A SURVEY OF THE WEAPONS AND HAZARDS WHICH MAY FACE THE PEOPLE OF THE UNITED STATES IN WARTIME

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I. INTRODUCTION

The emphasis in this paper is on the importance of nuclear weapons as wartime hazards to a nation's populace. Non-nuclear weapons may be a more serious threat to small countries in close proximity to the attacker than they are to the United States, though they are a much less serious threat than nuclear weapons in large-scale attacks against population centers. In some limited circumstances, bacteriological weapons are a potential danger. Although there is no guarantee that novel "Sunday Supplement" type super-effective weapons will not appear in the future, there are none in the offing. Many new developments have lethal applications, but we know of none that threatens to become of major civil defense concern in the next decade or two. The logistics of delivery and distribution have so far always overwhelmingly favored the more compact and more far-reaching effects of nuclear weapons (as suggested in Fig. 1).

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This paper was written as an introduction to the effects of modern weapons for a Civil Defense Protective Construction Symposium held April 19-23, 1965 in Washington, D.C. and sponsored by the National Academy of Sciences. It was also the basis for a chapter in a forthcoming book on Civil Defense edited by Professor E.P. Wigner and the Civil Defense Research Group at Oak Ridge National Laboratory

II. NON-NUCLEAR WEAPONS

CONVENTIONAL HIGH EXPLOSIVE WEAPONS

As in past aerial warfare, bombs and missiles carrying conventional high explosives are capable of extensive damage only when delivered in large numbers and with high accuracy. The usual general purpose bomb or even block-buster must strike or come close to striking its target in order to damage it seriously. Underground shelters are invulnerable to such explosives unless the weapons penetrate to or into the shelter. The air armadas of World War II with their enormous load carrying capacities no longer exist, nor are they necessary for delivering nuclear weapons. Their absence from current air forces precludes the immediate or near future use of heavy bombardment by conventional high explosives. Missile accuracies and load carrying capacities, although seemingly ever increasing, do not promise city target destruction by high explosives in the forseeable future. Although still very useful in tactical and limited warfare, high explosive weapons are less of a threat to civil populations and national survival than they were twenty years ago.

There are, however, numerous situations which might favor resurgence of high explosive weapons. At present, both cold war skirmishes and limited wars (of liberation or insurgency) either threaten to use or actually use high explosives. If such wars become more intense and continue for long periods, it is very likely that sufficient aircraft will be assembled to make bombardment with high explosives a serious matter for civilians in towns and cities.

At some future time, perhaps with the happy advent of a successful nuclear disarmament, conventional high explosives may again become the most serious threat to the physical survival of cities. Annihilation by high explosives is indeed possible - it just costs more and takes longer.

BIOLOGICAL WARFARE

Biological warfare as currently conceived depends on the exploitation of known pathogenic organisms. Since the development of entirely new organisms is highly improbable, the threat from biological agents may be limited to somewhat more virulent or resistant strains of existing organisms.

It is possible to defend oneself successfully against nuclear attack and still be vulnerable to biological agents. Indeed, there exist military and political situations that could make their use attractive, particularly against high concentrations of population. The most intense research development has thus far been concentrated on lethal agents that attack humans, but those damaging to crops and livestock are also available.

Most biological agents are inexpensive to produce. It is the difficulty of disseminating them over hostile territories that constitutes the chief problem in their effective employment. Twenty square miles is about as much as can be effectively covered by a single aircraft.(2) Large-area coverage is a task for vast fleets of fairly vulnerable planes flying tight patterns at modest or low altitudes. While agents vary in their biologic decay rate, most of them perish in normal open-air environments.

Shelter and simple prophylactic measures for both people and the food they eat can be fairly effective against biological agents. For this reason the likelihood of wholesale biological warfare is less than the chance of its limited employment against population concentrations - perhaps by covert delivery, since shelters with adequate filtering could insure rather complete protection to those inside.

The impact of a biological attack on our economy could of course be very great, but in view of the huge effort needed to deliver it, along with its rather indirect and problematic results, there appear to be other more serious threats.

