressures. Beyond the downtown area, the impulse in the blast wave will have been restored within a distance equal to about 5 times the average building height in the downtown area. At lower overpressures and where streets are wider than the building height, little alteration in the blast wave can be expected.

PANEL 30

AREA OF LIGHT DAMAGE

From about 9 miles in to about 6 miles from a 500 KT air burst (1 to 2 psi), an area of light blast damage would appear as portrayed in panel 31. Large structures would suffer broken windows and doors and damage to light interior partitions. Most one-and two-family dwellings could be occupied; but broken studs, rafters, plaster, and damaged roofs would be commonplace as illustrated in panel 12. While this certainly looks disheartening in a peacetime context, it serves to illustrate that the chance of surviving blast effects in this region is very good indeed. Some tree limbs would be down, causing minor damage to overhead wires. Gas and water service connections and interior piping would be racked and, in many instances, broken. Street debris would be minor and limited to light signs and building ornamentation dislodged by the 35 to 70 miles per hour wind gust. Light corrugated metal siding on industrial buildings would be at least partially torn away.

People in basements would be most probably uninjured. Aboveground, many injuries from flying glass, other missiles, and impact against walls would occur, but most injuries would be minor cuts and abrasions. Almost everyone should survive and the simplest precautions could reduce injuries to a low level.

For the fire effects of the thermal pulse, see chapter 3.

PANEL 31

PANEL 31

THE AREA OF MODERATE DAMAGE

From about 6 miles in to about 3 miles from the detonation (2 psi to 5 psi), most large buildings would have lost their windows, window frames, and interior partitions. Those with light exterior walls will have been swept through by the blast wave, with most of the walls and contents of the upper floors ejected out the far side at the higher overpressures. Load-bearing masonry buildings will have suffered some collapse in this area. There will be many injuries and some deaths among people on the upper floors, but people in basements may survive relatively uninjured except in some brick buildings and near basement entrances.

Most one- and two-family residential buildings will have suffered damage ranging from severe damage to collapse. Building debris and contents will have been blown over a large area in an outward direction. Debris depths will vary greatly depending on the number of stories, the extent to which the general area is built up, the overpressure causing collapse, and the dynamic pressure which distributes the debris. Light structures in the area of moderate damage will produce debris depths ranging from less than 1/2 foot to about 3 feet with depths of 1/2 foot to 1 foot predominating. Up to half the occupants of the aboveground parts will have been killed and the remainder injured. People in residential basements may survive for the most part, although the first floor may have collapsed.

Trees and utility poles will be down over the inner part of the area. Service connections to residences and industrial buildings will be disrupted. Blast damage to electric power systems would be light in the outer edges of this region, but water pressure may be lost due to the damage to service connections. Some sporadic failures may occur in buried water and gas mains.

Debris will be substantial in cross streets; but radial streets should be mostly clear except in narrow downtown streets. Here the debris depths may range up to 2 feet or so with the debris generally distributed radially away from ground zero. Access should be possible to most of the area on foot although the collapse of occasional load-bearing wall buildings may effectively block some streets. Tree and pole damage will occasionally block vehicular traffic on otherwise traversable streets.

For the fire effects of the thermal pulse, see chapter 3. For the possible effects of the electromagnetic pulse (EMP), see chapter 4.

PANEL 32

AREA OF SEVERE DAMAGE

From about 3 miles in to about 2 miles from the detonation (5 psi to 10 psi), the damage to structures becomes increasingly severe. Small wood-frame and brick residences have been destroyed and distributed as debris over hundreds of feet. Load-bearing masonry-walled buildings have collapsed over most of the area, with the exception of monumental buildings. Framed buildings with relatively weak walls will have been gutted throughout the area; and, in the inner region, the framing will have collapsed away from the blast. Of the people aboveground, there will be many survivors but few uninjured survivors. In the outer part of the area, people in the better basement shelters may survive with few injured. Casualties increase nearer in, approaching the 2 mile circle. Inside 2 miles, there will be few survivors in basements with flat-plate floors overhead and in load-bearing wall masonry buildings of the ordinary type.

Traffic into this area would be greatly hampered or impossible without debris clearance. The debris in areas of lightly-constructed buildings would probably not block radial streets severely, but large and small chunks of masonry and construction steel would make clearance in densely built-up areas a major undertaking. The feasibility of pedestrian movement would be variable throughout the area, with radial streets most likely accessible in the regions of light to moderate density of construction. However, in the downtown areas, at the 2 mile range, debris can easily reach tens of feet in depth and the collapse of building frames can virtually preclude any kind of operations.

At the 1 mile range, failure of freeway overpasses would be commonplace, and many railway and major highway bridges would fail. Survival would be possible only in the strongest underground facilities such as subway stations.

There would be no electricity or water pressure in this area and there would be increasing numbers of breaks in gas and sewer mains. Radio antennas and telephone lines would be damaged to the extent that communication would be made unlikely. Automobiles would be inoperable, and other vehicles would be damaged or trapped in debris except in open areas.

For the fire effects of the thermal pulse, see chapter 3.

PANEL 33

SUGGESTED ADDITIONAL READING

The following sources provide additional background on the material in this chapter.

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11. White, C. S., The Nature of the Problems Involved in Estimating the Immediate Casualties from Nuclear Explosions, CEX 71.1, NTIS, U.S. Department of Commerce, Springfield, VA.

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13. Wiehle, C. K., Summary of the Dynamic Analysis of the Exterior Walls and Floor Systems of 50 NFSS Buildings, Stanford Research Institute, June 1974.