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The Short-term Consequences of Nuclear War for Civilians

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The Environmental Effects of Nuclear War

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2. The Short-Term Consequences of Nuclear War for Civilians

Abstract

Much of the debate over nuclear weapons policy continues to revolve around discussions of the usefulness of nuclear attacks on military targets. Much less attention, however, is devoted to either the number or the importance of the civilian casualties that such attacks would cause.

The short-term civilian casualties that would result from the use of nuclear weapons at three different levels of "limited nuclear war" are considered. These levels range from the employment of neutron bombs during an otherwise "conventional" battle in the Germanies to a nuclear attack against the strategic forces of the U.S. In addition, the consequences of all-out attacks by the superpowers on each other's cities are briefly discussed. It is found that nuclear planners and strategists have almost always grossly underestimated the human costs of the use of nuclear weapons.

Introduction

It is widely believed that, if one of the superpowers resorted to the use of nuclear weapons, the subsequent exchanges might well escalate to all-out nuclear war. It is also widely believed that neither superpower can hope, by attacking the nuclear forces of the other, to eliminate the possibility of its own destruction. These beliefs are major deterrents to the use of nuclear weapons.

The U.S. defense posture vis à vis the Soviet Union in Europe, the Persian Gulf, and elsewhere is, however, based on another premise: that the U.S. is willing, if necessary, to initiate the use of nuclear weapons to stop the Soviet Union from crossing certain imaginary lines that have been drawn around areas the U.S. considers to be of "vital interest."

In order for this threat of first nuclear use to be credible to the Soviets, however, it is first necessary to convince ourselves that the benefits would outweigh the costs. This may explain why there is little discussion in the official literature of the considerations that might discourage the use of nuclear weapons.

The principal subject of this paper is one of these neglected areas: the unintended immediate casualties among civilians that would result from the use of nuclear weapons on military targets. The longer-term effects are discussed in subsequent chapters. In these estimates we take account of the likely effects of short-term radiation fallout of the type described by Upton in chapter 5 but we do not consider the long-term fallout effects on people or on ecosystems as outlined in chapters 5 and 6. The casualty figures discussed in this chapter are therefore on the very low side, and provide a minimum to which should be added estimates of the broader environmental effects. We discuss here the civilian fatalities that would result from the use of nuclear weapons for several cases that we and others have analyzed in some depth:

- Battlefield use in the Germanies (East and West) against conventional forces such as tanks;
- Use on the "theater" level--also in the Germanies--against medium- and intermediate-range nuclear weapon systems and nuclear warhead storage depots;
- Use against missile silos, bomber bases, and nuclear naval support facilities in the U.S.; and
- Use against the cities of the superpowers.

Battlefield Use of Nuclear Weapons

Any major conflict on the conventional level between the superpowers would bring with it the danger that the losing side would resort to battlefield nuclear weapons. In Europe, this threat of "escalation" is implicit in the deployment of thousands of short-range nuclear warheads and delivery systems by the NATO and WTO (Warsaw Treaty Organization) forces.

According to the U.S. Army Field Manual (U.S. Army, 1982), U.S. battlefield nuclear systems are designed for use against

- Enemy nuclear delivery systems.
- Key command and control elements.
- Support forces in the rear of commited elements.
- Follow-on or deep-echeloned forces; and
- Reserves.

Battlefield nuclear systems range from atomic demolition mines, with explosive yields on the order of ten tons (0.01 kiloton) TNT equivalent, to bombs carried by tactical fighter-bombers, with yields of over one million tons (one megaton) TNT equivalent. Between these extremes in both yield and range are nuclear artillery shells and short-range surface-to-surface ballistic missiles (Cochran et al., 1983).

The Field Manual also describes how NATO use of these weapons would be authorized in "packages:"

> A package is a group of nuclear weapons of specific yields for use in a specific area and within a limited time to support a specific tactical goal. Each package must contain nuclear weapons sufficient to alter the tactical situation decisively and to accomplish the mission.

The 1976 edition of the Field Manual gives as an example a package consisting of 2 atomic demolition mines (ADM), 30 rounds of nuclear artillery, 10 surface-to-surface missiles, and 5 air-delivered bombs (see Fig. 2-1).

Efforts would, of course, be made in planning and targeting such a set of nuclear warheads to minimize "collateral damage" to populated areas. This would be hard to do. The most-discussed hypothetical nuclear battlefield in the world in Europe and the most heavily nuclearized region in Europe is the two Germanies. The average popu-

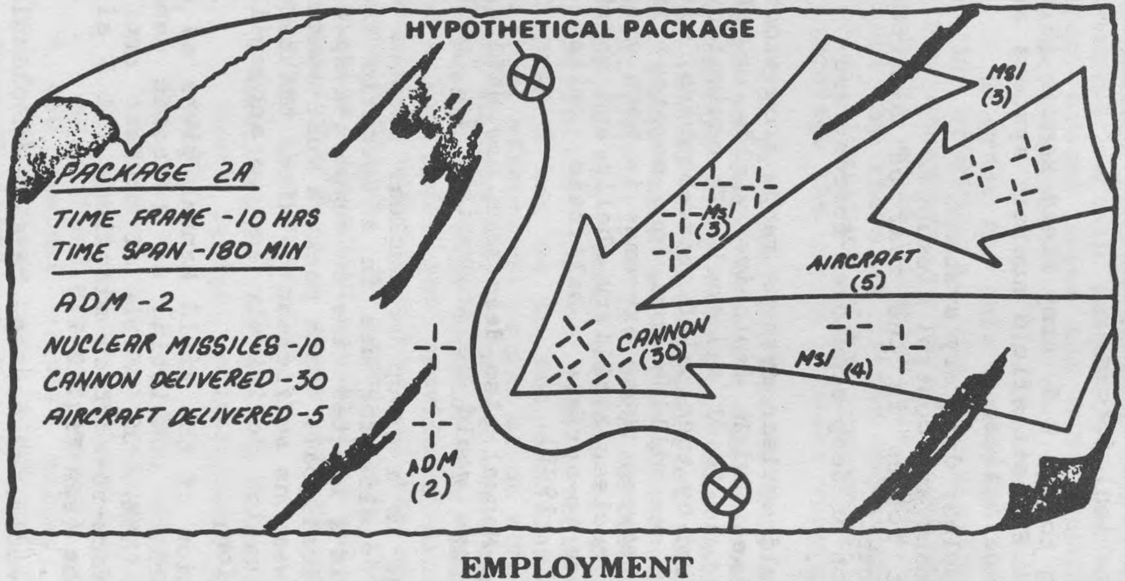

Fig. 2-1. A hypothetical "package" of battlefield nuclear weapons being delivered in front of and on the spearhead and follow-up formations of an attacking ground force. It includes 2 atomic demolition mines (ADM), 30 nuclear projectiles fired by artillery ("cannon"), 10 warheads delivered by short-range battlefield missiles ("Msl"), and 5 nuclear bombs delivered by aircraft (U.S. Army, 1976).

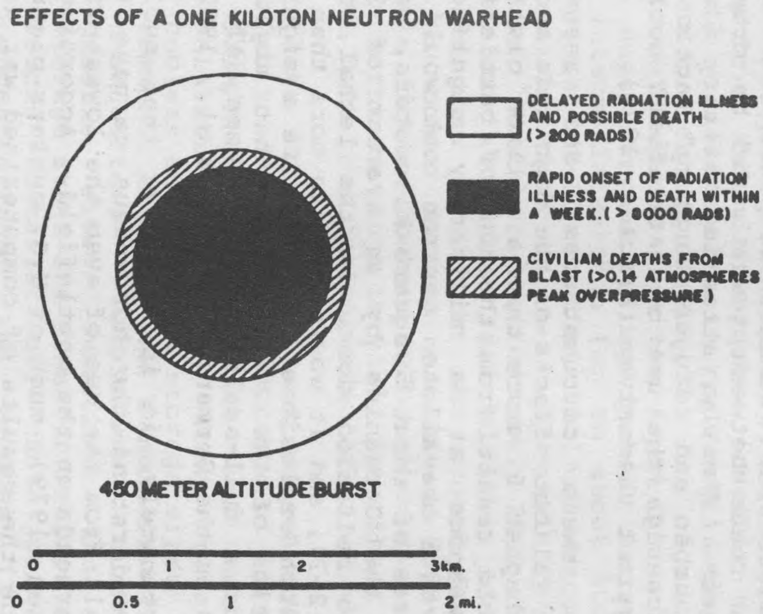

Fig. 2-2. Lethal Areas Around Ground Zero for a Neutron Bomb Exploded at an Altitude of 450 Meters. The innermost circle shows the area of desired military effect: rapid onset of debilitating radiation illness. The slightly larger circle shows the area of serious blast damage to civilian structures. And the largest circle shows the area in which unshielded persons would receive large enough radiation doses to cause death from radiation illness within two months (von Hippel, 1983).

lation density of this area is 200 persons per square kilometer, with one populated place per four square kilometers (Arkin et al., 1982). Additional targeting difficulties would flow from the fact that roads naturally pass through these cities, towns, and villages and therefore so would many of the military units that would be the targets of battlefield nuclear weapons. In many cases, the roads between towns would be crowded with refugees. Finally, attacking military forces might use urban and refugee "hugging" tactics so as to discourage the use of battlefield nuclear weapons against themselves (Bracken, 1979).

Under these circumstances, and assuming short-term fallout effects of the magnitude specified in chapter 5, more than a million civilian deaths could result from the use of battlefield nuclear weapons at a militarily significant level. Even a one-kiloton neutron bomb would expose an area of about 5 square kilometers, populated in the Germanies by an average of 1000 people, to radiation doses in the lethal range (see Fig. 2-2), and it would require more than one thousand such explosions to immobilize a significant fraction of the 20,000 tanks that might be involved in a full-scale battle between NATO and WTO forces in the Germanies (Arkin et al., 1982).

Unfortunately, it is not clear that nuclear planners understand the horrendous carnage that would result from the use of even the lowest-yield nuclear warheads on the battlefield. According to Paul Bracken (1979), much of U.S. nuclear planning is based on the results of computerized war games that predict thousands, not millions, of civilian fatalities from the use of nuclear weapons on the battlefield. He reports that these very low fatality numbers are obtained because the computers are programmed to assume that there are no refugees on the roads and to

> treat Soviet forces as automata who cross into West Germany and advance directly into [unpopulated] NATO nuclear killing zones. Here they are detected and destroyed by the lowest yield nuclear weapon capable of doing the job. Command and control difficulties, confusion, false targeting and other problems are simply assumed away . . . What actually prevents either side from getting too close

to the 4000 towns and cities in Germany is a collection of Fortran statements (Bracken, 1979).

Preemptive Use of Nuclear Weapons in Europe

Clearly, the consequences for civilian populations of even the use of relatively low-yield nuclear weapons on the battlefield could be catastrophic. And, it is quite possible that, in a crisis so severe that it resulted in the crossing of the nuclear threshold, the use of nuclear weapons would spread from the front lines. Indeed, both superpowers have deployed in Europe medium- and intermediate-range (up to about 5000 km for the Soviet SS-20 missile) nuclear weapon systems to back up their short-range battlefield nuclear systems. There are approximately 2000 warheads on land- and submarine-based missiles with ranges greater than 150 km in and around Europe plus nuclear bombs for an estimated 2500 nuclear-capable fighter-bombers and medium-range bombers. These warheads range in yield from about one kiloton to more than one megaton (Arkin et al., 1982).

