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The Prompt and Delayed Effects of Nuclear War

The prompt effects of nuclear weapons are the basis for the size of U.S. strategic forces. The delayed effects are equally great, ensuring that these forces remain a more than ample deterrent

by Kevin N. Lewis

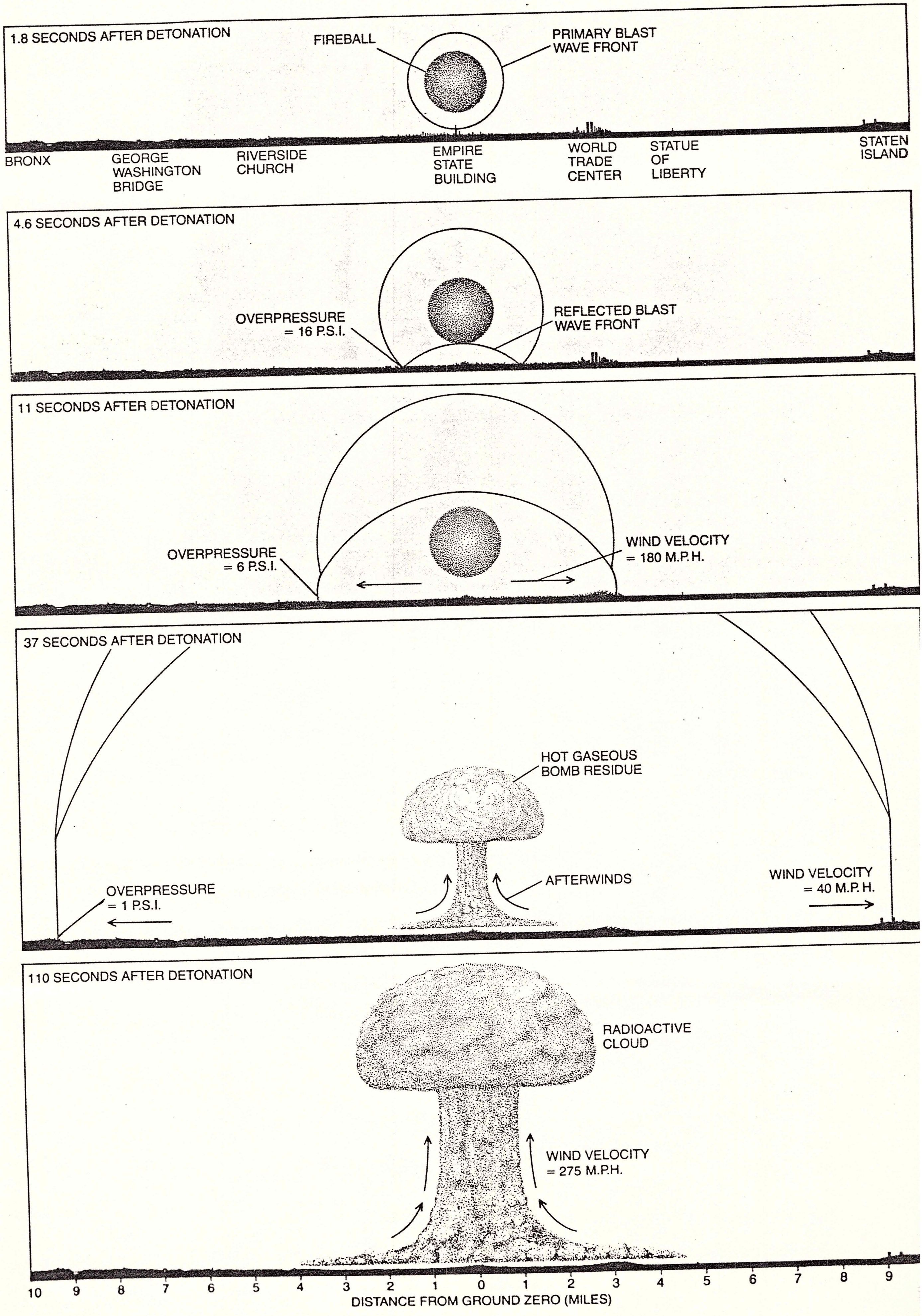
The primary purpose of this country's strategic nuclear forces is to deter the U.S.S.R. from launching an attack on the U.S. or its allies. To accomplish that mission the U.S. maintains the constant ability to inflict intolerable damage on the U.S.S.R. The long-range missile and bomber forces of the U.S. have been designed to survive even an all-out surprise attack by the U.S.S.R. in numbers sufficient to deliver a devastating retaliatory counterattack. Since the U.S.S.R. has similar forces, it is considered unlikely that either side would find it advantageous to attack the other. It is this mutual retaliatory potential, or assured-destruction capability, that is widely held to be responsible for the strategically stable military balance between the two superpowers.

