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BIOLOGICAL BLAST EFFECTS

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Introduction

This presentation, though generally concerned with biological effects of airborne blast phenomena, will be limited to deal briefly with three main topics. First, the scope and nature of the several blast hazards will be delineated. Secondly, tentative criteria for threshold damage to humans will be set forth. Thirdly, these criteria will be related to nuclear weapons in terms of ground ranges and areas involved for 1 MT and 10 MT surface detonations, and to allow appreciation of the relative importance of blast with other effects, appropriate values for ionizing and thermal radiation will be noted.

Scope and Nature of Blast Hazards

General

Blast injury to a biological target, including man, depends primarily upon (a) the pressure pulse that emanates from an explosion in soil, water or air, (b) the mass movement of material surrounding the explosion which, in the case of air detonations, involves blast winds that accompany the pressure variations, and (c) the consequences of the interaction of these phenomena with the target and its immediate environment. All of these factors vary in magnitude and duration as dictated by a variety of circumstances among which are type and weight of explosive and range from the detonation.

Scope

For the purposes of discussion it is helpful to distinguish four categories of air blast damage to biologic media defined as follows (1, 2):

1. Primary blast effects include injuries caused by variations in environmental pressure which follow an explosion due both to the primary pulse and its reflections from structures or objects

near the biological target. These pressure variations are customarily measured in pounds per square inch (psi) either above or below the pressure existing prior to the detonation.

Biologic damage depends upon a variety of factors, including the rate, character and magnitude of the pressure rise and fall and the duration of the several segments of the pressure pulse.

2. Secondary blast injuries are those which follow the impact of penetrating and nonpenetrating missiles energized by blast winds.

Important in "fixing" the hazard to animals and man are missile velocity, mass, size, shape, composition, and density, along with the specific regions and tissues of the body involved in the traumatic experience (3, 4, 5, 6).

3. Tertiary blast effects incorporate damage which is a consequence of physical displacement of the biologic target by blast shock and winds.

The seriousness of the problem depends upon the magnitude of the accelerative "load" imposed on the total organism and its several parts, the decelerative experience — particularly when violent impacts with solid surfaces are involved — and the portions and areas of the body concerned. Thus, the time-history of displacement both during acceleration and deceleration are important. However, a less precise parameter — velocity at impact — is actually quite useful and has the virtue of simplicity.

4. Miscellaneous effects of blast, biologically, can involve exposure to ground shock; dust, whether arising from the earth's surface or the walls of inhabited structures; and temperature phenomena — other than those related to thermal radiation per se — such as compression and aerodynamic heating, contact with hot dust and debris and conflagration heat from blast-produced fires.

Nature of Blast Injuries

Since blast injuries and related problems have been extensively studied and described (1-4, 7-55) and applicability of the data to long duration overpressures and to displacement and missile hazards directly related with nuclear blast has to some extent been explored (1-4, 44-55), only a cursory summary of pathology will be detailed here.

Primary Blast

With regard to pressure-related phenomena, as a general rule, one can say damage is most marked in those regions wherein there exists the greatest variation in tissue density and, particularly, in the air-containing organs of the body. A corollary of these facts is that the air-containing organs, their nearby tissues and the junction of the ribs and soft tissues are sensitive indicators of blast damage; e.g., the eardrum, the sinuses and lung.

The most dangerous lesion, usually associated with fatality within a few minutes, involves lung damage resulting in "air" bubbles reaching the general circulation, including the vessels of the heart and brain. Also, suffocation from lung hemorrhage and edema with heart failure from lack of oxygen and high concentrations of carbon dioxide can occur early. Bruising and bleeding of the lung, if untreated, can result in serious pneumonic infections in humans. Too, unless cases with lung hemorrhage can be kept at rest, recurrence of bleeding is a frequent and quite serious complication. Bruising of the heart, the liver, spleen and abdominal organs, with areas of hemorrhage and sometimes rupture of the hollow viscera occur. Late complications from perforation peritonitis, pneumonia with lung abscess and areas of degeneration in the central nervous system require careful and prolonged care.

One new (57) lesion, discovered by Richmond recently, involves fracture of the thin bones separating the paranasal sinuses from the orbit. The finding was observed during shock tube exposure of animals to pressure conditions realistically simulating nuclear blast.

Missiles

Missiles which penetrate into major body cavities and damage critical organs, such as the heart, liver, spleen, other abdominal organs, the eyes

and brain, are similar to the ballistic problems associated with war casualties (5, 6, 58-64). Many of these require early surgery to avoid fatalities, appropriate care for fractures and prolonged treatment to handle infections of major body cavities and deep lacerations.

Nonpenetrating missiles impacted against the chest can produce bilateral lung lesions very similar to those of primary blast with early fatality (64). Skull fracture, concussion, rupture and hemorrhage of the liver and spleen, and skeletal fracture can be very dangerous as can crushing injuries from heavy masses of masonry and other building materials (65-73).

Displacement

Damage from displacement can be of two general types. One type involves differential displacement of different portions of the body — loss of a hand or limb, for example. The other type occurs from total displacement of the entire organism with the decelerative experience being the most hazardous. The trauma which occurs can be similar to automobile and aircraft accidents and, in type and required treatment, poses only a few problems of an unusual nature. However, the hazards of violent impact are of considerable importance in the case of nuclear explosions because of the great range and long duration of the blast winds (1, 49-53, 65, 67-79).

Miscellaneous Effects

The nature of damage from ground shock concerns trauma from displacement and impact with heavy objects as has been noted above.

Sufficiently high concentrations of dust under certain circumstances has proved fatal to man simply through deposit in, and obstruction of, the small airways of the lung (80). The danger depends upon time of exposure and the concentration of appropriately sized dust particles. Studies inside blast protective shelters at the Nevada Test Site indicate there need be no serious hazard to occupants providing the inside walls of structures are not finished with dust-producing materials (54).

Thermal problems can involve burns from other than thermal radiation, but these qualitatively are similar to the latter and others appearing before the Committee will deal with the injuries involving exposure to heat.

Combined Effects

In practice it is not the rule to observe primary, secondary or tertiary blast effects alone. Indeed, in a nuclear explosion these will be seen in all possible relationships, plus damage from ionizing and thermal radiation. It is instructive, however, to call attention to the Texas City Disaster of 16 and 17 April 1947, which has been well documented both from the physical (81) and medical points of view (39-42).

Figures 1 and 2 show missile damage to a grain elevator and oil storage tanks (81). Figure 3 depicts the inside of an industrial installation after the explosion, and gives some suggestion of the hazardous debris created by the blast (81). Figure 4 shows one type of injury from glass to an engineer sitting at a desk with his right side turned toward a window a few feet away (39). This man was blown under a table, was completely "blinded" by flying glass, and was dazed but not unconscious. He noted chest pain, coughed blood intermittently for a week and suffered the following injuries: penetrating wound of the right eye with prolapse requiring evisceration; multiple lacerations of the right side of the face with severance of the facial nerve and parotid duct; lacerations of the neck, eyelids, left deltoid region and both lower extremities; perforation of the right eardrum and blast injury to the lung (39).