These "theater" nuclear weapon systems are intended to destroy a whole range of targets:

> IRBM/MRBM [Intermediate and Medium Range Ballistic Missile] sites; naval bases; nuclear and chemical storage sites; airbases; command, control, and communication centers; headquarters complexes; surface-to-air missile sites; munitions and petroleum storage areas and transfer facilities; ground forces installations; choke points; troop concentrations; and bridges (U.S. House Comm. on For. Affairs and Sen. For. Rel. Comm., 1980).

This list corresponds to over one thousand potential targets in the Germanies alone (Arkin et al., 1982).

There are, to our knowledge, no official estimates of the civilian casualties that might result from the use of a significant fraction of these theater nuclear weapons on their intended targets. In order to gauge the possible consequences, therefore, an independent calculation was recently undertaken. The scenario examined involved an attack limited to the nuclear targets in the above list located in the Germanies (Arkin et al., 1982). This target set comprised a total of 171 surface-to-surface missile sites, military air bases and nuclear weapons storage depots (see Fig. 2-3). It would be natural to give these targets the highest priority since they pose the greatest destructive threat to the opposing forces in this region. It was assumed that each would be targeted by one or two 200-kiloton warheads.

The resulting civilian casualties in the two Germanies were estimated to range from 1.5-11 million deaths (7-25 million total casualties). The low figures were obtained by assuming that one 200-kiloton warhead exploded at an altitude of 2 kilometers over each target--too high to cause local fallout. The high figures were obtained by assuming attacks with two warheads--one air-burst and one ground-burst--on each target. This latter type of attack was assumed for "time urgent" targets such as nuclear air bases by NATO planners in a recent war-game (Campbell, 1981).

Thus, even the very limited use of theater nuclear weapons assumed in this scenario against purely military targets would leave a large fraction of the 76 million people living in the two Germanies dead and injured. These casualty estimates do not include the deaths that would result from the radioactive fallout carried by the wind into neighboring countries. (Fig. 2-4 shows the projected fallout pattern from the groundbursts using "typical June winds.") Nor do they include longer-term deaths, such as those from radiation-induced cancers, exposure, starvation, and epidemics.

Once again, the attacks envisioned in this scenario are very restrained--both in terms of the types of targets attacked and the small fraction of the available nuclear arsenal used. This restraint does not seem very plausible. All of the land-based nuclear delivery systems in Europe are vulnerable to nuclear attack, and the initiation of nuclear warfare would result in enormous pressures being put on nuclear decision-makers to "use them or lose them."

<u>Preemptive Strikes at the Intercontinental Level</u>

The leaders of both superpowers have stated that the use of theater nuclear weapons in a regional war would probably result in further esca-

Fig. 2-3. Nuclear Targets in the Germanies. The area of each circle is 180 square kilometers —approximately equal to the area of destruction below a 200 kiloton warhead exploded at an altitude of 2 kilometers (Arkin et al., 1982).

lation to the use of long-range "strategic" nuclear weapons against targets located in the U.S. and the Soviet Union. Indeed, a principal argument for the deployment of U.S. cruise and Pershing II missiles in Western Europe is that, since these weapons can reach deep into the Soviet Union, they will make it even more difficult to limit nuclear war to Central Europe.

At the intercontinental level, the highest priority targets for each side would once again be the nuclear forces of the other side. In fact, much of the history of the nuclear arms race is that of efforts by each side to make the other side's nuclear weapon-systems more vulnerable to attack while trying to decrease the vulnerability of its own. The MX missile, for example, was originally intended both to increase the U.S. threat to Soviet ICBMs and to be less vulnerable than existing U.S. Minuteman missiles to attack by those same Soviet ICBMs.

As we have seen, almost no official information has been made available to the public about the civilian fatalites that could result from the use of nuclear weapons on the battlefield or theater levels. More information has been made available in the case of intercontinental attacks against strategic nuclear forces, however, because of a controversy triggered in 1974 when the Secretary of Defense, James Schlesinger, argued that the U.S. should be better prepared to respond "to a limited attack on military targets that caused relatively few civilian casualties" (Schlesinger, 1974).

The idea that a nuclear attack on the U.S. would not inevitably kill vast numbers of people was a novel one. Schlesinger was therefore questioned in March, 1974, at a Senate Foreign Relations subcommittee hearing, as to what he meant by "relatively few civilian casualties." He replied, "I am talking here about casualties of 15,000, 20,000, 25,000 . . ." (U.S. Sen. For. Rel. Comm., 1974a). The Senators were not satisfied with this answer, however. Schlesinger was asked to return and give them a briefing "on the consequences of the wide ranges of possible anti-military attacks against the U.S." (U.S. Sen. For. Rel. Comm., 1974b).

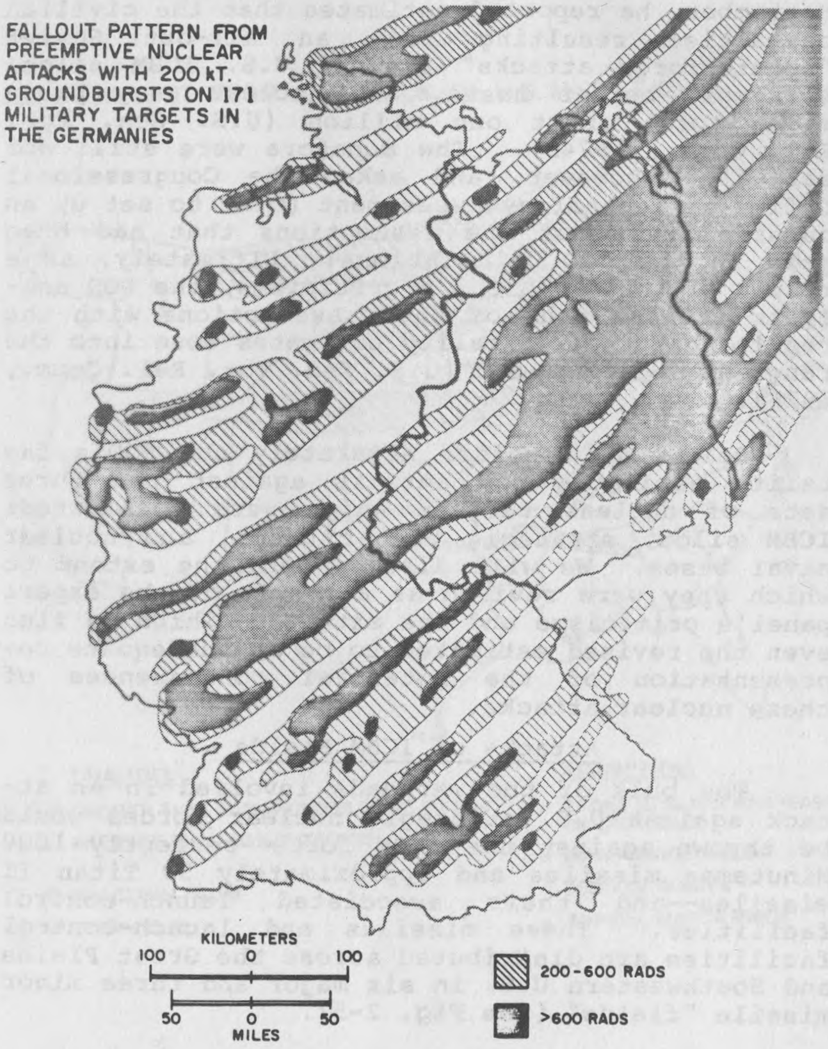

Fig. 2-4. Fallout from 200-kiloton ground-bursts on the targets shown in Fig. 2-3, given "typical June winds". The black areas are those where the radiation levels would be lethal to unsheltered persons. The shaded areas are those in which the radiation levels would be high enough to cause severe radiation illness (Arkin et al., 1982).

When Secretary Schlesinger returned in September, he reported estimates that the civilian casualties resulting from an all-out Soviet "counterforce attacks" against U.S. ICBM silos, strategic bomber bases, and nuclear navy bases might total about one million (U.S. Sen. For. Rel. Comm., 1974b). The Senators were still not satisfied, however, and asked the Congressional Office of Technology Assessment (OTA) to set up an outside review of the assumptions that had been made in the DOD calculations. Ultimately, as a result of the OTA group's criticisms, the DOD analysts revised many of their assumptions with the result that their fatality estimates rose into the range of 3-16 million (U.S. Sen. For. Rel. Comm., 1975).

Below, we consider separately the DOD's fatality estimates for attacks against the three sets of nuclear targets which were considered: ICBM silos, strategic bomber bases, and nuclear naval bases. We will discuss both the extent to which they were revised as a result of the expert panel's criticisms and the extent to which we find even the revised estimates to be an inadequate representation of the potential consequences of these nuclear attacks.

Attacks on ICBM Fields

The bulk of the warheads involved in an attack against U.S. strategic nuclear forces would be thrown against the ICBM force--currently 1000 Minuteman missiles and approximately 50 Titan II missiles--and their associated launch-control facilities. These missiles and launch-control facilities are distributed across the Great Plains and Southwestern U.S. in six major and three minor missile "fields" (see Fig. 2-5).

Since these missile fields are generally located in relatively sparsely populated areas, the blast and heat of Soviet warheads exploding over them would cause relatively few civilian casualties. The missile silos and launch control centers are so hardened, however, that in order to subject one to sufficient overpressure to destroy it, a nuclear warhead would have to be exploded at such a low altitude that the fireball would touch the ground. As a result, such dirt and debris would be sucked up into the fireball, be contaminated with fission products, and subsequently fall