Since in this view the avoidance of war depends in part on the integrity of the assured-destruction capability of the U.S., any degradation of that capability would be a grave matter. Accordingly recent assertions by some military analysts that the U.S.S.R. is actively pursuing measures to reduce the effectiveness of an American retaliatory strike have given rise to much concern. Specifically it is alleged that ambitious Russian civil-defense initiatives could create a dangerous strategic asymmetry in the absence of countervailing U.S. efforts. For example, in conjunction with a surprise "counterforce" attack on U.S. land-based missiles the U.S.S.R. could attempt to evacuate its cities, with the projected result that Russian fatalities in an all-out nuclear exchange would be substantially fewer than American ones. In such a situation the U.S. might be inhibited from further escalating hostilities, and the U.S.S.R. would then in various ways be able to impose its will. Even if all-out war were to ensue, the U.S.S.R., it is said, would be able to recover much faster than the U.S. One result of this line of reasoning has been a revival of interest in the moribund American civil-defense program; another has been the consideration of new strategic-missile targeting options designed to defeat the Russian civil-defense program.

Such hypothetical scenarios are based in part on underestimates of the damage the surviving U.S. forces could inflict on the U.S.S.R. Many estimates of this kind include only the easily calculable blast effects of nuclear weapons. They ignore the equally devastating effects of thermal radiation and ionizing radiation. When these additional effects are included in the calculations, it is clear that nuclear war remains an unmitigated mutual disaster, and that no conceivable civil-defense preparations could materially change the prospect. Therefore from an operational military point of view there is no validity to assertions that the U.S. retaliatory capability is "eroding." Moreover, it is extremely unlikely that the situation will change in the foreseeable future.

How is the damage from nuclear war estimated, and what consequences of such a war are routinely excluded from calculations of the damage? In this article I shall compare calculations frequently used to assess "adequate" levels of assured destruction with estimates of the probable wider results of a nuclear exchange between the two superpowers. The more comprehensive analysis shows that neither the U.S. nor the U.S.S.R. needs to be concerned about the integrity of its retaliatory capability. Although much of the current debate on the gravity of the Russian threat tends to ignore this fact, there can be no conceivable doubt that all-out war remains a losing proposition for both sides. Credible deterrence of course relies on many factors other than the ability to conduct a massive retaliatory attack. It is in the interest of all parties, however, that the notion of "winning" an all-out nuclear war, in the sense of one side's being able to improve its relative position at an acceptable cost, be dismissed from the strategic debate, and that the full consequences of such a calamitous event be brought to public attention.

Specific criteria of retaliatory effectiveness were first established under the direction of Secretary of Defense Robert S. McNamara in the early 1960's. Up to that time strategic military planners lacked any formal quantitative standards for determining the appropriate levels of U.S. retaliatory forces. Secretary McNamara therefore advanced the concept of assured destruction, arguing that the destruction of between 20 and 25 percent of the U.S.S.R.'s population and at least 50 percent of its industrial capacity would constitute unacceptable damage in the eyes of that country's leaders. By establishing these measures McNamara was better able to coordinate Air Force and Navy planning, to match strategic military requirements with existing force structures and to eliminate programs that were superfluous. Although the task of defining a certain level of damage had a political purpose, namely to threaten the government of the U.S.S.R. with intolerable de-