Two other cases are quoted from the report of Drs. Virginia and T.G. Blocker (39).

"Case V. N.B., a colored female, aged thirty-seven, was standing out in the open near the Seatrain with her left side turned toward the ship. She felt the blast and saw debris flying through the air in all directions before she was knocked unconscious by a flying missile. When she 'came to', she was in water up to her waist and part of her clothes had been blown off. The patient was approximately two months pregnant at the time, and within an hour had an inevitable abortion without complication. Injuries sustained were (1) severe laceration of the left leg; (2) lacerations of the scalp; (3) mild head injury; (4) perforation of the left eardrum; (5) spontaneous abortion; and (6) minor abrasions and contusions.

"Case VII. S.R., a colored male, aged thirty-nine, had just come

from loading flour on the High Flyer and was standing at the end of Pier O facing the burning ship. When the explosion occurred, he was thrown upward so high that he could see over Warehouse O; he was then blown laterally into the water near the Seatrain installation. He did not lose consciousness and was able to swim to land. Most of his clothes were blown off. Injuries sustained were (1) perforation of both eardrums; (2) severe scalp lacerations; (3) severe laceration of left upper arm with extensive infection; (4) left ulnar paralysis; and (5) laceration of right foot."

Figure 5 summarizes various types of injuries involved in the Texas City experience in which about 560 persons were killed or missing, 800 cases hospitalized and between 3,000 and 4,000 other less serious casualties occurred (39). The disaster illustrates very well the catastrophic character and nature of blast injuries and, if multiplied several fold, illustrates many of the biomedical consequences of large scale nuclear blast delivered to an unprotected urban or suburban area.

Tentative Criteria for Threshold Damage

A few selected quantitative data regarding the environmental conditions which define gross biological hazards will now be noted as background for fixing tentative threshold criteria for blast damage to humans. The objective is to estimate conditions likely to be at, or near, those which will just cause casualties, with a casualty defined simply as a person sufficiently injured to be unable to care for himself and thus become a burden to someone else. Information relevant to the primary, secondary, and tertiary problems will be set forth separately below.

Primary Effects

In general, it can be said that (a) mammalian material tolerates slowly rising overpressures much better than those developing almost instantaneously, and (b) overpressures of long duration are likely to be more damaging than pressure pulses of short duration.

Fisher, Krohn and Zuckerman (37, 38) in an excellent study at Oxford University, using high explosives and pressure pulses from 1 to 3 msec in

duration, have shown that the overpressures required to fatally injure 50 per cent (P_{50}) of mice, guinea pigs, rabbits, monkeys and goats were near 27, 32, 55, 100 and 200 psi, respectively. The figures could be related to the weight of the animals by the equation

$$P_{50} = 0.24 W^{2/3} + 23.7$$

where

P_{50} = local static overpressure in psi

W = body weight in gms

The authors solved this equation for the 60 and 80 kgm man and predicted human tolerance to "short"-duration, high explosive generated overpressures would be 390 and 470 psi for 50 per cent mortality, respectively. The same authors from field studies in bombed cities in England noted 12 human exposures for which the estimated overpressures ranged from 170 to 500-600 psi. There was one fatality related with 450 psi. Ten individuals survived from 170-450 psi and the other was not killed at between 500-600 psi.

These estimates of human tolerance did not contradict the observations of Desaga in Germany (9) who noted two deaths among 13 men exposed to high explosive bombs. The estimated maximal overpressure was 235 psi which resulted from an incident pressure of 58 psi reflecting from the corner walls of an open-topped, concrete, gun emplacement where the men were located. Desaga (9) further noted that man's tolerance to high explosive blast was similar to that of the large dog for which he noted just fatal conditions as follows:

Table 1
 "Fast"-rising "Short"-duration Overpressures Required for
 Near 100 Per Cent Mortality in Dogs

Max Static Overpressure psi	Overpressure Duration msec
216	1.6
218	1.6
125	4.1
85	8.6
79	10.3
76	11.8

Clemedson (24) using mice in a shock tube study, confirmed the effect of duration on mortality, which data were also consistent with the opinions of Hooker who worked many years earlier in the United States (10).

Observations at the Nevada Test Site in 1953 revealed rather severe though non-fatal injuries to dogs exposed to nuclear-produced pressure pulses in open blast protective shelters at maximal overpressure between 12 and 25 psi, but enduring for from 500 to almost 800 msec. Too, there were findings indicating that the rate of pressure rise was of importance.

At the time, the Nevada experience seemed inconsistent with the earlier high explosive blast results, but it is now known from subsequent work in the field (1, 2, 49, 50) and in the laboratory (2, 55, 56) that studies of the effects of long duration overpressures simply extend the high explosive data. However, to date, the gap between the short duration high explosive work and the long duration field and shock tube investigations has not been filled, though appropriate experiments are now under way in Albuquerque.

The most recent experiments involving overpressures ranging from 80 to much over 1,000 msec in duration (56, 82) were carried out in a shock tube with four species of animals and represent the best data available for estimating human tolerance to long duration overpressures. Animals were exposed in cages bolted to a metal plate closing the end of the shock tube.

and hence the incident and the reflected overpressures were applied almost simultaneously. To show the incident and reflected pressures associated with 1, 50 and 99 per cent mortality, Table 2 was prepared.

Table 2
Shock Tube Mortality Data for "Fast"-rising Long Duration
Overpressures When Incident and Reflected Pressures Are
Applied Almost Simultaneously

Animal Species	Overpressure in psi for indicated mortality					
	1%		50%		99%	
	Incident	Reflected	Incident	Reflected	Incident	Reflected
Mouse	7	20	11	29.8 ± 1.1	15	44
Rabbit	9	25	12	33.4 ± 1.2	15	44
Guinea pig	10	28	13	36.7 ± 0.7	17	48
Rat	10	28	14	38.7 ± 0.6	18	53
Man*	20-35		40-50		55-65	

*Tentative estimate. Data AEC Project, Lovelace Foundation,
Albuquerque, New Mexico.

The reader will note that Table 2 contains a tentative estimate of human tolerance which applies only to "fast"-rising, "long" duration pressure pulses. Too, it is important to understand that the pressures estimated for beginning mortality — 25-35 psi — can arise in two ways. First, in case an individual were close to a reflecting surface an incident pressure ranging from about 8 to 12 psi can reflect to 25-35 psi. In such a case the maximal pressure of 25-35 psi is applied almost instantaneously.

Secondly, an individual in the open or in a large building could be exposed to an incident pressure near 25-35 psi and in such a case a maximal pressure of this value would also be applied almost instantaneously. This point is emphasized because the pressures usually quoted in weapons effects manuals applies to incident, "free-field" pressures. It is necessary to specify tolerance in terms of the maximal, fast-rising pressure and to know that this can involve (a) an incident pressure which is maximal, or (b) a much lower incident pres-

sure which reflects to the maximal pressure specified. In terms of range from a nuclear detonation this distinction can involve a considerable variation in distance.