CHEMICAL WEAPONS

Chemical weapons, like biological weapons, are relatively inexpensive, but face nearly insurmountable logistics problems in delivery. Although chemical agents produce casualties more rapidly, the greater quantities that must be delivered to target seriously limit their large-scale deployment. Again, chemical research does not promise the development of significantly more toxic chemicals than we already possess, although the low volatility of some chemical agents makes them more persistent than most biological agents.

III. SPECIAL WEAPONS

RADIOLOGICAL WEAPONS

Radiological weapons, a term which has been applied to nuclear weapons so devised as to produce unusually large amounts of radioactivity, but sometimes used to describe the very much less effective use of collected radioactive wastes in aerosol spray or powder form, could be used to increase the level of local fallout.* Such nuclear weapons might produce isotopes that give off more energetic (and hence more penetrating) gamma rays than occur in normal fission products, or might make selective use of isotopes whose halflives are such as to maximize radiation over particular time periods. Another possible modification might be aimed at producing an isotope that, because of its chemical or physical properties, readily concentrates in living organisms and so increases its biological effectiveness.

The advantages of such modifications are much less real than apparent. In all weapons delivered by missiles, minimizing the total weight for a given payload is very important. If the total payload is not to be increased, then the inclusion of inert material to be activated by neutrons must lead to reductions in the explosive yield. If all the weight is devoted to nuclear explosives, then more fission fragment activity can be created, and it is the net increase in activity which must be balanced against the loss of explosive yield. As it turns out, a fission explosion is a most efficient generator of activity, and significantly greater total doses are not achieved by the use of inert materials. An increase in the dose rate at one time by using special isotopes can be bought only at the expense of lower rates at earlier or later times. The maximum increase of intensity above that from fission products alone is not so large as to compensate for the usual uncertainties in fallout intensities due to meteorology conditions and the point of burst. The advantages of radiological weapons are uncertain, while the disadvantage in giving up explosion energy available for blast and thermal damage is obvious and frequently serious.

*Radiological warfare discussed further in Section 9.110 of Ref. 1.

THE NEUTRON BOMB

If the neutron bomb (so called because it would maximize the effectiveness of the neutrons) could be produced, it would necessarily be limited to rather small yields so that the neutron absorption in air would not seriously reduce the dose. The use of small yields against large-area targets, however, would again run into the delivery problems faced by chemical agents and explosives. In the unlikely event that an enemy desired to minimize blast and thermal damage and create little local fallout but still employ nuclear weapons to kill the populace, he would have to use large numbers of carefully placed neutron producing weapons (burst high enough to avoid blast damage on the ground, but low enough to avoid excessive absorption of the neutrons by the air). In this case, however, adequate radiation shielding for the people would leave the city unscathed.

PENETRATING WEAPONS

Penetrating weapons offer a possibility quite the opposite of the so-called neutron bombs in that they create almost nothing but blast damage. The depth of penetration by impact velocity is generally limited to depths of, at most, around 100 feet for average soil conditions. Unless rather small-yield weapons are used in conjunction with penetration, the blast effects are not seriously degraded, but there is no prompt radiation and less thermal radiation. The fallout will be very much intensified very close by, and consequently much reduced at the larger distances downwind.

NUCLEAR WEAPONS

The effects from a single nuclear explosion are reasonably well understood. The assessment of the damage from an attack is another matter altogether for its accuracy depends on a knowledge of the number of weapons, the yields employed, and the intended targets of the weapons delivered. When projecting into the future, it is not difficult to arrive at widely differing estimates of yields and numbers of weapons that a nation may possess.

Using a country's total capabilities without regard to either intent or competing economic demands, one can construct upper limits on yields and numbers which are frequently too large to be believable or useful. Put another way, because there are no convenient and overriding natural limitations on either the size (and hence the yield) or the number of weapons that can be manufactured, it is more profitable in making future projections to consider some other equally indefinite factors. A vague but historically supported conclusion from past attempts at predicting future enemy weapon stores is that for the next few years and perhaps well into the next decade the number of very large-yield weapons (100 MT class) may be measured in tens, while those in the 1 to 10 MT class may number in the hundreds. But the inventories must inevitably grow with time, as the manufacture of nuclear materials continues, and as additional nations develop their own atomic forces.