1.8 SECONDS AFTER DETONATION
FIREBALL
PRIMARY BLAST WAVE FRONT
BRONX
GEORGE WASHINGTON BRIDGE
RIVERSIDE CHURCH
EMPIRE STATE BUILDING
WORLD TRADE CENTER
STATUE OF LIBERTY
STATEN ISLAND
4.6 SECONDS AFTER DETONATION
OVERPRESSURE = 16 P.S.I.
REFLECTED BLAST WAVE FRONT
11 SECONDS AFTER DETONATION
OVERPRESSURE = 6 P.S.I.
WIND VELOCITY = 180 M.P.H.
37 SECONDS AFTER DETONATION
HOT GASEOUS BOMB RESIDUE
AFTERWINDS
OVERPRESSURE = 1 P.S.I.
WIND VELOCITY = 40 M.P.H.
110 SECONDS AFTER DETONATION
RADIOACTIVE CLOUD
WIND VELOCITY = 275 M.P.H.
10 9 8 7 6 5 4 3 2 1 0 1 2 3 4 5 6 7 8 9
DISTANCE FROM GROUND ZERO (MILES)

struction, the specific percentages chosen reflected the capabilities of the U.S. strategic forces programmed at that time. The required levels of destruction were also based to some extent on the characteristics of the particular target system represented by the U.S.S.R.

The population and economic resources of the U.S.S.R. are concentrated in a remarkably small number of major urban centers. About a third of the population and nearly two-thirds of the industrial capacity are concentrated in the country's 200 largest cities. Nuclear attacks on additional cities would not appreciably increase the retaliatory damage (except for the delayed effects of radioactive fallout). McNamara's criterion of assured destruction could therefore be loosely translated into the ability to destroy the 200 largest cities in the U.S.S.R.

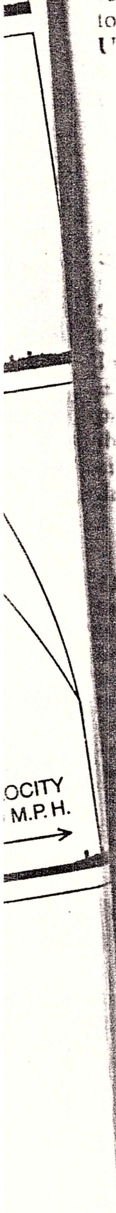
[illegible] this assumption, U.S. force requirements could be set by determining the number of nuclear warheads needed to destroy the social and economic targets of importance in those 200 cities. [illegible] planning is sensitive to many operational factors, such as the composition and layout of cities, but above all [illegible] predicting accurately how [illegible] population will be affected by [illegible] effects of nuclear explosions. [illegible] practice retaliatory damage [illegible] by matching the physical effects of nuclear explosions with the relevant target characteristics on a city-by-city basis. In calculating such damage levels U.S. planners have at their disposal a large store of information on each target, sophisticated analytical techniques and an advanced data-processing capability. The results of these detailed calculations can be approximated fairly well, however, with the aid of some simple procedures.

The yield of a nuclear weapon is usually described in terms of the quantity of chemical explosive required to release an equivalent amount of energy; a nuclear weapon is said to have the power of kilotons (thousands of tons) or megatons (millions of tons) of TNT. As in a chemical explosion, the energy from a nuclear explosion is generated very quickly in a small volume. When the nuclear explosion is set off in the air, the energy released instantaneously vaporizes the components of the warhead, creating a hot, rapidly expanding fireball. The explosion gives rise to two prompt effects that in an attack on a city can be devastating. First, as the fireball expands it sends a shock wave through the surrounding medium. The shock wave, which travels away from the point of the explosion at supersonic speeds, does blast damage to structures and people. The hot fireball also radiates thermal energy, mainly photons in the visible and infrared regions of the electromagnetic spectrum, which can cause burns and ignite materials that are not protected by some kind of opaque screen. Roughly half of the weapon's energy is eventually converted into mechanical blast motions and about a third is released in the form of thermal radiation. The rest of the energy is represented by prompt nuclear radiation and delayed thermal and nuclear radiation, none of which are treated as being important in assured-destruction planning but all of which nonetheless add to the destructiveness of a nuclear attack.

The mechanical motions of a nuclear explosion are analogous to those of a tidal wave. The shock front is literally a wall of compressed air. As it passes, structures are exposed to a nearly instantaneous rise in the local atmospheric pressure, and they may be crushed. Following the shock front are strong winds analogous to the water currents that follow a moving ocean wave. The forces resulting from these winds may also lead to the collapse of structures in the target area. Depending on their shape and construction, buildings may be vulnerable either to the shock wave or to the winds that follow it or to both. The "hardness" of a target (its ability to withstand the destructive effect of the shock wave) is generally described in terms of the induced peak "overpressure" (in pounds per square inch above atmospheric pressure) at which the target is destroyed.