In passing, this point can be emphasized further by noting that if the cage of the guinea pig, for example, is mounted 1 ft from, instead of against the reflecting plate of the shock tube, the maximal or reflected pressure which is fatal to 50 per cent of the animals is quite different (56); e. g., about 58 compared with 37 psi maximal (reflected) overpressure. In the case of the higher tolerance the animal was first exposed to the incident pressure and about 1.4 msec later to the reflected or max pressure. Table 3 summarizes the situation for emphasis.

Table 3
Comparison of the Incident and Reflected Long-Duration
Overpressures Fatal to 50 Per Cent of Guinea Pigs Exposed
in a Shock Tube Against and 1 Foot from a Reflecting Surface

Location of cage	Overpressure in psi for 50 per cent mortality		Time interval in msec between incident and reflected pressure
	incident	reflected	
Against end-plate	13	36.7 $\pm$ 0.7	Essentially none
1 ft from end-plate	18	57.1 $\pm$ 1.1	1.36

With regard to estimating a threshold for human damage to long-duration overpressure based on lung damage, it can be said that slight lung hemorrhage has been noted in mice, rabbits, rats and guinea pigs exposed in a shock tube against a reflecting surface to an incident overpressure of about 6 psi which reflected to near 15 psi. Consistent with this, an incident pressure of approximately 8 psi is known to have produced lung hemorrhage in a dog exposed in front of a reflecting surface to full-scale nuclear blast (53).

Thus, on the basis of the few animal data available on sharp-rising, long-duration pressure pulses, it is felt that human lung damage will occur in minimal form under circumstances which involve (a) an "open" exposure to 15 psi incident, or (b) exposure to 6 psi incident in a location where reflections to 15 psi max could occur almost immediately after arrival of the incident overpressure.

In case one desires to use the response of the more sensitive eardrum as a criteria in estimating the tolerance of man to blast, there are also uncertainties because the response of the human tympanic membrane to blast-produced overpressure is not known at all precisely. However, the classical study of Zalewski in 1906 (83) is helpful. Using human cadavers, this investigator applied slowly increasing pressures to the external auditory meatus until rupture of the eardrum occurred. Data are summarized in Table 4.

Table 4
Pressures Required to Rupture the Eardrums of Human
Cadavers and Dogs when Pressure was Applied
Within 24 Hours After Death (83)

Species Studied	No. of cases	Age group in years	Pressures required to rupture tympanic membranes in psi		
			minimum	maximum	mean
Human	19	1 - 10	20.9	43.2	33.1
	15	11 - 20	6.0	44.1	25.5
	15	21 - 30	15.3	29.6	20.5
	17	31 - 40	6.4	35.4	23.2
	11	41 - 50	16.8	31.5	20.7
	12	51 - 60	13.5	38.3	21.0
	14	61 - 70	5.4	31.5	18.8
	8	Above 70	16.2	26.5	20.7
Total	111	Average	5.4	44.1	22.9
Dogs	10	Not stated	9.1	22.8	14.9

The average pressure required to rupture the human eardrum varied with age from about 33 psi for the first decade of life to near 20 psi for the older age groups. However, the lowest and highest pressures for rupture were 5.5 and 44.1 psi, respectively. Dogs (age not stated) similarly studied by Zalewski revealed pressures for rupture ranging from about 9 to 23 psi with a mean of 15 psi. Exposure of young dogs to nuclear blast at the Nevada Proving Grounds (1, 50) indicated that the maximal pressures for rupture of the eardrum ranged from 4.1 to 85.8, with 31.2 psi being the statistically determined pressure required for 50 per cent failure of the tympanic membrane (50). The highest overpressure without rupture was noted to be 66.6 psi.

Apparently the blast data for young dogs are fairly close to the laboratory results obtained on human material. Too, the studies of Zuckerman (43) noting human field data in bombed British cities are reasonably consistent with the material presented previously.

On a tentative basis, therefore, it seems reasonable to believe that human eardrum failure begins at near 5 psi maximal which can be either an incident or reflected overpressure. In case of the latter, about 2.5 psi is close to the incident pressure which will reflect to 5 psi under appropriate conditions.

Human response to slowly rising overpressures of both short and long duration is not known. However, it has been demonstrated that dogs are much more tolerant to long-duration pressures rising to a maximum in from 20 to 150 msec (48) than they are to sharp-rising pulses. Eardrum failure, damage to the sinus membranes and fracture of the thin orbital bones do occur, though lung damage is markedly minimized for the slower rising overpressures. Further details need not be given here since the present objectives are directed to setting thresholds involving the minimal overpressure which is likely to cause human casualties.

Secondary Effects

The physical and biological factors that determine the seriousness of human injury from objects striking the surface of the body — whether or not they penetrate skin tissues and bone — are complex indeed. Ignoring most of these, and for the sake of brevity, the missile problem will be limited and simplified here by using only impact velocity and missile mass to illustrate the just threshold conditions for penetration into a major body cavity of a dog and for nonpenetrative fracture of the human skull.

Table 5 gives the data of Bowen, et al. (4) obtained by firing irregular glass missiles against the abdominal wall of dogs, and in terms of missile mass and impact velocity, defines conditions for expecting glass missiles to pierce the body wall and enter the abdominal cavity 1, 50 and 99 per cent of the time.

Table 5

The Velocity-Mass-Probability Relationships Required
for Small Window Glass Fragments to Traverse the
Abdominal Wall and Reach the Peritoneal Cavity of Dogs*

Mass of glass fragment gms	Impact velocities in ft/sec for indicated probabilities of penetration in per cent		
	1%	50%	99%
0.05	320	570	1000
0.1	235	410	730
0.5	160	275	485
1.0	140	245	430
10.0	115	180	335

*Data from Bowen, et al., AECU-3350

The reader will note that a 10 gm glass fragment, having a velocity of 115 ft/sec has only a 1 per cent probability of traversing the abdominal wall of a dog. Since clothing will degrade the velocity of small missiles moving relatively slowly, and because of the less serious nature of skin and tissue lacerations, an impact velocity of 115 ft/sec for a 10 gm glass fragment has been arbitrarily chosen as the threshold for human casualties from glass and other frangible materials. Such a decision may well have to be modified later, since a quantitative study of eye injury from glass and other small irregular missiles has not yet been done. However, the 10 gm-115 ft/sec criteria is strengthened somewhat by the data of Journee (5) who noted that spherical bullets weighing 8.5 gm only produced a contusion of the skin when fired at human cadavers at velocities up to 150 ft/sec, whereas a velocity of 128 ft/sec for 6 to 12 mm caliber rifle bullets was set as the lower limit at which penetrating wounds begin in man (5).