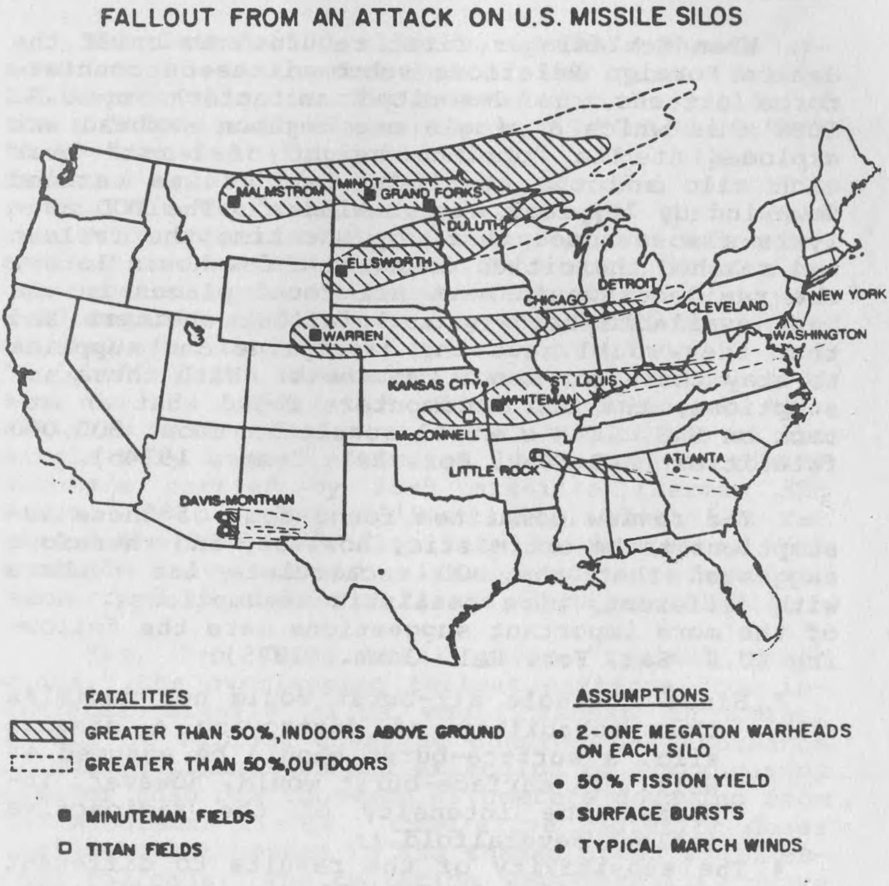

Fig. 2-5. Predicted fallout pattern, given "typical March winds" from 2 one-megaton warheads surface-burst on each U. S. ICBM silo. Within the shaded areas the cumulative biological doses of radiation would rise above the 450 rad average lethal level—even for people who stayed sheltered indoors, where the radiation level is assumed to be one third of that outdoors (U. S. Sen. For. Rel. Comm., 1975).

to earth as radioactive fallout downwind from the target. Most of the fatalities associated with attacks on U.S. ICBM silos were found to be due to radiation doses from this fallout.

When Schlesinger first returned to brief the Senate Foreign Relations subcommittee on counterforce attacks, he described an attack on U.S. ICBM's in which a single one megaton warhead was exploded at its "optimum height of burst" over each silo and the resulting fallout was carried downwind by "typical August winds." The DOD analysts also assumed that, by the time the fallout had reached the cities downwind a few hours later, the residents would have all found places in the best available below-ground fallout shelters and that they would have the discipline and supplies to stay there for about two weeks. With these assumptions, the DOD's computers found that an attack on U.S. ICBM's would result in about 800,000 fatalities (U.S. Sen. For. Rel. Comm., 1974b).

The review committee found some of these assumptions to be optimistic, however, and therefore suggested that the DOD recalculate its numbers with different, more realistic assumptions. Some of the more important suggestions were the following (U.S. Sen. For. Rel. Comm., 1975):

- Since a single air-burst would not maximize the probability of destroying a missile silo, a surface-burst should be assumed as well. (A surface-burst would, however, increase the intensity of the radioactive fallout severalfold.);
- The sensitivity of the results to different wind conditions should be investigated. (As a result, the DOD analysts found that the greatest casualties would result with "typical March [not August] winds".); and
- Less optimistic assumptions should be made about the use of fallout shelters. (The DOD therefore made calculations assuming that about 45 percent of the population did not stay in below-ground shelters.)

As a result of these changes, the DOD's casualty estimates increased by an order of magnitude. It was now estimated that the U.S. would suffer as many as 5 million fatalities from an attack with two 550 kiloton warheads exploded over each ICBM silo (one at the surface and one at "optimum height-of-burst") and as many as 18 million deaths if the warhead yields were increased to 3 megatons (U.S. Sen. For. Rel. Comm., 1975).

The lower (550 kiloton) yield warheads assumed are near the low end of the range (0.5 to 1.0 megatons) ordinarily assumed for the yields of the multiple warheads on Soviet SS-17, SS-18, and SS-19 missiles (Tinajero, 1981). The higher (3 megaton) yield warheads fall outside of this range, but there is another scenario that would result in approximately this megatonnage being deposited on the ICBM fields. This would involve a one megaton surface-burst on each missile silo and a 20 megaton surface-burst on the hardened launch control facility that is associated with each "flight" of ten Minuteman silos. It is believed that in the 1960s, U.S. ICBM launch-control facilities were each targeted with one or two of the single very heavy (estimated 10-20 megaton yield) warheads carried by SS-9 missiles (Berman and Baker, 1982). The SS-18 missile, which has replaced the SS-9, has also been flight-tested with a single heavy warhead, although most are believed to carry 8-10 lighter warheads (Tinajero, 1981).

Fig. 2-5 shows that, given "typical March winds," the overlapping fallout patterns from individual missile silos would result in lethal levels of fallout covering hundreds of thousands of square kilometers and extending to distances of greater than one thousand kilometers downwind from the Minuteman fields. Cumulative radiation doses inside intact houses in the shaded areas would exceed 450 rads. The radiation dose-lethality curve shown in Fig. 2-6 indicates that a 450 rad dose would result in approximately a 50 percent fatality rate in the exposed population.

Attacks on Nuclear Bomber Bases

A Soviet counterforce attack would also be expected to target the 19 U.S. Strategic Air Command (SAC) bases that are the permanent bases for U.S. intercontinental nuclear bombers and the additional SAC bases that host the tanker aircraft that would refuel these bombers during their missions or would act as dispersal bases during a crisis (Berman and Baker, 1982). Fig. 2-7 shows the locations of the 46 SAC bases to which these missions were assigned in 1974 (U.S. Sen. For.

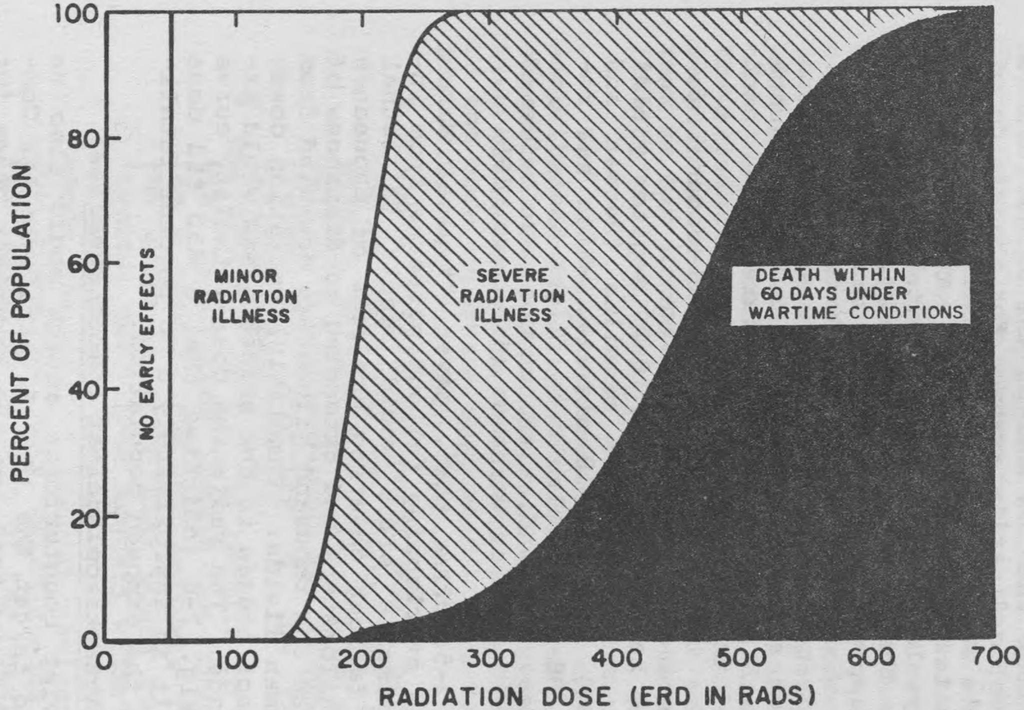

Fig. 2-6. The approximate probability of radiation illness and death as a function of accumulated whole-body dose (Arkin et al., 1982).

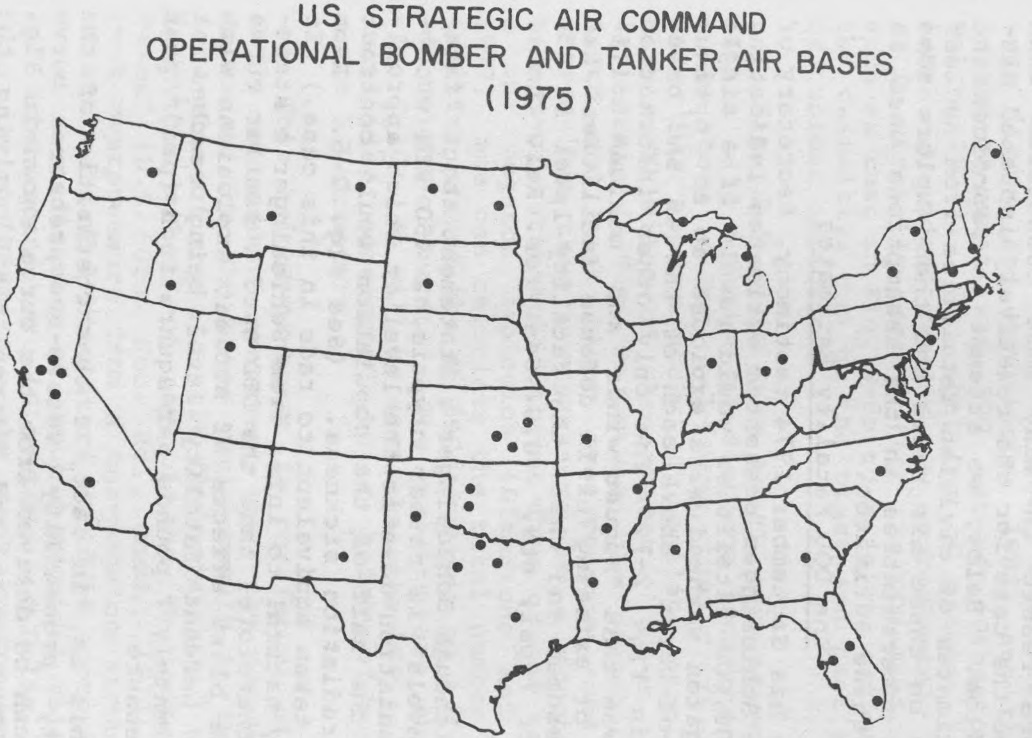

Fig. 2-7. The locations of U. S. nuclear bomber, tanker, and dispersal bases as of 1975 (U. S. Sen. For. Rel. Comm., 1975).

Rel. Comm., 1975; see, also, Air Force Magazine, 1982). Some of these SAC bases are located quite close to urban areas. The blast and heat from nuclear explosions over these air bases would therefore result in many more casualties than would be the case for the relatively isolated missile silos. Below, we attempt to reproduce the DOD estimates of civilian fatalities from nuclear attacks on these air bases and then explore some of the uncertainties in the assumptions used in making these estimates.

The DOD Fatality Estimates

In his September 1974 testimony, Secretary of Defense Schlesinger presented estimates indicating that 300,000 fatalities would result if a single one megaton warhead were exploded at an "optimum height-of-burst" above each of the 46 SAC bases shown in Fig. 2-7. The only other information given was that "August winds" and "maximum utilization of existing civil defense facilities" had been assumed and that "the fatality level is 450 REM's or 7 psi, etc." (U.S. Sen. For. Rel. Comm., 1974b).