Thermal radiation can lead directly to flash-burn casualties and indirectly (through the ignition of nearby materials) to flame-burn casualties, superposing both effects on blast casualties. The extent of such damage depends on both the power of the radiant energy delivered (usually measured in calories per square centimeter) and the period over which the energy is delivered. Destructive blast effects decay with distance faster than thermal effects. Therefore under ideal conditions a nuclear explosion can do substantial incendiary damage well beyond the area devastated by blast. The thermal damage, however, is much influenced by external factors, including the presence of clouds or of snow cover, the relative transparency of the atmosphere and the composition of the target. Hence thermal effects are far less predictable than direct blast effects.

Since retaliatory forces are planned on the basis of assured damage, the consequences of an attack are typically calculated only on the basis of the more predictable blast effects. Consider the problem of allocating a suitable "package" of nuclear weapons to an urban area after a review of the targets within that city. Aim points for each weapon are selected in such a way as to ensure that the desired blast effects will cover all the targets. If the targets are close enough together, a single warhead may suffice. If the targets are dispersed or hardened, it may be preferable to allocate more than one weapon to a target area, as opposed to increasing the yield of a single weapon. This approach guards against the failure of a single large warhead, which would leave a tar-



[illegible] PROMPT EFFECTS of the explosion of a one-megaton nuclear warhead detonated at a [illegible] of 6,500 feet over the heart of New York are depicted chronologically in the sequence [illegible] on the opposite page. Immediately after such a detonation an extremely hot, luminous [illegible] would form. The fireball would emit intense thermal radiation (*color*), capable of caus[illegible] burns and starting fires at a considerable distance. The explosion would also give rise [illegible] destructive blast wave, which would move away from the fireball at supersonic speed; at [illegible] seconds after the detonation, for example, the front of the blast wave (*black circle*) would [illegible] half a mile ahead of the fireball. In addition the nuclear processes responsible for [illegible] explosion would be accompanied by the emission of hard radiation, mainly gamma rays [illegible] neutrons (*wavy white lines*), which would have enough range in air to reach the ground in [illegible] area. When the primary blast wave from the explosion hit the ground, another [illegible] wave would be caused by reflection. At a certain distance from ground zero (depending [illegible] height of the explosion and the energy yield of the weapon) the primary and reflected [illegible] would fuse near the ground to form a single reinforced Mach front; in the case of a [illegible] warhead detonated at 6,500 feet the Mach effect would begin some 4.6 seconds [illegible] detonation at a distance of 1.3 miles from ground zero. At that point the overpressure [illegible] the air pressure above ambient atmospheric pressure) would be 16 pounds per square [illegible] At 11 seconds after detonation the Mach front would have moved outward to 3.2 [illegible] ground zero, the overpressure at the Mach front would be 6 p.s.i. and the veloci[illegible] wind just behind the front would be approximately 180 miles per hour; appreciable [illegible] of thermal radiation and nuclear radiation would continue to reach the ground. At 37 [illegible] after detonation the Mach front would be nearly 9.5 miles from ground zero, the over[illegible] at the front would be 1 p.s.i. and the wind velocity behind the front would be 40 miles [illegible] (Glass would be broken at overpressures down to .5 p.s.i.) Although thermal radiation [illegible] longer be significant, gamma rays would still reach the ground in potentially lethal [illegible] The fireball would no longer be luminous, but it would still be very hot, and it would [illegible] rise rapidly, causing air to be drawn inward and upward, producing strong air cur[illegible] afterwinds. These winds would raise dirt and debris from the city to form the stem [illegible] would eventually become the characteristic mushroom cloud. By 110 seconds after [illegible] the hot residue of the fireball, while continuing to rise, would have begun to expand [illegible] As a result the vaporized fission products and other weapon residues would condense [illegible] cloud of radioactive particles. By this time the cloud would have risen to a height [illegible] miles. The maximum height attained by the cloud (after 10 minutes) would be about [illegible] Ultimately the particles in the cloud would be dispersed by the wind, and unless there [illegible] precipitation there would probably be no early (or local) fallout of radioactive material.

get "uncovered." It also reflects the fact that few industrial and military complexes are sufficiently concentrated or have the right shape to be attacked by a single weapon of the type that currently constitutes the bulk of the U.S. strategic arsenal.