The realistic nature of the masses and velocities of glass fragments noted in Table 5 is established by the figures in Table 6 which details the masses and velocities for glass, stone and irregular steel objects empirically observed at stations located from the 1.9 to 17.3 psi lines during full-scale nuclear explosions at the Nevada Test Site. Unfortunately, to date, no full-scale missile experiments have been carried out to determine the expected missile environment inside a variety of industrial plants, office buildings

Table 6

Relation Between Overpressure and Missile Parameters

Max pressure psi	Type of missile	Velocity ft/sec		Mass, gms		Max missile density No/sq ft
		geometric mean	range	geometric mean	range	
1.9	Window glass	108	50-178	1.45	0.03-10	0.4
3.8	Window glass	168	60-310	0.58	0.01-10	159
5.0	Window glass	170	50-400	0.13	0.002-140	388
8.5	Natural stones	275	167-413	0.23	0.038-22.2	35
15.0	Natural stones	692	379-1100	0.50	0.043-8.82	4.7
17.3	Natural stones	432	300-843	0.21	0.010-13.4	99.1
17.3	Irregular steel objects	240	195-301	34.5	9.0 - 86.0	3.6

and other structures much larger than the "typical" brick and wooden frame houses to which past studies have been limited.

Objects striking the human head may cause skull fracture and concussion, both potentially dangerous experiences. Fortunately, quantitative investigations by Gurdjian, et al. (70), using human material, are available to support an estimate of the skull-fracture hazard. Using the data of these authors and adopting a missile of 10 lbs, which is near the average weight of the adult, human head, Table 7 was computed to state the impact velocities that can be associated with skull fracture. The table shows considerable variation in velocities required for fracture; e.g., the minimum impact velocity associated with fracture was near 15 ft/sec, while the maximal without fracture was computed to be 23.1 ft/sec.

Table 7
Average Minimal Impact Velocities From a 10 lb. Missile
Expected to Cause Skull Fracture and
Maximal Velocity Without Fracture

Region of blow	Impact velocities expected to fracture the human skull*	
	ft/sec	mph
Posterior midline	16.6	11.3
Frontal midline	17.4	11.8
Above ear	18.2	12.4
Top midline	19.4	13.2

Maximal without fracture	23.1	15.7
Minimal with fracture	14.6	9.9

*Computed from the data of Gurdjian, et al. (70)

Although damage to the thorax and lungs from the impact of 0.4 and 0.8 lb. nonpenetrating missiles have been studied, information for heavier and lighter objects is lacking (64,82). Also unavailable, are quantitative figures for missile impact velocities near and over the regions of the liver and spleen that will rupture these friable organs and produce hemorrhage often severe enough to require early surgery if fatality is to be avoided.

Under such circumstances, 10 ft/sec has been adopted tentatively as the impact velocity for a 10 lb nonpenetrating missile, below which the number of human injuries will approach a minimum.

Tertiary Effects

To deal simply with the hazards of displacement from blast-produced winds, it has been assumed that significant human injury will occur mostly during decelerative impact with solid objects having a mass much greater than that of man. Data from four sources has been selected as guides in estimating threshold conditions for injury.

First, it is useful to note an animal study involving decelerative impact which reported the impact velocities associated with 50 per cent mortality in mice, rats, guinea pigs, and rabbits to be 38, 44, 31 and 31 ft/sec, respectively. Extrapolation of these figures to man predicts that on the average an impact velocity of 27 ft/sec or 18 mph would be associated with death of half the individuals (82). These are interesting figures because National Safety Council reports on urban automobile accidents have associated a mortality of 40 per cent with automobile accidents at speeds of less than 20 mph and a 70 per cent fatality rate with speeds of less than 30 mph (69). Table 8 summarizes the above data.

Secondly, Black, et al. (76) dropped human cadavers feet first with knees locked onto a hard surface from heights of 1, 2, 3, 4 and 6 feet and concluded that the threshold for fracture of the heel, foot and ankle bones lay between impact velocities of 11 and 16 ft/sec. Draeger, et al. (79) using an impact table and human cadavers to study ankle and foot fracture, demonstrated an impact velocity of 12-13 ft/sec (8-9 mph) to be near the threshold for skeletal fracture of the lower extremities.

Thirdly, Gurdjian, et al. (70), by drops onto a solid surface, subjected heads of human cadavers to impact loading and defined conditions for experimental skull fracture. The findings have been summarized in Table 9 in terms of impact velocity. Fracture was produced at a minimal impact velocity of 13.5 ft/sec (9.2 mph), while the maximal velocity without occurrence of fracture was 22.8 ft/sec (15.5 mph). These findings are fairly consistent with British work done during the Second World War (76, 78).

Table 8

Average Velocities of Impact Against a Hard Surface
Associated with 50 Per Cent Mortality of the Indicated
Species of Animals with Extrapolation to Man*

Species of Animal	Average animal mass gms	Average impact velocity for 50 per cent mortality		Equivalent height of fall (approx.) ft
		ft/sec	mph	
Mouse	19	38	26	22
Rat	180	44	30	30
Guinea pig	650	31	21	15
Rabbit	2,600	31	21	15
Man (computed)	72,574 (160 lbs)	27	18	11

National Safety Council release on urban automobile accidents shows 40 and 70 per cent of fatalities were associated respectively with speeds of or less than 20 and 30 mph. - Quoted from De Haven.

*Data AEC Project, Lovelace Foundation, Albuquerque, N.M.

Table 9

The Ranges of Impact Velocities Associated with
Experimental Fracture of the Human Skull

Range impact velocities ft/sec	Approx. velocity in mph	Approx. height of fall in.	Number of subjects	Fractures in per cent
13.5-14.9	9.5	37	9	19
15-16.9	10.9	48	10	22
17-18.9	12.2	61	12	26
19-20.9	13.6	75	11	24
21-22.9	15.0	91	4	9
Total			46	100

Minimum velocity with fracture - 13.5 ft/sec (9.2 mph)

Maximum velocity with fracture - 22.8 ft/sec (15.5 mph)

Maximum velocity without fracture - unstated.

Fourthly, from the findings of Ruff (84), it is possible to deduce a velocity of about 8 ft/sec (6 mph) as likely to produce spinal fracture assuming impact with a solid surface in the sitting position.

The above data encourages one to adopt an impact velocity of 10 ft/sec as a tentative threshold criteria for human damage from abrupt decelerative impact following displacement by blast-produced winds. Though arbitrarily chosen, the 10 ft/sec (6.8 mph) figure is quite likely low enough to avoid any significant number of casualties and if serious injuries occur, they are likely to be few indeed.

Empirical work by Taborelli, et al. (51, 52) in the 1957 Nevada Test Series, using 160 lb anthropometric dummies exposed at stations where measured overpressures were 5.3 and 6.9 psi, demonstrated the displacement possible to humans from nuclear blast. Table 10 summarizes the findings.