Although Schlesinger's statement about "fatality levels" is rather cryptic, a 450 REM whole-body radiation dose is the level at which approximately one half of the population would contract fatal radiation sickness. (See Fig. 2-6. Rems may be taken equivalent to rads in this case.) It is only natural to infer from Schlesinger's statement, therefore, that the DOD used a similar curve for the blast effects of nuclear explosions with the 50 percent fatality level being reached at approximately 7 pounds per square inch (psi)[1] peak overpressure.

This is, in fact, a characterisitic of the fatality probability versus-overpressure curve which can be derived from the curve shown in Fig. 2-8a (Oughterson and Warren, 1956) giving the probability of death as a function of distance from ground zero at Hiroshima. (The low "tail" on the fatality curve beyond 3 km in Fig. 2-8a presumably reflects an imperfection in the survey

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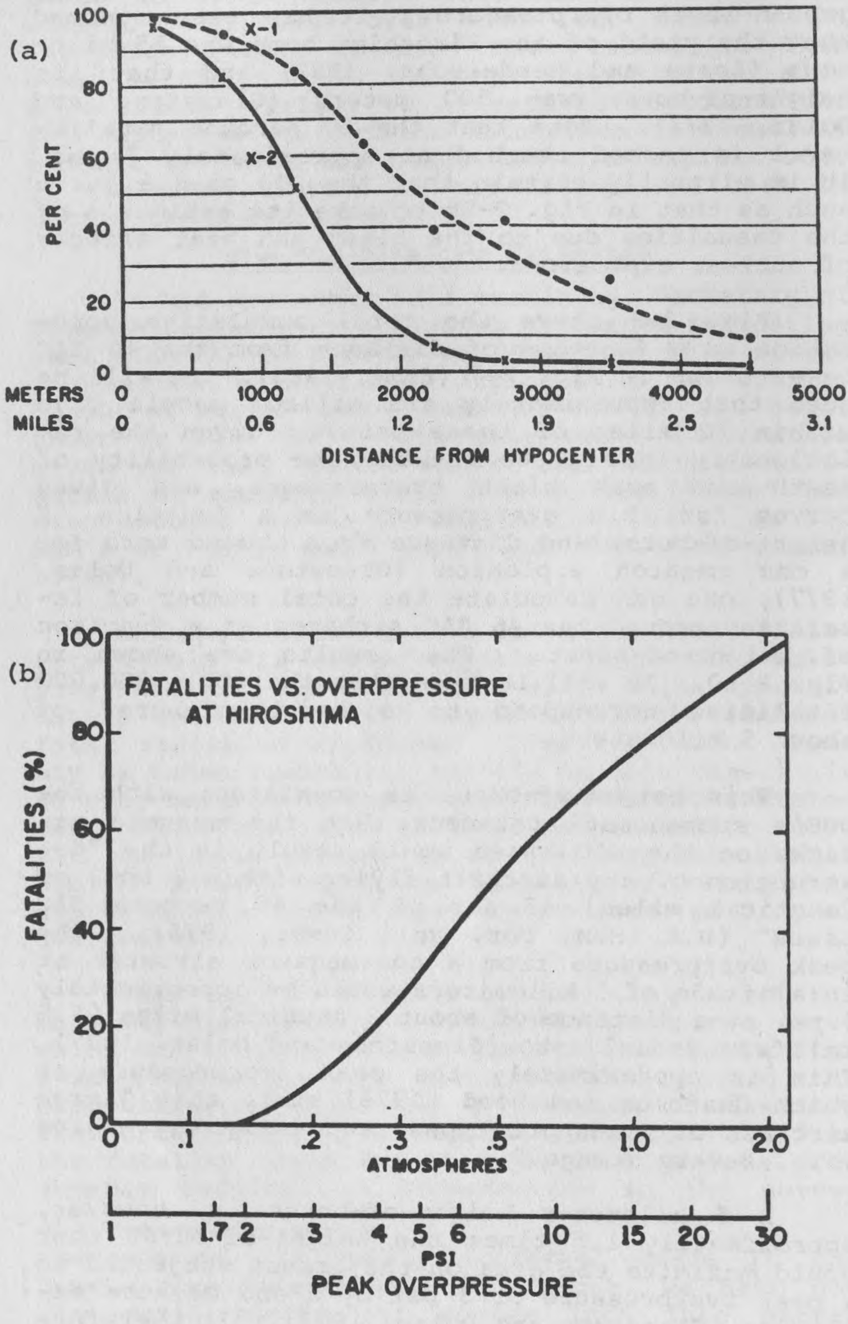
[1]Because of its nearly universal usage in the nuclear-weapons-effects literature, we have not converted pounds per square inch into metric units in the text. One psi = 0.0689 Bars.

used and has been suppressed in our parameterization of the curve.) Fig. 2-8b shows this fatality curve replotted as a function of peak ground-level overpressure. It has been assumed that the yield of the Hiroshima bomb was 15 kilotons (Loewe and Mendelsohn, 1982) and that its height-of-burst was 500 meters (Glasstone and Dolan, 1977). Note that the 50 percent fatality level is indeed reached at approximately 7 psi. It is virtually certain that the DOD used a curve such as that in Fig. 2-8b to make its estimates of the casualties due to the blast and heat effects of nuclear explosions.

Fig. 2-9 shows the total cumulative population as a function of distance from the 46 SAC bases shown in Fig. 2-7 (FEMA, 1983). It will be seen that approximately six million people live within 10 miles of these bases. Given the relationship in Fig. 8b between the probability of death and peak blast overpressure, and given curves for this overpressure as a function of height-of-burst and distance from ground zero for a one megaton explosion (Glasstone and Dolan, 1977), one can calculate the total number of fatalities around the 46 SAC airbases as a function of height-of-burst. The results are shown in Fig. 2-10. It will be seen that the DOD's 300,000 fatalities correspond to a height-of-burst of about 5 kilometers.

This height-of-burst is consistent with the DOD's subsequent statement that the assumed attacks on the SAC bases would result in the "destruction of any aircraft flying within 2 to 3 nm [nautical miles] of any of the 46 targets SAC bases" (U.S. Sen. For. Rel. Comm., 1975). The peak overpressure from a one-megaton airburst at an altitude of 5 kilometers would be approximately 3 psi at a distance of about 3 nautical miles (5.5 km) from ground zero (Glasstone and Dolan, 1977). This is approximately the peak overpressure at which Quanbeck and Wood (1976) state that "large aircraft of transport types are likely to receive . . . severe damage."

A 5 kilometer height-of-burst is, however, approximately 1.5 times the height-of-burst that would maximize the area on the ground subjected to a peak overpressure of 3 psi by a one megaton explosion (Glasstone and Dolan, 1977). It therefore


(a)
100
80
60
40
20
0
PER CENT
X-1
X-2
METERS 0 1000 2000 3000 4000 5000
MILES 0 0.6 1.2 1.9 2.5 3.1
DISTANCE FROM HYPOCENTER
(b)
FATALITIES VS. OVERPRESSURE
AT HIROSHIMA
FATALITIES (%)
100
80
60
40
20
0
0 .1 .2 .3 .5 1.0 2.0
ATMOSPHERES
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PSI
PEAK OVERPRESSURE

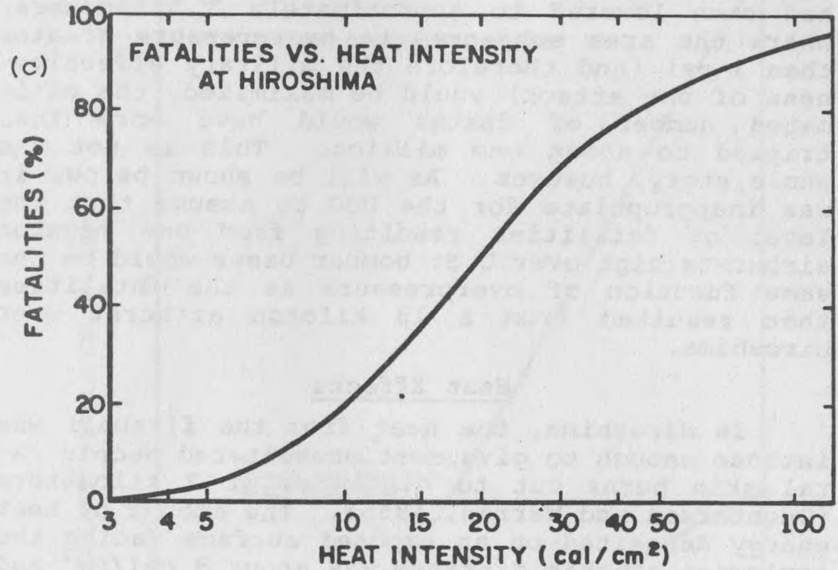

Fig. 2-8. Fatalities at Hiroshima as a function of: a) distance from ground zero, b) peak overpressure, and c) time-integrated thermal radiation intensity. The original data are shown in Fig. 2-8a (Oughterson and Warren, 1956) where the small "x" symbols indicate the total mortality rate at different distances from ground zero, "x-1" the mortality rate due to burns among people in the open directly exposed to the fireball, and "x-2" the mortality rate from ionizing radiation among people shielded from the termal radiation. The dashed curve in Fig. 2-8a indicates the total incidence of mortality plus severe injury.

appears that, as with their initial assumptions about the likely characteristics of a Soviet attack on U.S. ICBM silos, the DOD analysts chose a height-of-burst for the attack on the SAC bases that would limit civilian fatalities in exchange for some lessening of the desired military effect. As Fig. 2-10 shows, if the height-of-burst had been lowered to approximately 3 kilometers, where the area subjected to overpressure greater than 3 psi (and therefore the military effectiveness of the attack) would be maximized, the estimated number of deaths would have more than tripled to about one million. This is not the whole story, however. As will be shown below, it was inappropriate for the DOD to assume that the level of fatalities resulting from one megaton airbursts high over U.S. bomber bases would be the same function of overpressure as the fatalities that resulted from a 15 kiloton airburst over Hiroshima.

Heat Effects

In Hiroshima, the heat from the fireball was intense enough to give most unsheltered people fatal skin burns out to distances of 2 kilometers (Oughterson and Warren, 1956). The amount of heat energy deposited on an exposed surface facing the explosion at this distance was about 8 cal/cm^2 and the peak blast overpressure was 3.5 psi.

It would take a somewhat greater intensity from a one megaton airburst (about 11 cal/cm^2) to be as damaging because of the longer duration of the thermal pulse (Glasstone and Dolan, 1977). If the one megaton explosion occurred at an altitude of 5 kilometers on a clear day, the thermal radiation intensity would exceed this level out to approximately 13 km from ground zero. At this distance, however, the corresponding peak overpressure would be only about 1.5 psi--too low according to the overpressure model shown in Fig. 8b to cause a significant percentage of deaths. It appears, therefore, that in this case the heat effects of the nuclear explosion must be explicitly taken into account.