Each city has a unique set of target characteristics, but some simple rules make it possible to predict damage and fatalities. In general any structure not specifically designed for blast resistance would be destroyed if it were exposed to an overpressure of five or more pounds per square inch (p.s.i.) above the ambient atmospheric pressure of some 15 p.s.i., and those structures that would not actually collapse would typically be damaged beyond repair. Some reinforced buildings (and heavy equipment inside them) could withstand an overpressure of 40 p.s.i. or more, but if these targets were considered important, an attacker could lower the height at which his weapons were set to explode or could aim his weapons (or allocate new warheads) to achieve the desired effects. Still, as a rule of thumb an overpressure of 5 p.s.i. is considered sufficient to destroy most structures.

The human body can endure a far more intense blast than most buildings. Therefore in a nuclear attack most of

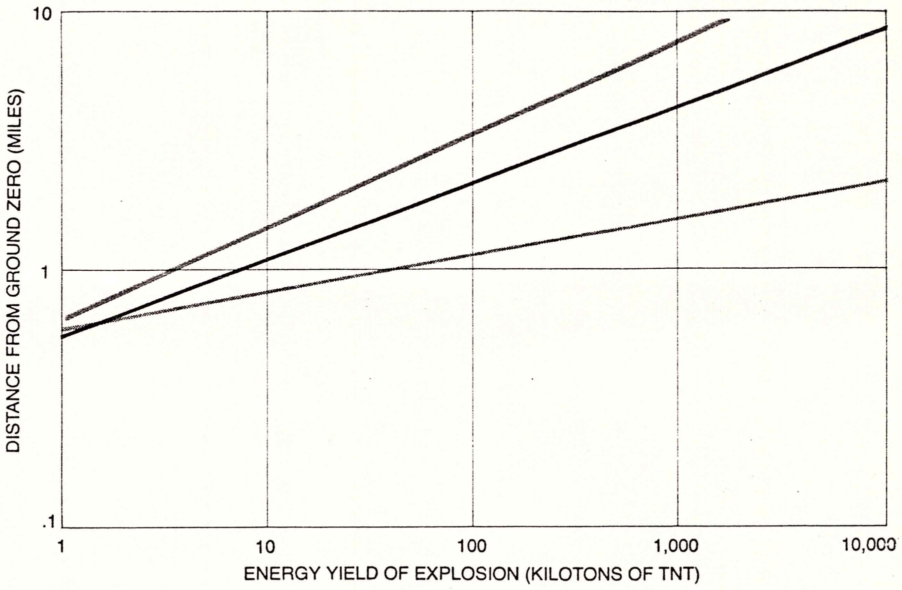
LETHAL AREA is defined by U.S. nuclear-war planners as the circular region within which the number of survivors of a nuclear explosion equals the number of fatalities outside the region. This simplifying assumption makes it possible to arrive at an estimate of the prompt fatalities resulting from a nuclear explosion by multiplying the lethal area by the population density (assuming that the population density over the entire area is uniform). As a general rule the lethal area is considered to extend roughly to the 5-p.s.i. overpressure contour, which for the one-megaton airburst represented on page 28 corresponds to a circular area with a radius of 4.3 miles (*area within black circle*). The lethal-area concept excludes several important (if less predictable) delayed effects of nuclear explosions, such as fires and radioactive fallout. On a clear day, for example, a one-megaton airburst could ignite fires as much as 10 miles away. If these fires were to consolidate into a mass fire, the entire region within that range (*colored area*) would be devastated, enlarging the lethal area fivefold.

the blast casualties would be caused by indirect effects. The bulk of the population would be at risk from being inside or near collapsing buildings, from being hit by debris thrown by the shock wave or from being hurled into an immobile surface. Thermal effects would also cause many fatalities within a certain range, regardless of external conditions. In estimating fatalities the simplifying concept of the "lethal area" is often used. Based on theoretical and empirical data developed by the Atomic Energy Commission in the 1950's, the lethal area is defined as the circular region within which the number of survivors would equal the number of fatalities outside the circle, assuming that the population density over the entire area is uniform.