Table 10
Blast Displacement of 160 Lb Anthropometric Dummies

Max pressure psi	Max Q psi	Initial dummy position	Max horizontal velocity ft/sec	Time to max velocity sec	Displacement in ft
5.3	1.8	Standing	21.4	0.5	21.9 downwind
		Prone	zero	-	None
6.9	15.4	Standing	not known	not known	256 downwind 44 to right
		Prone	not known	not known	124 downwind 20 to right

Even at 5 psi the maximal velocity attained in 0.5 sec by the dummy was a little over 21.4 ft/sec, which speed is well above those required to fracture the skull and lower extremities. Though the displacement velocity at 6.9 psi was not obtained in the Nevada studies, the total displacement of 124 and 256 ft for the prone and standing dummies, respectively, demonstrates the unequivocal displacement hazard which can occur following nuclear explosions.

Miscellaneous Effects

No attempt has been made to deal with the threshold for human casualties as a consequence of miscellaneous blast effects. Those, however, who wish to explore the dangers from dust are referred to the publication of Desaga (80).

Summary

The tentative criteria described above for primary, secondary, and tertiary blast effects representing those conditions thought to be near the human casualty threshold are summarized in Table 11. It is the current opinion of the writer that the data in Table 11 represent best estimates for conditions at which human casualties will approach a minimum; e.g., some individuals situated where the indicated overpressures, missile and displacement velocities exist will escape damage because of fortunate local geometry; many persons will be injured, but only to the extent that they can care for themselves; others will become casualties in that they require care from their associates, but these will be relatively few indeed.

Table 11

Threshold Criteria Estimated to be Near Conditions at Which
Casualties Will Approach a Minimum or be Absent

Blast Effect		Criteria adopted as indicated
Primary	Lung damage	15 psi incident <u>and</u> maximal overpressure 6 psi incident reflecting to 15 psi maximal
	Eardrum rupture	5 psi incident <u>and</u> maximal overpressure 2.5 psi incident reflecting to 5 psi maximal
Secondary	Penetration into abdomen	115 ft/sec for a 10 gm glass missile
	Nonpenetrative skull fracture	10 ft/sec for a 10 lb masonry missile
Tertiary	Skull fracture from impact	10 ft/sec for 160 lb man

Relation of Blast Criteria to Nuclear Explosions*

An attempt will now be made to relate the arbitrarily chosen and tentative criteria for threshold biological blast damage to nuclear war. Specifically, the ranges and areas involved for potential damage to man will be presented only for surface nuclear detonations of 1 and 10 MT explosive yields.

To aid initial orientation, Figure 6 was prepared, using the data of Glasstone for surface bursts at sea level (85). The figure shows iso-pressure lines from $2\frac{1}{2}$ to 100 psi defining the expected range-yield relationships for detonations of megaton yield. The overpressures represent "free-field" phenomena — overpressures which would occur over open terrain in the absence of buildings and other structures — and are maximal incident pressures measured side-on to the advancing pressure front.

Primary Blast Effects

Figure 6 contains iso-pressure lines for 2.5, 5, 6 and 15 psi which overpressures were noted in Table 11 to be related with the criteria adopted for primary blast effects. Table 12 notes these pressures and shows the ranges from ground zero and the areas covered for surface burst explosions of 1 and 10 MT.

With regard to the threshold of 5 psi maximal for beginning failure of the normal human eardrum, Table 12 shows that this effect can be expected out to ranges of 2.8 and 6.1 mi for 1 and 10 MT surface bursts, respectively, at which distance an incident and maximal "free-field" overpressure of 5 psi is predicted. The corresponding areas are 25 and 120 square miles.

*The author wishes to acknowledge the helpful cooperation of Mr. I. G. Bowen, Head of the Physics Department, Lovelace Foundation, who contributed the analytical work required for formulating the tables and charts used in this section (86).

Table 12
Ground Ranges and Areas for the Indicated
Overpressures Arising from 1 and 10 MT
Surface Bursts at Sea Level

Incident Overpressure, psi	Corresponding Range and Area			
	1 MT		10 MT	
	mi	sq mi	mi	sq mi
2.5	4.5	64	9.7	300
5.0	2.8	25	6.1	120
6.0	2.6	21	5.5	95
15.0	1.5	7.1	3.3	34

In case exposure of man close to a reflecting surface or in other situations where reflections of pressure to 5 psi maximal might occur, it is necessary to note the distances and areas for 2.5 psi incident overpressure, for the latter can and will reflect to 5 psi under appropriate conditions. Thus, the maximal range for rupture of the tympanic membrane can be 4.5 and 9.7 mi, involving areas of 64 and 300 sq mi for the 1 and 10 MT surface bursts, respectively.

Because rupture of the tympanic membrane can be regarded as a primary blast injury which is "acceptable" in an emergency, it is helpful to note the ranges and areas for the criteria adopted for lung damage. In a geometry of exposure conducive to producing sharp pressure reflection, Table 12 shows that human lung damage might occur out to 2.6 and 5.5 mi, covering areas of 21 and 95 sq mi for 1 and 10 MT weapon yields, respectively, which data apply to the range of the "free-field" 6 psi incident overpressure assuming reflections to 15 psi maximal. For circumstances wherein pressure reflections would be minimal, the ranges for a free field incident overpressure of 15 psi would apply; e.g., ranges and areas of 1.5 mi and 7.1 sq mi for the 1 MT and 3.3 mi and 34 sq mi for the 10 MT yields, respectively.

Secondary Effects

The situation for biologic damage from impact with either penetrating or nonpenetrating missiles is not quite so clear-cut as is the case with damage from overpressure. One complicating circumstance arises from the fact that blast energized missiles, depending upon their mass, size and shape and the magnitude of the blast winds, gain velocity as a function of time, and during the phase of increasing velocity cover a finite distance. This statement means, among other things, that the velocity at impact is a function of the distance (and time) the missile travels before striking a biologic target. Thus, any attempt to assess the missile hazard briefly, forces an arbitrary decision as to the distance a target might be from the potential source of missiles; e.g., if one were 10 ft from a glass window, the missile velocity would be different than at 2, 5 or 20 ft.

For the present analysis, 10 ft of missile travel was arbitrarily selected and used by Bowen in computing the figures presented in Table 13, setting forth the overpressures, ranges and areas for the missile criteria adopted previously (see Table 11). For example, the overpressures at which a 10 gm glass missile would gain a velocity of 115 ft/sec in 10 ft of travel were calculated to be 2.2 psi for both the 1 and 10 MT surface bursts. The overpressures are of similar value for the two yields because the missile gains velocity very rapidly in the early phases of its displacement. Differences between the 1 and 10 MT yields only become apparent at distances of missile travel greater than 10 ft.

The 10 gm-115 ft/sec-10 ft criteria for the glass missile is met at ranges of 4.9 and 11 mi, covering 75 and 380 sq mi for 1 and 10 MT surface bursts, respectively.