A most important caution follows from the easy prediction of increasing numbers of nuclear weapons: (1) Targets not now considered worth attacking may become important. (2) Future views of weapon employment will surely be colored as much by the changes in the numbers, aiming accuracies, and efficiencies of new weapons as by other possibly novel characteristics of new weapon systems. (3) Weapon production rates, in turn, may be influenced by future concepts of warfare, e.g., by increased requirements for penetration aids for missile warheads, and correspondingly for antimissile defenses, or by the generation of entirely new targets with the appearance of weapon systems not currently anticipated.

IV. NUCLEAR EXPLOSIONS

INITIAL CHARACTER

A nuclear explosion is inevitably accompanied by a sudden flux of nuclear and electromagnetic radiations characteristic of nuclear reactions and of the scattering and absorbing properties of the explosion's surroundings. Enormous amounts of energy are very suddenly released in rather small masses and volumes, creating such high temperatures that a considerable fraction of the energy must escape from the weapon as radiated light or heat. But since such a sudden energy release in the atmosphere or in the earth cannot escape entirely or immediately as radiations, the extreme pressures are restrained long enough to cause a strong blast wave. The intensities of all these initial phenomena are capable of causing significant damage to people or to structures and equipment at far greater distances than from any other type of explosive weapon.

NUCLEAR RADIATION

The nuclear radiations, both instantaneous and long-lived, and the required shielding for protection from them are discussed in subsequent chapters. Generally speaking, the prompt or initial radiations from large yield (multi-megaton) explosions cannot penetrate the surrounding air in sufficient intensity to be a serious hazard at the largest distances where serious blast damage or radiation burns can still occur. To maximize the area of blast destruction and thermal ignitions, nuclear weapons must be detonated well above the earth's surface. At these heights they do not create extensive local fallout. For this reason, attacks directed against urban centers could well be devoid of nuclear radiation hazards either prompt or fallout.

UNCERTAINTIES INFLUENCING ATTACK PLANNING

There are many factors that greatly influence the hazards from a nuclear attack and can never be known in detail by an attacker. For instance, several aspects of the local weather influence the resulting damage. The wind pattern at all elevations, the cloud cover, the existence of precipitation, the presence or absence of snow on the ground, the temperature, the visibility near the ground, the humidity at the time of attack and during the preceding few days - all may modify either the fallout pattern or the area of thermal damage. The area of blast damage is less dependent on local weather and is only slightly affected by wind patterns at low overpressure levels (static air pressure in excess of normal air pressure).

The enemy can control only the approximate location, the probable elevation and the yield of the explosion. For bursts on or in the ground, he cannot accurately control the kind and condition of surrounding materials at the time of explosion, and such details can influence fallout and cratering.

Since most of these uncertainties apply to fallout, thermal effects, cratering, and ground shock, but not to blast, an attack planner may be led to count most heavily on damage by blast, and so arrange to maximize its effects to property and people.

HEIGHT OF BURST

Damaging levels of blast from air bursts extend to greater distances than from ground bursts principally because the shock wave, where reflected, can result in pressures several times the incident shock pressure. This height-of-burst effect can double the area of blast damage to ordinary urban structures, although it is relatively less impressive against hardened structures and is entirely ineffective against deeply buried shelters. The Hiroshima and Nagasaki bombs were exploded high enough above the earth's surface to increase the area covered by overpressures sufficient to damage homes and industrial buildings.

For somewhat similar reasons, an air burst provides greater coverage by thermal radiation fluxes capable of igniting fires. Both by shining down more effectively on a larger area (extensive exposure) and by providing a more efficient radiant source, an air burst poses a more serious thermal threat. At sufficiently high altitudes of burst, both the greater distance from the earth's surface and the decreasing ability of the thinning atmosphere to contain and convert the weapon energy into thermal radiation lessen the threat by lowering radiant exposures on the ground. For every weapon yield, then, some altitude of burst will maximize the thermal effectiveness, and some other altitude (perhaps not very different) should optimize the blast effectiveness.

One such case (burst heights to optimize the area covered by a blast overpressure of more than 3 psi, pounds per square inch) is illustrated in Fig. 2, showing the range for 1, 3, and 10 psi as well as the range limits for thermal ignition of fine kindling with various cloud conditions, all as a function of yield.(2) At 1 psi considerable damage will occur in homes: windows break, roofs fly off, walls collapse. At 3 psi many houses collapse or are damaged beyond repair. At about 10 psi modern multistory buildings are damaged "moderately," i.e., to an extent that would require extensive repair and would seriously jeopardize the lives of occupants.