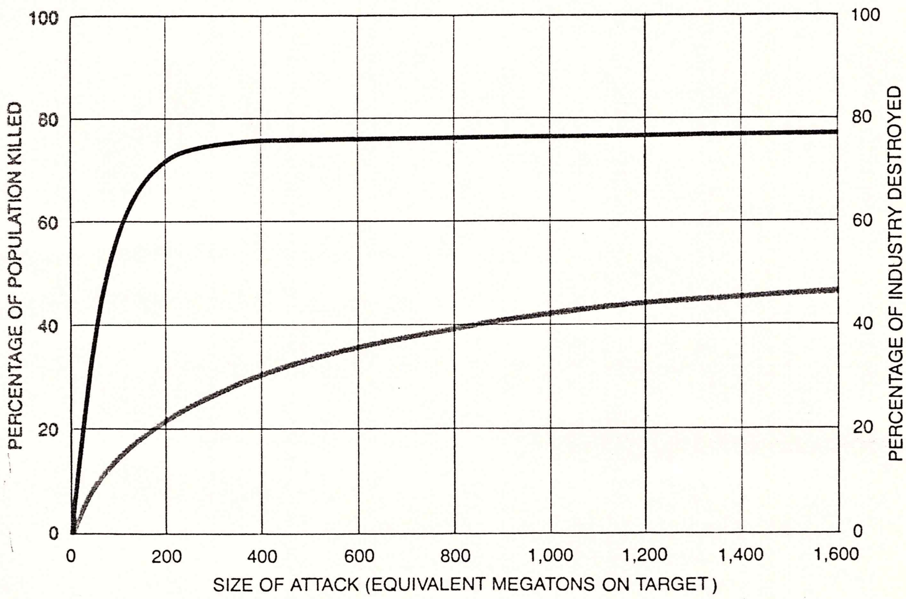
To simplify the calculations the estimated fatalities are redistributed, so that planners consider everyone within the circle to be a fatality and no one outside the circle to be a fatality. An estimate of prompt fatalities is then made by multiplying the lethal area by the population density. The experience of Hiroshima and Nagasaki and also test data indicate that for weapons in the range of 20 kilotons the lethal area extends roughly to the contour within which there is an overpressure of 5 p.s.i. Hence coverage by that overpressure is considered a satisfactory standard for calculating both the fatalities and the economic destructiveness of nuclear explosions.

Nuclear weapons will generate an overpressure of 5 p.s.i. to a distance proportional to the cube root of their yield. For this reason larger weapons are said to distribute their destructive power less efficiently than smaller ones. For example, a 100-kiloton bomb will generate an overpressure of 5 p.s.i. to a range of about two miles. Yet a warhead with 10 times the explosive yield (one megaton) will generate the same overpressure to only about twice that distance. In recognition of the inherently greater efficiency of smaller weapons, a scaled measure known as equivalent megatonnage, defined as the yield of a bomb in megatons raised to the two-thirds power, is considered a better index of countercity capability than the unadjusted yield in megatons. It was calculated by McNamara's systems analysis staff in the 1960's that the reliable delivery of 400 equivalent megatons would kill 30 percent of the population of the U.S.S.R. and destroy 75 percent of the industrial capacity; more recently the population damage and industrial damage have been estimated to be closer to 35 and 70 percent.

In actuality these damage levels are the lowest that would result from nuclear explosions, since they are typically calculated on the basis of the predictable "prompt" effects described above. When delayed effects (fires, fallout and



TYPICAL RANGES to which three different harmful effects of nuclear weapons extend are represented here for a typical airburst as a function of the energy yield of the explosion. The colored line shows the distance to which thermal radiation can cause second-degree skin burns and ignite fires, creating the risk of a mass fire. The black line measures the radius of the 5-p.s.i. overpressure circle, within which the passage of the blast wave front, followed by 160-mile-per-hour winds, would cause massive urban destruction and a high percentage of fatalities. The gray line gives the range to which prompt nuclear radiation from the explosion would result in 100 percent fatalities. It is evident that under favorable weather conditions the destructive thermal effects of such an explosion could reach well beyond the area of major blast destruction. Prompt nuclear radiation, on the other hand, is clearly not an important damage mechanism for strategic nuclear weapons (which have explosive yields of anywhere from a few tens of kilotons to many megatons), since the areas covered by deadly radiation would also be exposed to severe blast and thermal effects. It is only at much lower yields (on the order of a kiloton or less) that prompt nuclear radiation becomes an important lethal mechanism; that relation in fact is the basic principle of the enhanced-radiation weapon, or neutron bomb.