Likewise, Table 13 shows the overpressures, ranges and areas for the 10 lb masonry missile to reach a velocity of 10 ft/sec in 10 ft of travel. For 1 and 10 MT yields the figures respectively are 2.4 and 2.1 psi, 4.6 and 11 mi, and 66 and 380 sq mi.

In addition, Table 13 shows data applicable to circumstances for which the 10 lb masonry missile was allowed to reach maximal velocity rather than

Table 13

Overpressure and the Respective Ranges and Areas
Computed for the Indicated Missile Velocities
Expected from a 1 and 10 MT Surface
Burst at Sea Level

	Incident overpressures, ranges and areas					
	1 MT			10 MT		
	psi	mi	sq mi	psi	mi	sq mi
10 gm glass fragment, 115 ft/sec in 10 ft:	2.2	4.9	75	2.2	11	380
10 lb masonry, 10 ft/sec in 10 ft:	2.4	4.6	66	2.1	11	380
10 ft/sec:	2.2*	4.9	75	1.5*	14	620

*Minimum overpressure where a velocity of 10 ft/sec is predicted. Corresponding displacements are: 1 MT - 26 ft
10 MT - 58 ft

the velocity over 10 ft of travel. It is instructive to note that winds from a 1 MT surface burst can energize a 10 lb masonry missile to a maximum velocity of 10 ft/sec over 26 ft of travel at a range of 4.9 mi from ground zero where an overpressure of 2.2 psi is expected. Area involved is computed to be 75 sq mi. For the 10 MT case, a velocity of 10 ft/sec over 58 ft of missile travel can occur at a minimum overpressure of 1.5 psi, reaching to 14 mi and covering an area of 620 sq miles.

Tertiary Effects

Dealing with the physical displacement of man involves treating man as a missile for computational purposes. As was the situation with the glass and masonry missiles, displacement velocity, among other things, is a function of time and distance. Calculations, for example, at 6 psi (Nevada altitude) for a yield of 10 MT indicate that a 160 lb object would reach a maximal velocity of 97 ft/sec (66 mph), at which time the distance of travel would be 330 ft. Because there are not very many circumstances in which a man might be thrown hundreds of feet without striking some object, data pre-

pared for the present study were limited to displacement distances of 1, 2, 5 and 10 ft.

Consistent with this, Table 14 shows the overpressures, ranges and corresponding areas at which a 160 lb human being would reach a velocity of 10 ft per second in 1, 2, 5 and 10 ft of travel. For 1 MT yields, the corresponding overpressures range from 4.3 to 2.1 psi for displacement distances of 1 and 10 ft, respectively; the corresponding range and areas are 3.1 and 5.1 mi and 30 and 82 sq mi. A 10 MT surface burst is similar overpressure-wise, being 4.3 and 1.8 psi for a velocity of 10 ft/sec over 1 and 10 ft displacements, respectively. However, the corresponding ranges and areas vary from 6.8 to 12 mi and 150 and 450 sq mi, respectively.

Minimum overpressures where a velocity of 10 ft/sec can be predicted for a 160 lb man, involving displacements of 28 and 55 ft at the time maximum velocity would be reached, are also given in Table 14. In these cases, ranges of 5.5 and 16 mi and areas of 95 and 800 sq mi can be involved for the smaller and larger yields, respectively.

Weapon-Threshold Criteria Summary

A summary of the interrelations between the several tentative criteria adopted to estimate the thresholds of human injury from blast phenomena in terms of ranges and areas involved is given in Figure 7 for 1 MT and in Figure 8 for the 10 MT surface bursts. To a great extent, of course, the two figures reflect the arbitrary choice of criteria, but each serves to show the ranges from ground zero at which primary, secondary and tertiary blast casualties will begin. Stated another way, one can say that inside the ranges shown for each effect, blast-related casualties will progressively increase in number.

In general, Figures 7 and 8 indicate a trend implying that the potential hazard from displacement is more significant than missile damage and that missile damage, in turn, is more important than primary blast injury. To be sure, conditions at the time of exposure will be critical, and no doubt entirely unpredictable for an uninformed and unprotected population under nuclear attack.

Table 14
Overpressures Computed for an Expected Displacement
Velocity of 10 ft/sec for a 160 lb. Human Being Travel-
ling the Indicated Distances. Ranges and Areas
Computed for Surface Bursts at Sea Level

Displacement in ft corresponding to velocity of 10 ft/sec	Incident pressure and corresponding range and area					
	1 MT			10 MT		
	psi	mi	sq mi	psi	mi	sq mi
1	4.3	3.1	30	4.3	6.8	150
2	3.3	3.7	43	3.3	8.0	200
5	2.4	4.7	69	2.3	10	310
10	2.1	5.1	82	1.8	12	450
	1.9*	5.5	95	1.3*	16	800

*Minimum overpressure where velocity of 10 ft/sec is predicted.
Corresponding displacements are: 1 MT - 28 ft
10 MT - 58 ft (After Bowen (86))

With regard to this statement, it is clear that if one were to stand against a wall to avoid exposure to blast winds, displacement injury might not occur, but the hazard from pressure reflections would be increased. Likewise, avoiding contact with firm surfaces to minimize injury from overpressure markedly increases the dangers of displacement. In either case, there exists the missile hazard, and the data clearly indicate that much in the way of protection could be achieved by avoiding blast winds and missiles whether the latter are those impelled by the blast winds or fall due to gravity following the passage of the pressure pulse. In quantitative terms, protection from missiles and blast winds — which might be achieved using a simply constructed fallout shelter — might well reduce the range of serious blast hazards from a 10 MT surface burst from 16 mi (Table 14) to 3.3 mi (Table 12), a difference in area involving 800 minus 34 or 766 sq mi.

There can be no question of the worth of such measures to avoid blast

casualties, but an understanding of the feasibility of protection from nuclear weapons involves consideration of factors other than blast effects.

Relation of Blast to Other Effects

To gain some perspective with regard to the total problem of protection, Table 15 was prepared using data from Glasstone (85) and is presented in preliminary form to point out the need for assessing the relative importance of thermal and initial ionizing radiation compared with blast phenomena. Though the figures for thermal radiation shown are well above those ordinarily assigned for first and second degree burns of the skin at all overpressures associated with the blast criteria presented in Tables 12, 13 and 14 — as is summarized in Tables 16 and 17 — it is nevertheless true that the missile hazard is worse inside buildings than in the open. Germane to this remark, is the fact that thermal fluxes noted in Tables 15, 16 and 17 are those for "free-field" conditions and they will actually be much lower by some unknown amount inside structures; e.g., conditions which maximize the missile hazard, tend to minimize injuries from thermal radiation.

Also, the figures for prompt ionizing radiation are of importance. Interestingly enough, even up to overpressures of 15 psi used as one of the primary blast criteria, prompt radiation expected for the 10 MT case is only about 10 rem (see Tables 15 and 17). Since this is an easily acceptable radiation flux in an emergency, one can say that prompt radiation represents no hazard beyond the 15 psi range (3.3 mi — 34 sq mi).