We have therefore fitted the Hiroshima fatality data with a family of simple models that give variable relative weights to the importance of blast and heat. (These models still ignore the

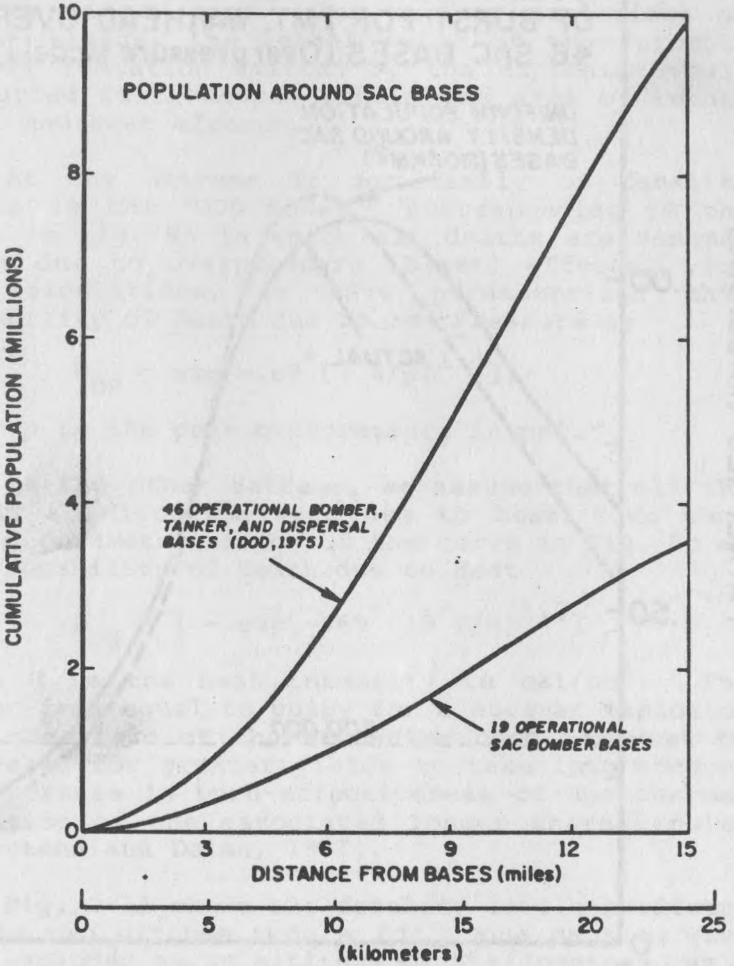

Fig. 2-9. Summed cumulative populations as a function of distance from the centers of 19 operational Strategic Air Command (SAC) bases and all 46 SAC bomber-related (including tanker and dispersal) bases.

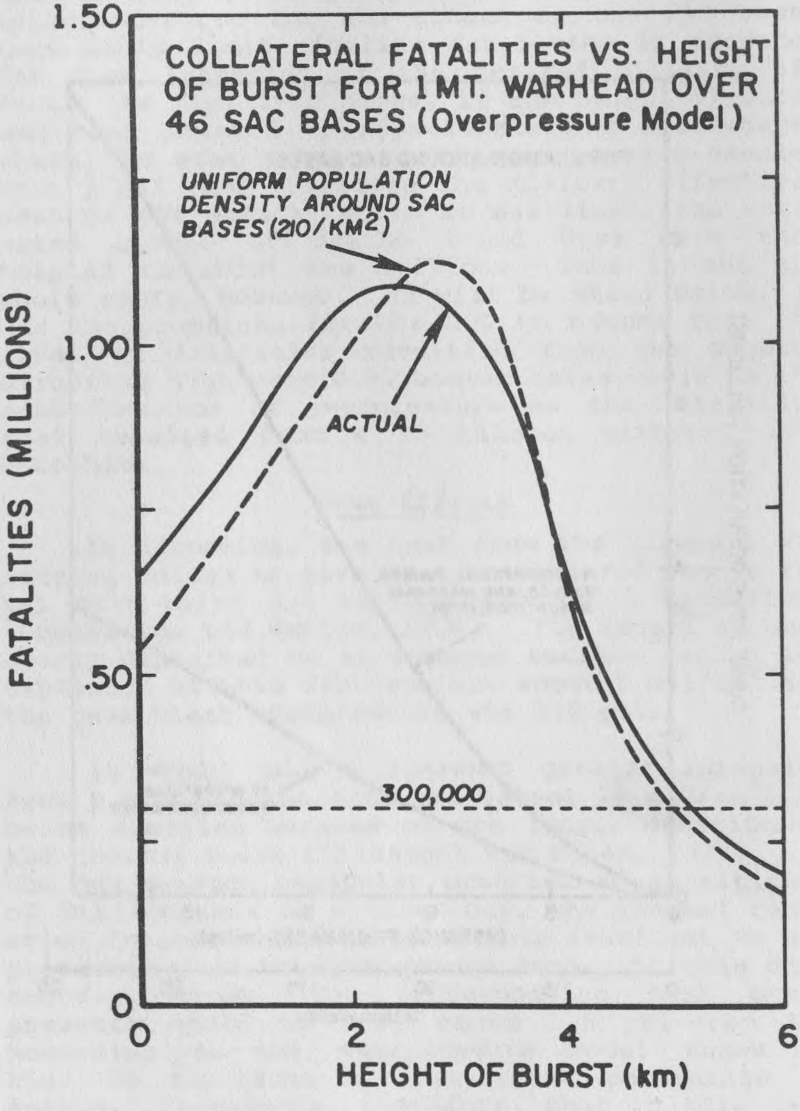

Fig. 2-10. Fatalaties calculated using the curve in Fig. 2-8b—given a one megaton explosion over each of the 46 SAC bases—as a function of the height-of-burst.

fact that, at distances closer than 1 km to ground zero at Hiroshima, people not shielded by thick walls were exposed to lethal doses of gamma radiation from the explosion. Most of these people would, however, have been killed by blast or burn effects in any case. For nuclear explosions of higher yields, the lethal range of the "prompt" nuclear radiation emitted by the explosion would be buried still deeper within the area of lethal blast and heat effects.)

At one extreme of our family of fatality models is the "DOD model," corresponding to the curve in Fig. 8b in which all deaths are assumed to be due to overpressure (blast) effects. For our calculations, we have parameterized this Probability of Death due to overPressure as

$$P_{DP} = \exp[-.69^{*}(7.4/p)^{1.4}],$$

where p is the peak overpressure in psi.

At the other extreme, we assume that all the deaths at Hiroshima were due to heat. We then have a parameterization of the curve in Fig. 8c as the Probability of Death due to Heat

$$P_{DH} = 1 - \exp[-.69^{*}(19^{*}f/H)^{1.3}] ,$$

where H is the heat intensity in cal/cm^2. The factor f is equal to unity for a nuclear explosion with the yield of the Hiroshima bomb but must be increased for greater yields to take into account the decrease in burn-effectiveness of the thermal radiation of the associated longer thermal pulse (Glasstone and Dolan, 1977).

Fig. 2-11 shows the fatality levels predicted by the two extreme models for a one megaton warhead exploded at an altitude of 5 kilometers, as a function of distance from ground zero. It will be seen that the thermal effect model would predict a much higher number of fatalities in this case than the overpressure model used by the DOD--even though the parameters of both models are fixed to predict the same distribution of fatalities for the yield and height-of-burst of the Hiroshima weapon.

Between the extreme models, we have a spectrum of models obtained by taking their weighted

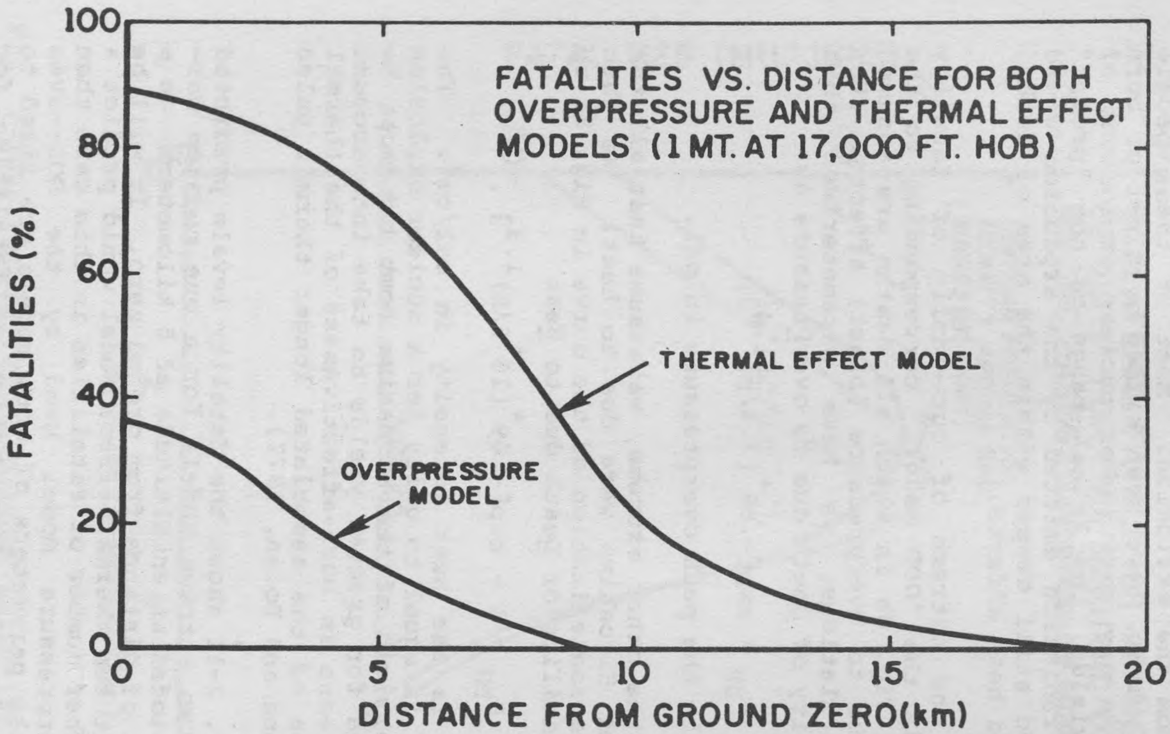

Fig. 2-11. Comparison of the incidence of fatalities as a function of distance from ground zero predicted by the overpressure and heat models, given a one megaton warhead exploded at an altitude of 5 kilometers.

average:

$$P_D = (1 - w)\, P^*_{DB} + w\, P^*_{DH},$$

where w, the weighting factor, can take any value in the range between zero (DOD overpressure model) and unity (heat model). Given a one megaton airburst at a height of 5 kilometers above each of the 46 SAC bases, the corresponding fatality predictions range from the DOD's value of 300,000 to 1.85 million.

It is unclear what value of w might give the most "realistic" model. A value of w = .2, corresponding to a fatality prediction of about 600,000, might seem appropriate if one assumed that 20 percent of the population would be exposed to direct thermal radiation effects--either outdoors or near windows indoors. Higher values of w would be appropriate if the heat radiated by the fireball caused firestorms well beyond the areas of serious blast effects. In either case, it appears that the failure to explicitly consider heat effects in the DOD fatality model was a major omission.