ASSURED-DESTRUCTION CRITERION, relied on by U.S. strategic planners to determine the retaliatory potential needed by U.S. nuclear forces to deter a surprise attack by the U.S.S.R., is calibrated here in terms of the number of delivered equivalent megatons it would take to destroy key population centers and industrial targets in the U.S.S.R. (Equivalent megatons are defined as the explosive yield of a nuclear weapon raised to the 2/3 power.) Given the decreasing value of adding extra equivalent megatons to such a retaliatory attack, it is evident from these curves that the delivery on target of some 400 equivalent megatons would be more than adequate to achieve assured destruction. Population damage (*color curve*) was estimated in terms of fatalities only; industrial damage (*black curve*) was determined by calculating the "manufacturing value added" destroyed during a U.S. retaliatory attack on the U.S.S.R. (Manufacturing value added is the incremental value imparted to raw materials in any industrial process.)

[illegible] are introduced, the damage estimates become much higher. The delayed effects also ensure that even if the mass-damage levels cited in assured-destruction definitions were not reached, an all-out nuclear war would still result in the devastation of the combatant countries.

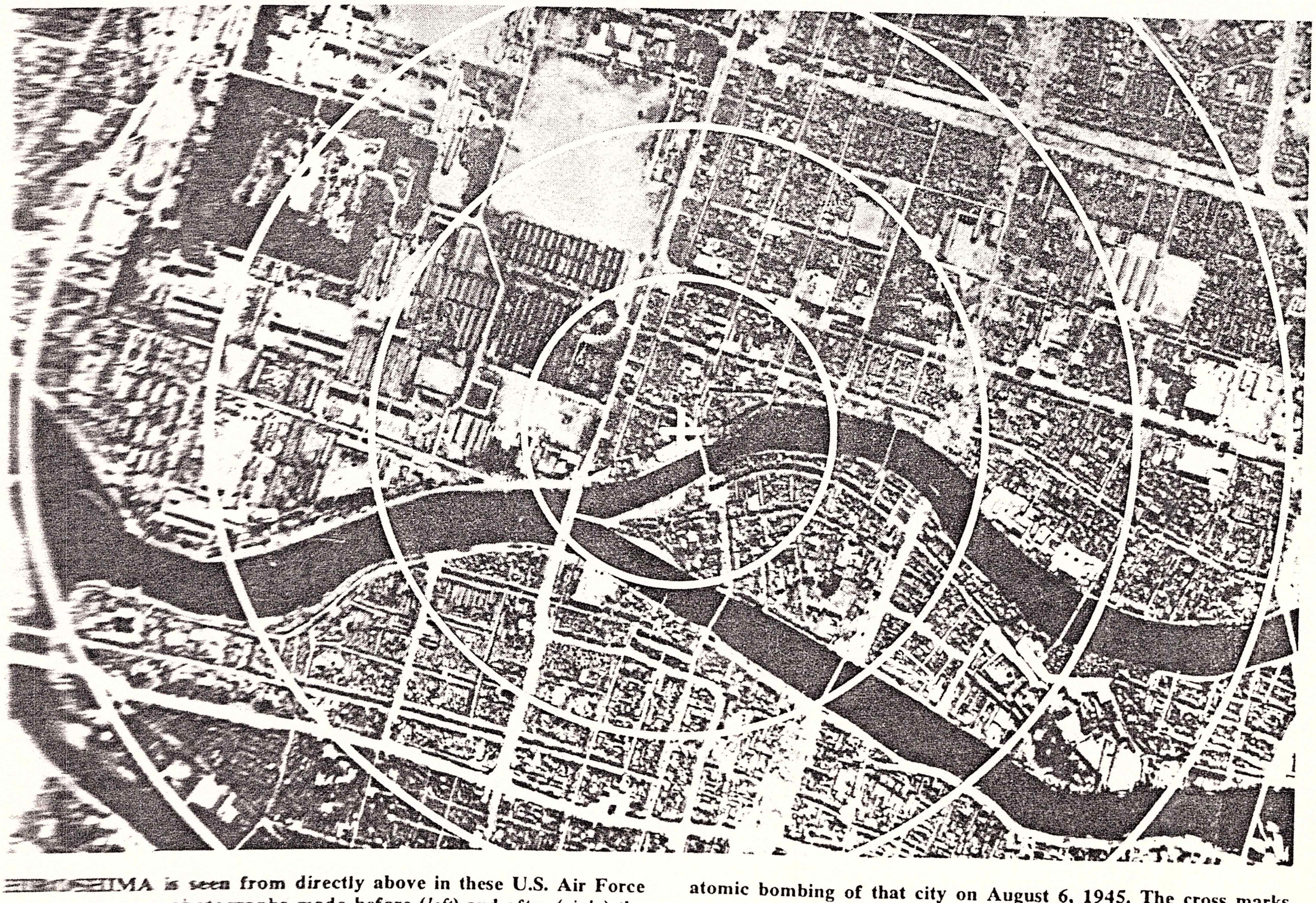
Prompt and delayed nuclear-weapons effects can be contrasted by considering an attack on a typical urban target, for example the greater Boston metropolitan area. The detonation of 10 one-megaton warheads, aimed at local economic and military targets, would generate an overpressure of 5 p.s.i. over more than 500 square miles. More than [illegible] million people would be killed by the prompt blast and thermal effects of the explosions, and more than 80 percent of the area's industrial capacity would be destroyed. It is likely that the secondary effects of the explosions, particularly fires and fallout, would increase these totals.