For 1 MT surface bursts, however, prompt radiation at the 15 psi range (1.5 mi — 7.1 sq mi) is 500 rem, a dose to be avoided at all costs (see Tables 15 and 16). Thinking in this vein leads one to remark that protection against missiles and blast winds should be easy — a simple fallout shelter, for example. The use of such protection, however, will serve to degrade both thermal radiation and the "free-field" prompt radiation "doses" by whatever factor is appropriate to the shielding characteristics of the shelter. In any case, effective protection at overpressures of 15 psi is not difficult and only simple technical problems are involved in its achievement.

Table 15

Various Effects of Biological Interest as a Function of Range
from Ground Zero for 1 and 10 MT Surface Burst at Sea Level

Range mi	1 MT				10 MT			
	P	IR	TR	V	P	IR	TR	V
.6	>100	>3000	880		>100	>3000	>1000	
.8	62	>3000	470		>100	>3000	>1000	
1.0	37	>3000	290		>100	>3000	>1000	
1.2	25	>3000	200	150	>100	>3000	>1000	
1.5	16	500	120	100	88	>3000	>1000	
2.0	9.2	40	65	60	44	850	650	
2.5	6.2	<10	40	39	27	120	400	
3.0	4.6	<10	27	28	18	23	270	110
4.0	3.0	<10	14	17	10	<10	140	65
5.0	2.2	<10	8.8	11	7.1	<10	88	46
6.0	1.7	<10	6.0	7.6	5.2	<10	60	32
8	1.1	<10	3.2	3.9	3.3	<10	32	20
10	<1	<10	2.0		2.4	<10	20	14
12	<1	<10	1.3		1.9	<10	13	11
15	<1	<10	.81		1.4	<10	8.1	7.5
20	<1	<10	.44		<1	<10	4.4	
25	<1	<10	.27		<1	<10	2.7	
30	<1	<10	.18		<1	<10	1.8	
35	<1	<10	.13		<1	<10	1.3	
40	<1	<10	<.1		<1	<10	<1	

P = peak overpressure in psi
 IR = ionizing radiation, exposure dose in rem (initial)
 TR = thermal radiation in cal/cm²
 V = velocity predicted for 160 lb man in a translation distance of
 10 ft

Pressure and radiation data from Effects of Nuclear Weapons

This leaves one last major early effect of weapons — the residual radiation — to assess in relation to blast effects. This problem, along with firestorm, has been considered beyond the scope of this presentation, but a few general remarks are nonetheless indicated.

First, the greatest population density is likely to be within the range of those weapon-produced hazards developing in a matter of seconds and minutes after an explosion — blast, prompt ionizing and thermal radiation effects. Because of the large number of people involved, these "early" effects and the need for protection from them cannot be ignored. Further, the nature and unpredictability of the residual radiation, particularly that due to fallout and the high levels involved from the latter, makes evacuation an unattractive policy. Under such circumstances the levels of residual radiation to be expected at very close ranges from ground zero — like 1, 2, 5, 10, 15, 20 and 30 miles — should and must be estimated if planning for maximal protection is to be sensible and complete. There can be no doubt that this is a critical problem and one regarding which very little empirical data are available.

Even without introducing thinking regarding protection, the "very close in" residual radiation levels need to be known to aid understanding and estimating the "cost" of nuclear war to a nation whose population is practically "naked" and completely unprepared and unprotected for a full-scale nuclear attack.

Table 16

Comparative Weapons Effect Data
Applicable to Indicated Blast Criteria
for a 1 MT Surface Burst at Sea Level

Incident over- pressure psi	Range in mi	Initial ionizing radiation rem	Thermal radiation cal/cm ²	Blast criteria for primary, secondary and tertiary effects
1.9	5.5	<10	7.2	Displacement of man 160 lb 10 ft/sec in 28 ft
2.1	5.1	<10	8.4	Displacement of man 160 lb 10 ft/sec in 10 ft
2.2	4.9	<10	9.3	Missiles (glass) 10 gm 115 ft/sec in 10 ft
2.2	4.9	<10	9.3	Missiles (masonry) 10 lbs 10 ft/sec in 26 ft
2.4	4.6	<10	10	Missiles (masonry) 10 lbs 10 ft/sec in 10 ft
2.5	4.5	<10	11	Eardrum rupture assuming pressure reflection
4.3	3.1	<10	25	Displacement of man 160 lb 10 ft/sec in 1 ft
5.0	2.8	<10	31	Eardrum rupture, assuming no pressure reflection
6.0	2.6	<10	37	Lung damage assuming pressure reflection
15.0	1.5	500	120	Lung damage assuming no pressure reflection

Computed and prepared by Bowen(86)

Table 17
Comparative Weapons Effect Data
Applicable to Indicated Blast Criteria
for a 10 MT Surface Burst at Sea Level

Incident over- pressure psi	Range in mi	Initial ionizing radiation rem	Thermal radiation cal/cm ²	Blast criteria for primary, secondary and tertiary effects
1.3	16	<10	7.2	Displacement of man 160 lb 10 ft/sec in 58 ft
1.5	14	<10	9.5	Missiles (masonry) 10 lb 10 ft/sec in 58 ft
1.8	12	<10	13	Displacement of man 160 lb 10 ft/sec in 10 ft
2.1	11	<10	16	Missiles (masonry) 10 lb 10 ft/sec in 10 ft
2.2	11	<10	16	Missiles (glass) 10 gm 115 ft/sec in 10 ft
2.5	9.7	<10	21	Eardrum rupture assuming pressure reflection
4.3	6.8	<10	46	Displacement of man 160 lb 10 ft/sec in 1 ft
5.0	6.1	<10	58	Eardrum rupture assuming no pressure reflection
6.0	5.5	<10	74	Lung damage assuming pressure reflection
15.0	3.3	10	220	Lung damage assuming no pressure reflection

Computed and prepared by Bowen(86)

Summary

1. The scope and nature of biological blast effects were noted and briefly described.

2. Four categories of blast hazards were defined as follows:

- a. primary effects due to blast-produced overpressures and their reflections,
- b. secondary effects from damage following the impact of penetrating and nonpenetrating missiles energized by blast pressures and winds and gravity,
- c. tertiary effects involving injuries occurring as a consequence of displacement of a biological target by blast shock and winds, and
- d. miscellaneous injuries due to ground shock, dust and blast associated thermal phenomena.

3. The character of primary, secondary and tertiary blast hazards was described to emphasize the seriousness of blast-produced injuries.

4. In further emphasis of the danger, the occurrence of combined injuries from pressure, missiles and displacement was discussed and actual experiences in the Texas City Disaster of 1947 involving over 550 dead or missing, 800 hospitalizations, and between 3000 and 4000 additional casualties were cited to make clear the need for immediate and prolonged care to avoid fatalities if blast injuries are allowed to occur.