Pattern Attacks

In its critique of the original DOD casualty calculations, the Office of Technology Assessment's review group questioned the assumption that only one nuclear warhead would be used to attack each SAC bomber and tanker base. The panel suggested that it was more likely that the areas around each of the bases would be "pattern" attacked with a number of warheads in order to try to destroy in the air as many as possible of the aircraft that had taken off on warning of attack (U.S. Sen. For. Rel. Comm., 1975). The DOD responded by estimating the number of fatalities that would result from pattern attacks on the SAC bases but buried its results in the consequences of a more comprehensive attack. We have therefore made our own estimates, using the set of fatality models described above.

The only indication given by the DOD of the nature of the pattern attack that it had assumed is the statement that this attack would cause the "destruction on any A/C [aircraft] flying within 8 nm [nautical miles] of the 46 target SAC bases"

(U.S. Sen. For. Rel. Comm., 1975). This corresponds to an area of aircraft destruction 7-16 times as large as that which had been given for a single one megaton warhead attack (2-3 nm [3.7-5.6 km] radius).

We have therefore estimated the number of fatalities that would be caused by a pattern attack by assuming airbursts of 7-16 one megaton warheads distributed over a circle of 8 nm (15 km) in a radius around each of the 46 SAC bases. We have also simplified our calculation by assuming an average probability of death throughout this circle equal to the average probability of death throughout this circle equal to the average probability of death in a circle under a one megaton airburst with a radius of 3.7 km (16 warhead case) or 5.6 km (7 warhead case). Deaths that would occur outside the 15 km radius have been neglected. With these assumptions and an assumed height-of-burst of 5 km, we estimate 1.0-1.6 million fatalities with the DOD's overpressure model (w = 0) and 5.3-6.4 million fatalities with the pure thermal effects model (w = 1).

Ordinarily, in discussions of counterforce attacks against the U.S., it is assumed that the escape time of the bombers and tankers would be minimized by striking their bases with warheads launched from submarines located as close as possible to U.S. shores. In this context, the barrage attacks discussed above would appear implausible because the number of one megaton warheads required (322-736 for 46 SAC bases) is too large to be delivered by the small number of Soviet ballistic missile submarines ordinarily on patrol near the U.S.

Some of the newer Soviet submarine-launched missiles, however, appear to have multiple warheads of smaller yield. The SS-N-18, for example, is believed to be equipped with seven warheads, each with an estimated yield of 300 kilotons (Tinajero, 1981). At a height-of-burst of about 2 km, seven 200 kiloton warheads would be able to cover as large an area with peak-blast overpressures in excess of 3 psi as the seven one megaton warheads exploded at 5 kilometers in the hypothetical pattern attacks discussed above. In such a case, only one SS-N-18 missile would be required for a pattern attack against each of the

SAC bases for a total of 46 missiles in all--about as many as could be carried by three of the Soviet Union's 13-plus Delta III class submarines (Jane's Fighting Ships, 1982-83).

We have therefore estimated the consequences of a pattern attack with an SS-N-18 missile on each of the 46 SAC bases and find 1.6 million deaths using the overpressure model and 0.4 million using the heat model. (The prediction of the overpressure model is higher in this case because of the lower altitude of burst.) If one of the seven warheads were ground-burst for the purpose of cratering and radioactively contaminating the runway of each base, there would be an additional 40,000 fatalities from radioactive fallout (assuming "typical March winds").

Our conclusion from the above discussion is that the DOD's original estimates of the civilian fatalities from a nuclear attack on U.S. bomber and tanker bases were too low--but by a factor that is quite uncertain.

Attacks on Nuclear Navy Bases

In peacetime, nearly half of U.S. ballistic missile submarines, (and therefore over 2000 U.S. strategic warheads) are located in four ports: Groton, Connecticut; Charleston, South Carolina; King's Bay, Georgia; and Bangor, Washington (Cochran et al., 1983). Other potential counterforce targets would be bases hosting attack submarines, aircraft carriers, and other ships carrying nuclear weapons that could be used to attack the Soviet Union or its navy. There are at least six such nuclear navy bases in the continental U.S. in addition to the four bases hosting ballistic missile submarines: Alameda, Long Beach, and San Diego, California; Mayport, Florida; Newport, Rhode Island; and Norfolk, Virginia (Cochran et al., 1983). (See Fig. 2-12.) Attacks on these bases would result in substantial numbers of fatalities in nearby urban areas.

In his 1974 briefing, Schlesinger presented an estimate of 250,000 fatalities resulting from an explosion of a one megaton warhead over four of the above ten naval bases (see Table 2-1). The assumed height-of-burst was not given.

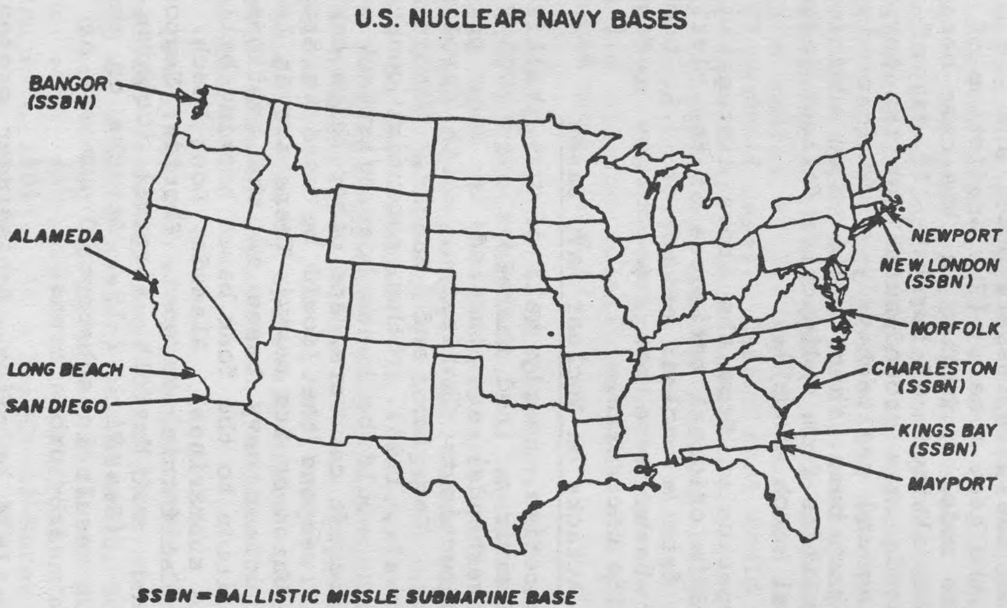

Fig. 2-12. Locations of the major bases in the continental U.S. out of which nuclear-armed naval ships operate.

Table 2-1

Estimated Civilian Fatalities from One Megaton Ground-bursts on Ten Nuclear Navy Bases (in thousands).

Base	DOD[a]	This Work Blast	Fallout	Total
Ballistic Missile Submarine				
Bangor, WA	--	2	34-260	36-260
Charleston, SC	45	38	0- 15	38- 53
Groton, CT	--	30	8-195	38-225
King's Bay, GA	--	0	0	0
Other Nuclear Navy Bases				
Alameda, CA	--	55	22-485	77-540
Long Beach, CA	60	75	72-170	145-245
Mayport, FL	--	8	0- 8	8- 16
Newport, RI	--	8	4-110	12-115
Norfolk, VA	50	73	1-105	74-180
San Diego, CA	90	51	21-435	72-490
	245	340	160-1780	500-2120

Table 1, Notes

[a]U. S. Sen. For. Rel. Comm., 1974b.

We have estimated the number of civilian fatalities--from the blast and fallout--that would result from an attack on each of the ten continental nuclear navy bases. A fallout program provided by the Federal Emergency Management Administration was adapted for this purpose (Schmidt, Jr., 1975). A one megaton ground-burst was assumed as well as the most pessimistic distribution of fallout protection factors used in the DOD's calculations (U.S. Sen. For. Rel. Comm., 1975). Several "typical" winds--March, June, and August--were used (Defense Communications Agency, 1981), resulting in a range of expected fatalities due to fallout. Our results are given in Table 2-1.

Total fatalities in the areas surrounding the ten naval bases were estimated to be 0.5 - 2.1 million. The contribution due to fallout varied from less than a third to nearly all of the total, depending upon the winds. "Typical March winds" gave the lowest estimates while "typical August winds" yielded the highest. In those cases where a DOD estimate was made (Charleston, Long Beach, Norfolk, and San Diego), the DOD figure lies near the bottom or below the fatality range that we calculated.

In a 1980 NATO war game designated "Operation Squareleg" it was assumed that U.S. and British missile submarine bases in Scotland would be attacked with ground-bursts of not one megaton, but 5-megaton warheads (Campbell, 1981). Our preliminary calculations show that the casualties resulting from a similar attack on the nuclear navy bases in the U.S. would be several times higher than in the one megaton case. The total number of fatalities due to blast alone would rise from 340 to 990 thousand.

Attacks on Nuclear Warning, Communications, Command, and Defense Facilities

In order to disrupt if not prevent a U.S. nuclear response, the highest-priority targets of a Soviet attack on the U.S. strategic nuclear system would be U.S. early warning systems, the command centers that would issue the orders for U.S. nuclear weapons use, and the communication systems that would transmit these orders.[2] Presumably, an attempt would be made to destroy U.S. strategic defensive systems as well. As a result of such considerations, Berman and Baker (1982) list, in addition to nuclear delivery systems and their local launch-control facilities, the following "nuclear threat targets" for Soviet intercontinental forces:

- 60 National Command Authority Centers;
- 5 airbases for airborne command posts;
- 60 transmitters for communicating with ballistic missile submarines;
- 132 radars;
- 28 fighter-interceptor sites; and
- 1 ABM test site.

Ball (1981) suggests that a number of ground stations linking the strategic "command-and-control" network to early warning, navigational, military communication, and meteorological satellites would also be targeted.

We have not yet estimated the casualties from an attack against the U.S. command-and-control system. The numbers are likely to be large because there are hundreds of targets, and many are located near highly populated areas. It is already evident from the above discussion, however, that U.S. deaths from a Soviet nuclear attack on U.S. strategic nuclear targets alone would probably number in the tens of millions--comparable to total Soviet losses in World War II--but incurred in a period of days or weeks instead of years.

Attacks on Cities

In view of the horrendous, albeit unintended civilian casualties which would result from serious attacks against strategic weapons and their control systems, retaliation against the cities of the attacking nation would become quite credible.

Attacks on Soviet Cities

In 1968, then Secretary of Defense Robert McNamara ordered the DOD to try to quantify the

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[2] These systems are sometimes denoted by the acronym C^3I denoting Command, Control, Communications, and Intelligence.