Surface or contact bursts are required if cratering, ground shock, fallout, and very high-level blast damage are to be expected. The details of burst, e.g., whether it occurs just above or just below the earth's surface, or whether it occurs inside a building or under water, can make very significant differences in these effects. A buried burst, even a shallow one, can be enormously more effective than a contact burst at digging craters, at creating downwind fallout, or at causing intense ground motions, while a low air burst is likely to be inefficient at producing such effects. Figure 3 illustrates ranges versus yield for 1, 3, 10, 30 and 100 psi, as well as for thermal ignitions and for various prompt radiation doses from surface bursts.(2) At 100 psi survival is likely only for persons inside well-designed shelters - those which provide protection against heavy doses of radiation and insure that neither blast nor fire can enter.

As mentioned earlier, allowing weapons to penetrate the ground by impact velocity forces alone does not put them at depths of burst much beyond thirty meters, so that only at quite small yields (< 1 KT) can burial effectively constrain the fallout to the immediate vicinity of the crater. For large yields, burial will appear as fairly shallow, thus enhancing cratering, but not seriously degrading blast or heat much below that for surface or contact bursts. At the same time, downwind fallout intensities may increase considerably. Such subsurface delivery is difficult but could be an advantage for some weapon applications. More complete disruption and longer denial of harbor facilities or concentrated transport and industrial areas could be achieved by such weapons. Airfield runways could more surely be cratered.

V. BLAST DAMAGE

The intensities of the air pressures and air motions very near a nuclear explosion are so high that virtually no aboveground structure can remain standing. However, underground or shallow-buried structures are likely to survive to within a half mile of a megaton burst. The important features of the intense blast from a nuclear explosion are the very high dynamic or wind forces that it generates and the long duration of the blast phase. For megaton weapon blasts and for conventional structures, the duration of the blast pressures and winds is longer than the response time of the building, i.e., the building collapses during the passage of the blast wave. The dynamic pressures last for two or three seconds for a megaton burst, and the overpressure lasts for one or two seconds. At high levels of overpressure, however, the pressures drop to a mere fraction of the peak pressure in a small fraction of a second, so that the effective blast forces on resistant and buried structures last for rather short times - short compared to the duration of the rest of the blast wave as well to structure response times. In large measure, it is this very transient nature of the intense blast that allows buried structures to survive, since the very massiveness of the surrounding soil provides the necessary inertia to resist the high forces long enough for the blast to dissipate.

While survival in shelter is possible remarkably close to a point of burst, casualties to unprotected persons are still likely at relatively great distances. Blast-driven glass fragments are a hazard as far away as 13 miles from a megaton surface burst (about ½ psi), and homes will be seriously damaged or collapsed at distances of three or four miles from the same burst (3 to 5 psi). Figures 2 and 3 include the expected ranges for various overpressures from both surface and air bursts as a function of the yield in the megaton range.

It is most striking to note an example of the following sort: a 100 MT weapon burst high enough to optimize 3 psi (at about 20,000 ft) covers an area 66 miles across with more than 3 psi, and could thus destroy buildings and cause casualties among an unsheltered population in unprecedented numbers. In contrast, persons in even fairly crude or hastily built shelters might expect to survive almost anywhere in that same area. Furthermore, while conventional structures aboveground would be heavily damaged in all that area, much of the underground space might remain habitable or be readily made so.

A similar comparison exists for a surface burst of 100 MT, for which the area covered by more than 3 psi may measure less than 35 miles across, but which will at the same time have a central region of virtually complete destruction. The size of that inner devastation zone must depend not only on the conditions of burst, which influence the size of the crater and the amount of massive debris, but also on the extent and sophistication of the protection provided. People in deeply buried shelters, or very carefully constructed facilities, can survive as close as one and a quarter miles from this 100 MT surface burst (1000 psi) and even closer.

It is this very great difference in the opportunities for surviving the immediate effects of nuclear attacks (for sheltered versus unsheltered people) that has induced many persons to consider adequate shelters and shelter planning as essential to preparations for the defense of civil populations in the event of war or attack.