5. Selected data relating environmental conditions defining gross biologic damage from overpressures, missiles and impact loading were presented as background for fixing tentative, but conservative threshold criteria for human casualties from blast.

6. A casualty was defined simply as an individual sufficiently injured to be unable to care for himself and thus become a burden to someone else.

7. The tentative criteria adopted were as follows:

- a. Primary blast effects based on (1) lung damage at an

incident and maximal pressure of 15 psi and at 6 psi incident overpressure for conditions wherein a reflection to 15 psi max occurs, and (2) rupture of the eardrum beginning at an incident and maximal overpressure of 5 psi and at an incident overpressure of 2.5 psi under circumstances where reflection to 5 psi max will occur.

- b. Secondary blast effects for penetrating and nonpenetrating missiles; the former referred to a 10 gm glass missile having a velocity of 115 ft/sec which has a 1 per cent probability of traversing the abdominal wall of a dog and entering the abdominal cavity; the latter was estimated considering a 10 lb masonry missile travelling 10 ft/sec as having only a slight chance of producing significant head and body injury.
- c. Tertiary blast effects assumed damage only on decelerative impact, and displacements involving velocities of 10 ft/sec for a 160 lb man were considered low enough to avoid significant numbers of serious head and skeletal injuries.

8. The tentative criteria arbitrarily adopted to "fix" the threshold for blast casualties were related to nuclear weapons of 1 and 10 MT yield, surface detonated at sea level, in terms of overpressures, ranges and areas involved.

9. The maximal ranges at which primary effects would be noted were estimated as follows:

<u>Effect</u>	<u>1 MT</u>	<u>10 MT</u>
Eardrum rupture	4.5 mi	9.7 mi
Lung damage	2.6 mi	5.5 mi

10. The estimated maximal areas involved for primary effects were:

<u>Effect</u>	<u>1 MT</u>	<u>10 MT</u>
Eardrum rupture	64 sq mi	300 sq mi
Lung damage	21 sq mi	95 sq mi

11. The distance travelled by a blast energized missile before impact was noted as one critical factor in determining impact velocity.

12. The estimated ranges at which casualties from penetrating and nonpenetrating missiles would begin for the 1 and 10 MT surface bursts at sea level were:

Type Missile	Weight Missile	Distance to impact	Range	
			1 MT	10 MT
Glass	10 gm	10 ft	4.9 mi	11 mi
Masonry	10 lb	10 ft	4.6 mi	11 mi
Masonry	10 lb	26 ft	4.9 mi	
Masonry	10 lb	58 ft		14 mi

13. The corresponding estimated areas over which missile casualties could be expected were:

Type Missile	Weight Missile	Distance to impact	Area	
			1 MT	10 MT
Glass	10 gm	10 ft	75 sq mi	380 sq mi
Masonry	10 lb	10 ft	66 sq mi	380 sq mi
Masonry	10 lb	26 ft	75 sq mi	
Masonry	10 lb	58 ft		620 sq mi

14. Casualties due to displacement, among other things, were noted to involve the distance of travel before impact.

15. Thus, the estimated ranges over which casualties could be expected for the 160 lb human travelling 10 ft/sec varied with displacement distance at impact for the surface bursts at sea level as follows:

Travel before impact	Range	
	1 MT	10 MT
1 ft	3.1 mi	6.8 mi
2 ft	3.7 mi	8.0 mi
5 ft	4.7 mi	10 mi
10 ft	5.1 mi	12 mi
28 ft	5.5 mi	
58 ft		16 mi

16. The corresponding areas involved for displacement-related human casualties were estimated as:

<u>Travel before impact</u>	<u>Areas</u>	
	<u>1 MT</u>	<u>10 MT</u>
1 ft	30 sq mi	150 sq mi
2 ft	43 sq mi	200 sq mi
5 ft	69 sq mi	310 sq mi
10 ft	82 sq mi	450 sq mi
28 ft	95 sq mi	
58 ft		800 sq mi

17. For megaton yields the estimated displacement hazard from blast reached to greater ranges from ground zero than those estimated for missile damage and the latter to greater distances than those expected for pressure injury.

18. Judging by the estimated areas involved, about 5 per cent of the blast hazard from a 10 MT surface burst arises from casualties related directly to overpressure while near 95 per cent concern damage from missiles and displacement.

19. The relation of nuclear blast effects to thermal and initial ionizing radiation were tabulated in preliminary form.

20. The absence of any hazard from initial ionizing radiation from a 10 MT surface burst over the entire range noted for blast casualties in to a distance of 3.3 mi (15 psi, 10 rem initial ionizing radiation, 220 cal/cm^2) was pointed out.

21. The tabular data presented for "free-field" effects of megaton surface bursts emphasized the short ranges for danger from initial ionizing radiation compared with the ranges for the several blast hazards; likewise, the relatively greater distances compared with blast effects, for potential damage from thermal radiation were noted.

22. The logic of seeking appropriate cover to avoid human casualties from thermal, displacement, missile and pressure effects was discussed

and the associated gain in shielding from residual and initial radiation was mentioned.

23. The need for estimating residual radiation levels expected at very close ranges from ground zero was thought critical, for any assessment of the total "cost" of nuclear war to a nation requires appreciation of the total hazards, including those to the entire population, from all untoward effects which occur as a consequence of nuclear explosions.

Figure 1. Missile and other blast damage to a grain elevator located approximately 600-900 ft from the explosions at Texas City. After Armistead (81).

Figure 2. Missile and other blast damage to liquid storage tanks located about 3200 ft from one of the Texas City explosions. After Armistead (81).

Figure 3. Missile and other blast damage to the compressor room of a chemical plant located about 2100 ft from one of the Texas City explosions. After Armistead (81).

Figure 4. Multiple lacerations of the face, head and neck of an individual located in an office with his right side turned toward a window. Approximate distance was 750 ft from one of the Texas City explosions. After Armistead (81) and Blocker and Blocker (39).

Figure 5. Comparison of the types of damages suffered by the injured at the Texas City Disaster. After Blocker and Blocker (39).

Figure 6. Ranges for various free-field incident overpressures for megaton explosions, surface burst at sea level. Data from The Effects of Nuclear Weapons (85).

ESTIMATED SPATIAL EXTENT OF BIOLOGICAL DAMAGE DUE TO BLAST
Computed for 1 MT Surface Burst at Sea Level

Figure 7. Approximate overpressures, ranges and areas for a 1 MT surface burst at sea level, corresponding to tentative criteria estimating thresholds of human injury from primary, secondary and tertiary blast effects. Data computed by Bowen (86).

ESTIMATED SPATIAL EXTENT OF BIOLOGICAL DAMAGE DUE TO BLAST
Computed for 10 MT Surface Burst at Sea Level

Figure 8. Approximate overpressures, ranges and areas for a 10 MT surface burst at sea level corresponding to tentative criteria estimating thresholds of human injury from primary, secondary and tertiary blast effects. Data computed by Bowen (86).

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