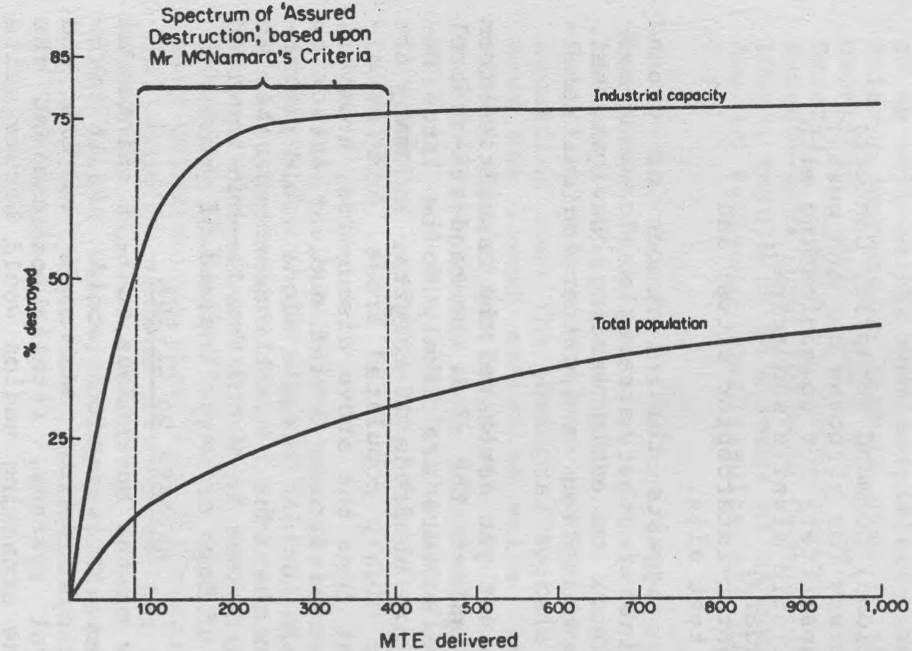

Fig. 2-13. In 1968, then Secretary of Defense Robert McNamara published estimates of the percentages of the Soviet population and industrial capacity that could be destroyed by the U. S. using 100, 200, 400, 800, 1200, and 1600 "equivalent megatons" of nuclear explosive power (McNamara, 1968). The above curves are interpolations of these numbers made by Kemp (1974).

amount of destruction that the U.S. could inflict on the cities and industry of the Soviet Union as a function of the "equivalent megatonnage"[3] of nuclear warheads used. An interpolation of the results (McNamara, 1968) gives the curves shown in Fig. 2-13.

No explanation was given in McNamara's report about the assumptions used in calculating these results. In the case of population, however, a reasonable guess can be hazarded on the basis of a comparison of the "assured destruction" curve in Fig. 2-13, which shows cumulative Soviet fatalities as a function of equivalent megatons used, with the curve in Fig. 2-14, which shows the cumulative Soviet urban population as a function of urban land area. One finds from Fig. 2-15 that the 25 percent of the total Soviet population (50 percent of the urban population) that lives in the most densely populated urban areas of the Soviet Union lives on about 1000 square nautical miles (3500 square kilometers). According to Fig. 2-13, this many people could be killed by 270 equivalent megatons. Dividing the two numbers gives an "equivalent area of death" of about 13 square kilometers per equivalent megaton.

This equivalent area of death corresponds to the area of a circle approximately 2 km in radius. This is the area that could be subjected to an overpressure greater than 30 psi by an airbust or about 20 psi for a ground-burst (Glasstone and Dolan, 1977).

In Hiroshima, however, the equivalent area of death was approximately equal to the area subjected to an overpressure greater than 5 psi (von Hippel, 1983). If this criterion had been used in the calculations done for McNamara, the megatonnages shown along the horizontal axis of Fig. 2-14 would be lower by a factor of 5 for ground-bursts and up to a factor of 12 for air-bursts. Thus, the use of an equivalent area of death scaled from that at Hiroshima would, for example, lead to a

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[3]The "equivalent megatonnage" of a nuclear weapon scales in the same way as the area that it can subject to more than a given peak blast overpressure: as the two-thirds power of the megatonnage.

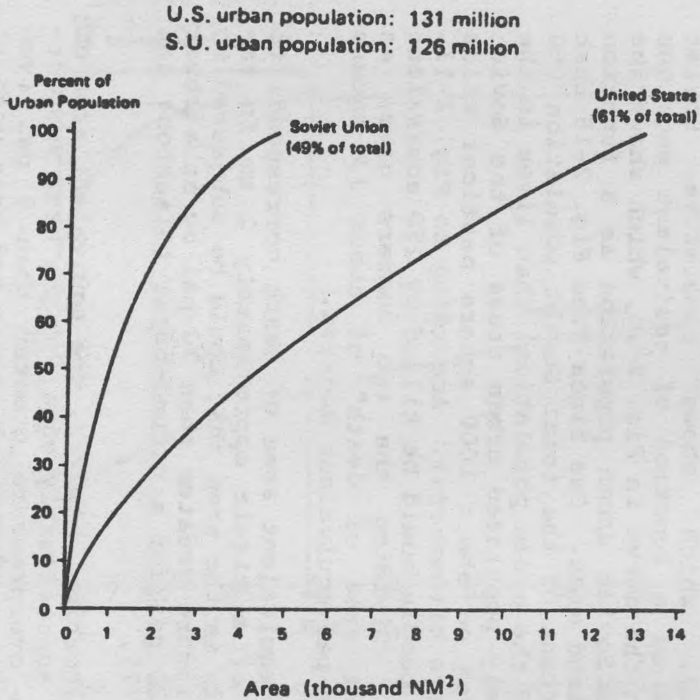
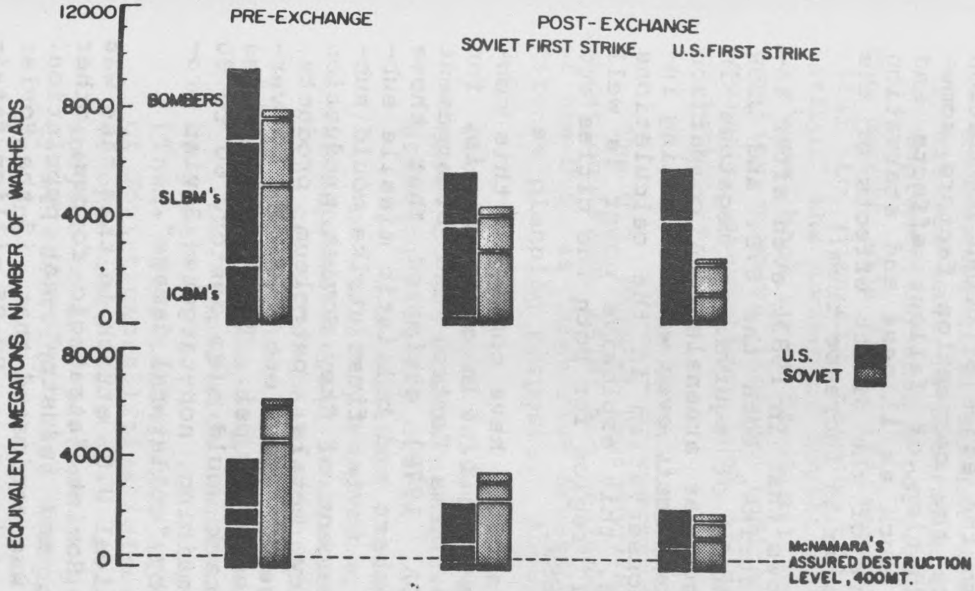


Fig. 2-14. Cumulative Soviet and U.S. urban populations as a function of land area, according to the U.S. Arms Control and Disarmament Agency (1978). One thousand square nautical miles (NM^2) equals 3,420 square kilometers.



CALCULATED RESULTS OF STRATEGIC COUNTERFORCE EXCHANGES; 1982 FORCES
(BOTH SIDES ON GENERATED ALERT)

Fig. 2-15. Comparison of the U.S. and Soviet strategic arsenals as of 1982. The arsenals are measured here in terms of numbers of warheads (first row) and equivalent megatonnage (second row) as they existed (left hand side) and after hypothetical counterforce exchanges initiated by the USSR (middle) or the U.S. (right hand side). The surviving forces were estimated assuming that the exchanges occurred after a period of crisis and that both sides therefore had a greater than usual percentage of their ballistic missile submarines at sea and bombers on quick-reaction alert (Feiveson and von Hippel, 1983).

range of estimates of 20-40 equivalent megatons rather than the approximately 200 equivalent megatons that McNamara's DOD calculated would be required to kill 20-25 percent of the Soviet population. (The overlapping of circles of death with each other and with the edges of urban population areas would reduce the correction factors somewhat, but the addition of fallout effects and secondary effects such as illness and starvation among the survivors of the direct effects of the nuclear explosions would increase them.)

Fig. 2-15 shows that in 1983, even after absorbing a first strike, both the U.S. and USSR would have thousands of equivalent megatons in their surviving nuclear arsenals. A comparison with Fig. 2-14 shows that, even without taking into account the conservatism in the calculations done for McNamara, this explosive power is well into the "overkill" region for both the cities and industry of the USSR.

More recent studies have confirmed this conclusion with more detail. In one analysis, for example, the U.S. Arms Control and Disarmament Agency (U.S. ACDA, 1978) estimated that those U.S. strategic bombers and ballistic missile submarines surviving a Soviet first strike could subject 65 to 90 percent of "key Soviet production capacity" (primary metals, petroleum products, electric power generation, etc.) to peak overpressures in excess of 10 psi. The ACDA estimated that the same attack would also destory 60 to 80 percent of the remaining, non-targeted Soviet production capacity by "collateral damage".

The hypothetical U.S. attack in this case was directed against Soviet "strategic forces, other military targets, and industry"--not population. Nevertheless, it was estimated that, if the Soviet population remained in place, 80-95 million fatalities would result. It was also estimated that this number of fatalities could be reduced to 23-34 million if Soviet cities were evacuated. The ACDA pointed out, however, that its assumptions concerning the effectiveness of evacuation were extremely optimistic:

> 80 percent of the urban population evacuates the cities to range up to 150 km and the remaining 20 percent take protection in the

> best available shelters. The evacuated people are located with the rural population, and both the evacuees and rural people go to the best availale rural shelters and build hasty shelters . . . This posture represents an immense civil defense effort and no analysis was made to determine the feasibility of implementing such a posture.

The report adds that, if "residual weapons [were used] to directly target the evacuated population," the number of Soviet fatalities could be increased back up to 54-65 million. None of these fatality numbers include indirect deaths due to exposure, starvation, lack of medical attention, epidemics, etc.

Attacks on U.S. Cities

The U.S. Federal Emergency Management Administration (FEMA, 1979) has designated certain areas of the U.S. as "high risk areas" for civil nuclear defense planning purposes. According to this report,

> Potential target values were developed . . . based on the following criteria listed in descending priority order:
>
> a. U.S. military installations
>
> b. Military supporting industrial, transportation and logistics facilities.
>
> c. Other basic industries and facilities which contribute significantly to the maintenance of the U.S. economy.
>
> d. Population concentrations of 50,000 or greater . . .
>
> [Then, after taking into account] projections of Soviet capabilities (circa 1980) . . . . envelopes were plotted . . . to depict areas subject to a 50 percent or greater probability of receiving blast overpressures of 2 psi or more.