VI. THERMAL RADIATION FROM NUCLEAR BURSTS

Since about one third of the energy of a nuclear explosion reaches to large distances in the form of heat - arriving within the first few seconds - the potential burns and fire ignitions are clearly important consequences of large-yield weapons. Although burns and fires - even large-scale conflagrations - are sufficiently common as to be quite well understood and each has been subject to a good deal of analysis, some uncertainty still remains concerning the overall efficiency with which large-yield nuclear explosions can initiate fires, and about how such fires will grow, and what determines the eventual areas of destruction. The important role that local weather and visibility play in this matter has already been touched on. The nature of the thermal radiation from the fireball source - both in spectral character and time history - is subject to some variation, not all of which is understood or well documented. The physical chemistry and dynamics of the ignition of fuels or burning of skin are incompletely analyzed, particularly as related to the transient thermal load. Much is already known, however, about the character of the thermal source, about the transmission in various meteorological circumstances, and about the susceptibility of exposed materials to sustained ignition. Our ability to predict the consequences from any given set of nuclear sources and weather conditions over any specific area is already good enough to provide estimates that are usually as accurate as predictions of blast effects and more accurate than those for fallout.

The susceptibility to sustained ignition by thermal flash is mainly limited to thin kindling fuels, e.g., dry newspaper, dry grass or leaves, some drapery and upholstery materials, broken wood, shingles, shavings, or paper trash. A crude but fairly reliable measure of thermal flash ignitability (for sustained burning) is the tendency of material to burn when exposed to the flame from an ordinary kitchen match. Dropping lighted matches wherever the bomb light might shine would expose a great many potential fire sources in many communities, but would also show that most wildland areas are basically non-ignitable during most of the seasons. Most exposed surfaces in the city are non-combustible and much of the remainder is not ignitable by thermal flash. Although many fires could simultaneously start wherever building interiors are illuminated by the bomb thermal energy, they are not likely to be immediately beyond control, and will often go out unattended as they exhaust the available fuel (as in trash barrels or isolated wood piles or even pieces of paper on tables or floors).

As fires spread from individual ignitions and involve whole structures and groups of buildings, the problems become those of the mass fire. Experience with mass fires in World War II and before - both conflagrations and fire storms - has suggested many passive countermeasures and remedial actions. In a long-range sense, city planning and building code specifications can do much to minimize the consequence of thermal flash exposure. Simply cleaning up or covering those combustibles susceptible to thermal ignition could make a great difference in the consequences. Hanging non-flammable shields over window openings and removing likely fuels from exposed positions could also help.

Training and providing for "first-aid" fire fighting by building occupants would help to meet the enormous task facing professional fire fighters, but any organized effort is likely to be complicated by fallout and accompanying blast damage that causes widespread simultaneous disruption of communications and water flow. It may be that aside from assembling or preparing some fire fighting hand tools and extinguishers before attack, fire fighting measures by civilians must be restricted to their moving promptly to put out the fires within their immediate reach as best they can. Most of these fires are likely to be in easily spotted, exposed positions and involve light, readily extinguishable fuels. Such efforts might prove to be the best active countermeasure that can be taken after attack.

VII. GROUND SHOCK AND CRATERS

Nuclear air bursts create pressures and motions in the ground by the air overpressures on the surface, but at almost all levels the air-induced ground motions are of lesser consequence than the direct air blast effects. Injuries can be sustained from sudden motions of the walls and floors of buried shelters at high overpressures; which may even collapse such structures, but the dangers from shock transmitted to occupants is almost never severe until overpressures exceed 100 psi. Occupants in shelters intended to survive above 200 psi should be protected with padding, with straps, or by bunks and hammocks. Shelter appurtenances must be secured or isolated so as to avoid their becoming dangerous missiles within the shelter. Shelters in hard rock suffer less displacement but higher accelerations and are generally less likely to lead to ground shock casualties than shelters located in soil.

Even deeply buried structures may suffer damage from bursts on or near enough to the earth's surface to cause cratering. They are relatively unaffected, however, by air-burst weapons. They must also be very close to the point of burst and subsequent crater from contact or ground bursts to be collapsed by the direct earth stress. The cratering action from nuclear explosions is well enough understood for us to predict with some confidence crater dimensions, the extent of damaging earth stresses, and the quantities and distribution of crater debris. One set of predictions for crater dimensions(3) suggests the following radii, depths and volumes for large-yield contact bursts.

CRATER DIMENSIONS - CONTACT BURST IN SOIL

Yield (MT)	Radius (ft)	Depth (ft)	Volume (Millions of Cu. yds.)
1	410	120	0.9
10	780	200	5.4
100	1500	330	33

The crater and associated ground shock, debris, and local fall-out are very much larger for nuclear weapons which are able to penetrate the soil before detonation. The following are estimates for a burst depth of 100 feet.

CRATER DIMENSIONS - 100 FT DEPTH OF BURST IN SOIL

Yield (MT)	Radius (ft)	Depth (ft)	Volume (Millions of Cu. yds.)
1	1050	290	14
10	1900	430	69
100	3300	630	305

Even though these craters are enormous, they clearly do not indicate that a target city could in any sense be covered by one or a few craters. Because debris is distributed widely and far beyond the crater's edge, even such impressive masses of dirt do not represent much more than heavy dust layers and an occasional shower of dirt clumps or rock projectiles beyond the immediate crater's lip.

Crushing stresses beneath a crater do not extend much more than one and a third crater radii (five to seven times the depth), so that very deeply buried shelters are likely to be immune to any but the largest imaginable weapon's burst after considerable earth penetration. Even shallow buried structures may survive at only a little beyond the crater's edge (less than half a mile from a surface burst 100 MT explosion, and perhaps as close as two hundred yards from a 1 MT burst).

VIII. FALLOUT

The vast areas that can be contaminated with serious levels of radioactivity in the downwind fallout from a nuclear burst make the subject of fallout a most serious one for civil defense considerations.

The nature of fallout is well understood. Its physical (size distribution) and chemical properties (solubility, and ability to react with other materials on contact or ingestion) have been intensively studied. Its radiological properties (gamma ray and beta ray energy spectra, decay rates, and damaging capabilities) are known in detail. Even so, predictions of the expected casualties from any specific attack, are not accurate, and are even more uncertain when attacking weapon characteristics such as burst height, target material, bomb design materials, and yields are in doubt.

The vagaries of the winds at the high altitudes where the atomic debris is swept out of the rising cloud to be distributed "downwind" make precision impossible. The details of the conditions of burst - the earth materials adjacent to the weapon - can have a dominant influence on the scavenging of the fission fragment atoms that carry the radioactivity. Unless these radioactive atoms are collected on or in other large particles, they are prone to drift off around the world in the upper atmosphere and do not contribute to the local fallout intensity. For this reason, low air bursts, which do not dig up much material from the earth's surface or do not inject much of it into the fireball and through the vaporized bomb debris inside the fireball, do not create as serious a fallout hazard as ground bursts or buried bursts.

The very intense nature of the explosion tends to mix violently the radioactive bomb vapors with large masses of air and dirt. The high temperatures remaining in the fireball cause these vapors to rise rapidly to very high altitudes before they are dropped out and allowed to drift away downwind. This process insures a rather wide distribution of fallout, and for the large yields can mean a dust plume that falls out over hundreds of miles. At the same time it reduces the likelihood that even the close-in areas will receive doses very much in excess of a few thousand roentgen, i.e., no area near a burst is likely to be irradiated with fallout doses greatly in excess of doses further downwind, which generally will not exceed 3000 r from any one burst.[(1)]

IX. FUTURE WEAPON DEVELOPMENTS

There must always exist some concern that we have not fully anticipated all future possibilities for weapons that might be used against populations, or weapons, either defensive or offensive, that could radically alter our civil defense measures. Nevertheless, we have suggested that the most significant weapon developments of the future are likely to lead only to sophisticated employment of currently anticipated nuclear weapon types. We do not now foresee any largely new form of threat as more effective.

Even the use of tremendous yields in such bizarre applications as upper atmosphere thermal flashes or deep water bursts to generate Tsunami waves on shorelines seems less impressive and less decisive than the use of the same or smaller weapons at more conventional distances from target cities or countries.

Countermeasures are feasible against the rather indirect threats of poisonous gases, germ warfare, weather control, or against thermal or water wave or ground shock effects from distant explosions. It is perhaps most difficult and most expensive of all to counter a direct attack by nuclear weapons. Such weapons already exist in sufficient numbers and sizes to cause unprecedented levels of damage and of casualties. Until and unless these types of weapons are successfully countered or appear to have lost their promised effectiveness, there is little urgency for developing and employing radically different weapons for strategic uses.