This hypothetical attack is also discussed in a report published by Oak Ridge National Laboratory (Haaland et.,a 1976). (See Fig. 2-16.) There, it is described as being associated with a specific attack scenario involving a total of 1444 warheads with the following distribution of yields: 20 megatons (241), 3 megaton (176), 2 megatons (184), and 1 megaton (843). This appears to be the approximate distribution of yields which the Soviet strategic arsenal would have if all

Hypothetical Nuclear Attack for Cross Relocation Planning.
Circles Show Areas Covered with 2 psi Or Greater over Pressure from Blast.
Number of Delivered Weapons: 1444. Total Yield Delivered: 6559 Megatons.

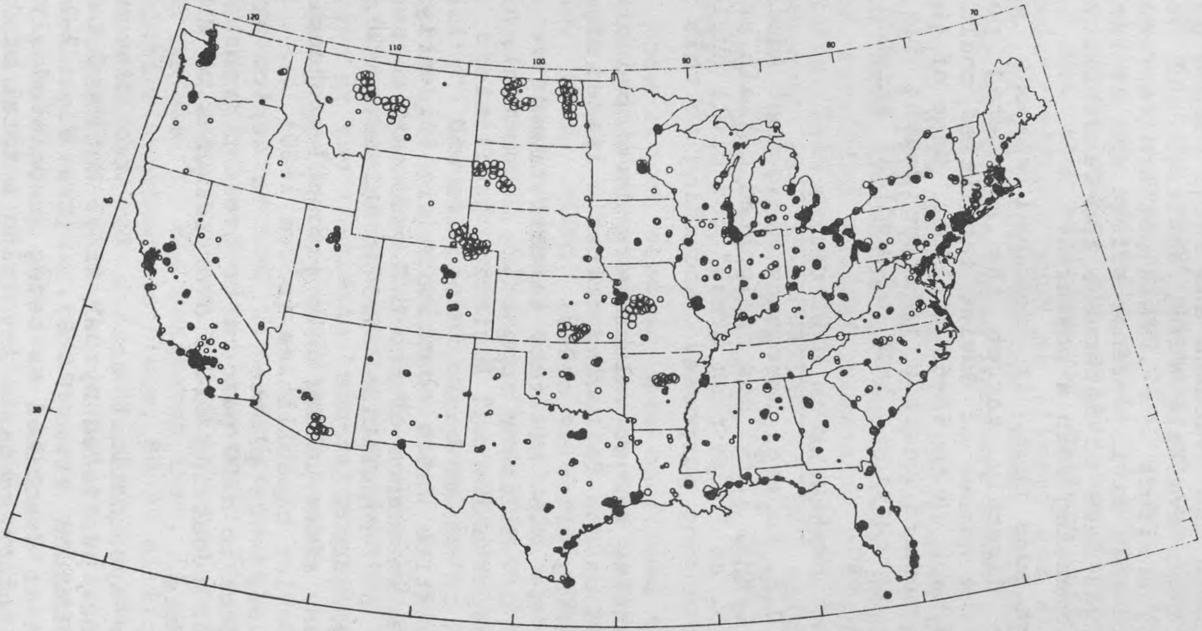


Fig. 2-16. CRP-2B Attack Pattern on the U.S. The hypothetical Soviet attack used by the Federal Emergency Management Administration for civil defense planning purposes (Haaland et al., 1976). The areas within the circles would be subjected to peak overpressures in excess of 2 pounds per square inch.

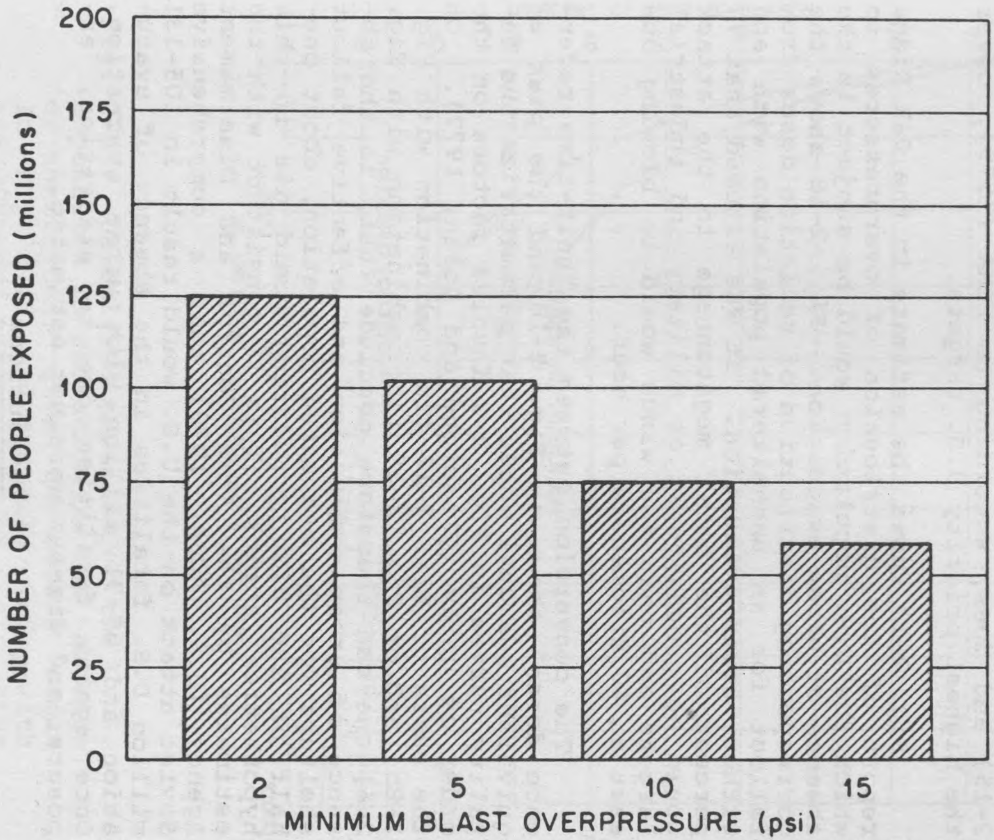


Fig. 2-17. Calculated exposure of the U.S. population to peak blast overpressures, given the attack shown in Fig. 2-16 and in the absence of urban evacuation (Haaland et al., 1976).

Soviet ballistic missiles carried single warheads. Since the scenario was devised, many of these missiles have been replaced with missiles carrying multiple independently-targetable warheads. In terms of both total and equivalent megatonnage (6560 and 3300 respectively), however, the attack is still physically possible (see Fig. 2-15) and does, according to FEMA (1979), cover the highest priority U.S. targets.

Fig. 2-17 shows the estimate in the Oak Ridge report of the distribution of overpressures to which the U.S. population would be subject in the absence of urban evacuation. Fig. 2-18 shows the corresponding distribution of radiation doses from fallout for an unsheltered population with and without urban evacuation. It was assumed that 77 percent of the total megatonnage in the attack would be ground-burst on military and industrial targets and that the winds would be blowing due east at 40 kilometers per hour.

The conversion between the "unit-time reference doses" shown in Fig. 2-18 and the peak equivalent residual doses that parameterize the fatality curves in Fig. 2-6 involve factors on the order of unity (Glasstone and Dolan, 1977). On the basis of Fig. 2-17 (in combination with Fig. 2-8b) and/or Fig. 2-18 (in combination with Fig. 2-6) one can therefore conclude that, in the absence of urban evacuation and effective fallout shelters for the evacuated population, about one-half of the U.S. population would die in this hypothetical attack. This is consistent with the estimates by the Arms Control and Disarmament Agency (U.S. ACDA, 1978) that a comprehensive Soviet attack on the U.S. would result in 105-131 million U.S. fatalities in the absence of evacuation and 69-91 million with urban evacuation. Once again, fatalities due to starvation, exposure, and disease were not estimated.

Conclusions

Most discussions of "limited" nuclear war focus solely on the political and military costs and benefits. Typically, they take little or no account of the possible consequences for civilian populations of such uses of nuclear weapons. When mentioned, these consequences are often dismissed without any attempt at quantification as the unin-

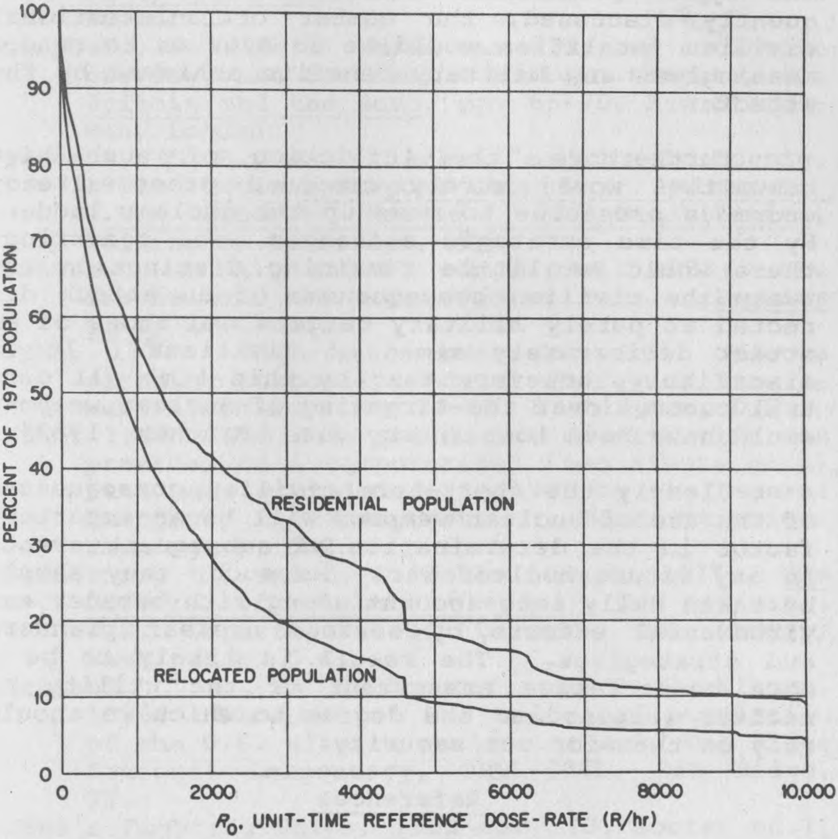


Fig. 2-18. Calculated exposure of the U. S. population to radiation in the absence of sheltering, given the attack shown in Fig. 2-16 and easterly winds—with and without evacuation of the cities and towns (Haaland et al., 1976).

tended "collateral effects" of attacks aimed at purely military targets.

The above discussion shows, however, that for the types of limited nuclear attacks most frequently discussed, the number of unintentional civilian fatalities would be so huge as to render meaningless any military benefits achieved by the attacker.

Furthermore, the infliction of such high casualties would surely compound other already enormous pressures to move up the nuclear ladder. By the time strategic exchanges were occurring, there would be little remaining distinction between the civilian consequences of an attack directed at purely military targets and those of an attack deliberately aimed at civilians. It is also likely, however, that by this time all central control over the targeting of nuclear weapons would have been lost in any case [Bracken, 1983].

Clearly the short-term civilian consequences of the use of nuclear weapons will be an important factor in the determination of subsequent events in any future nuclear war. As such, they should be taken fully into account along with broader environmental effects by serious nuclear planners and strategists. The result is likely to be a more conservative assessment of the utility of nuclear weapons and the degree to which we should rely on them for our security.

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