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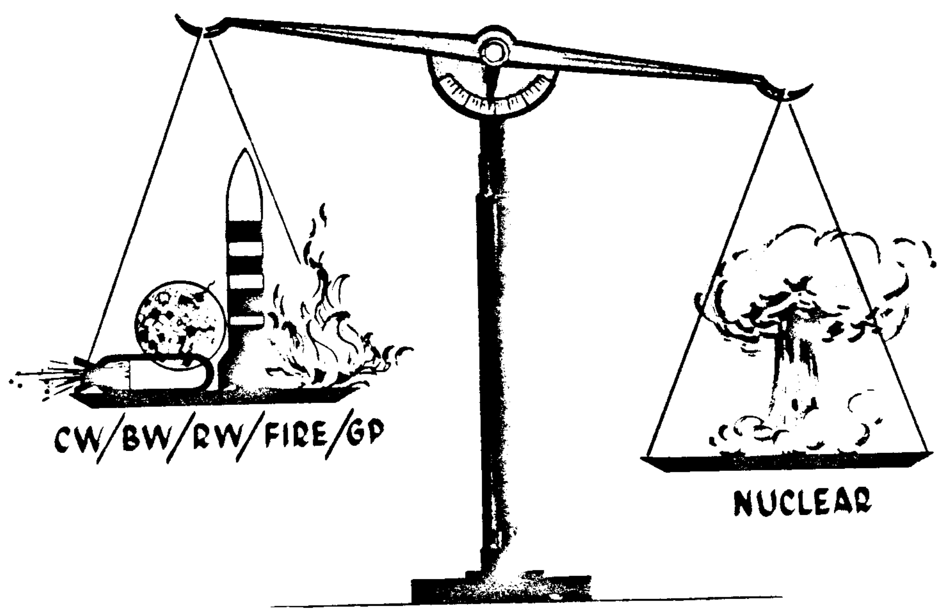

Fig. 1

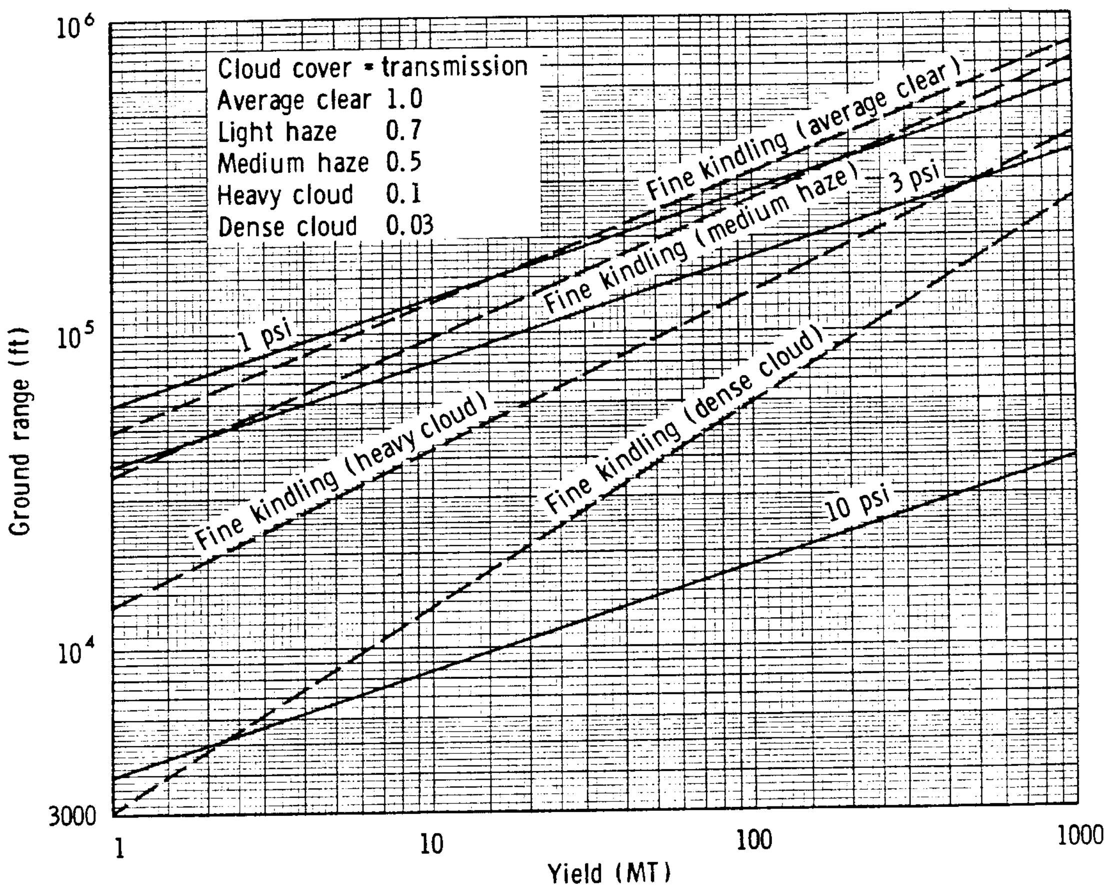

Fig. 2 —Bursts at altitudes to maximize range for 3 psi overpressure

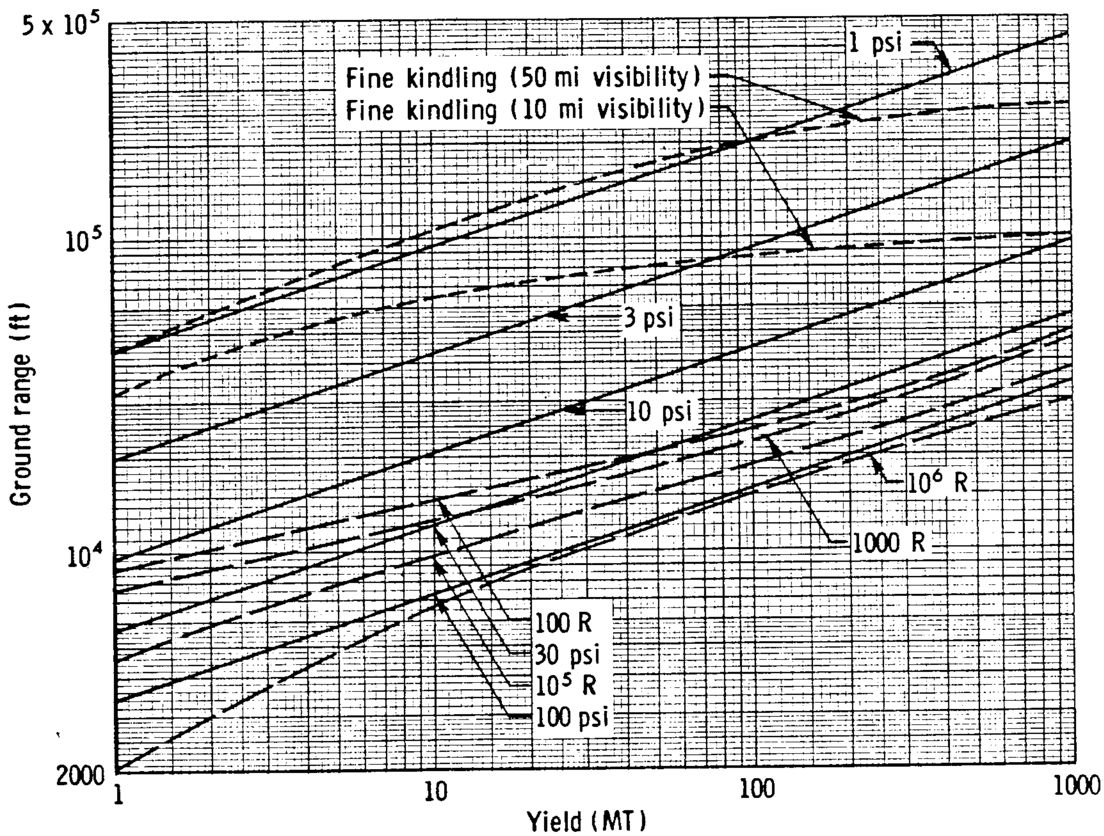

Fig. 3. —Effects of surface bursts