If conditions were favorable to the attack, the most devastating effect might be incendiary. Under certain weather conditions each one-megaton burst could ignite fires as much as 10 miles away. In such an attack a fire threat would presumably exist throughout much of eastern Massachusetts. Flash-induced fires would be joined by blast-triggered fires from toppled furnaces, stoves and boilers. Scattered debris and ruptured tanks and pipelines would add fuel to the fires. Firebreaks would be bridged by materials hurled by the blast. After the attack the suppression of possibly hundreds of small fires per acre would be a monumental task; water mains would be shattered and firefighting equipment and crews would be destroyed or disabled. In Hiroshima some 70 percent of the city's firefighting equipment was crushed in the collapse of firehouses and 80 percent of the firemen did not report to their posts.

Depending on weather conditions and the characteristics of the target area (particularly the density of flammable structures), the many individual fires might consolidate into one of two types of mass fire: a firestorm or a conflagration. A firestorm is driven by a strong vertical updraft of heated air, which is replaced by cool air sucked in from the periphery of the fire. A conflagration is driven in addition by a strong ground wind that was present before the attack. Whereas a firestorm continues only as long as its centripetal winds do, a conflagration can continue as long as fuel is available.

The consequence of a mass fire is total devastation within the affected area. The temperatures in a mass fire can exceed 1,000 degrees Celsius, a temperature higher than that necessary to melt glass and metal and to burn ordinarily fireproof materials. In Hiroshima an atomic bomb with a yield on the order of 15 kilotons caused a firestorm that lasted for six hours, totally destroying 4.4 square miles of the city. American cities are constructed of materials that are more fire-resistant than those in Hiroshima; on the other hand, American cities are more built up and more fuels, notably gasoline and heating oil, are available to feed fires. Most important, the yields of many modern strategic nuclear weapons exceed those exploded at Hiroshima and Nagasaki by two or more orders of magnitude. In addition much of the area under attack would be exposed to thermal radiation from more than one fireball.

Blast shelters would provide little protection against large fires. The survival of the occupants of such a shelter would depend critically on the temperature and humidity inside the shelter, and if mass fires were to start, the problem of maintaining a shelter environment in which people could survive would be aggravated beyond solution. Moreover, unless there was an independent supply of oxygen for each shelter, carbon monoxide and other toxic gases generated by



[illegible]IMA is seen from directly above in these U.S. Air Force [illegible]ance photographs made before (*left*) and after (*right*) the atomic bombing of that city on August 6, 1945. The cross marks ground zero, the point on the ground directly under the explosion. The

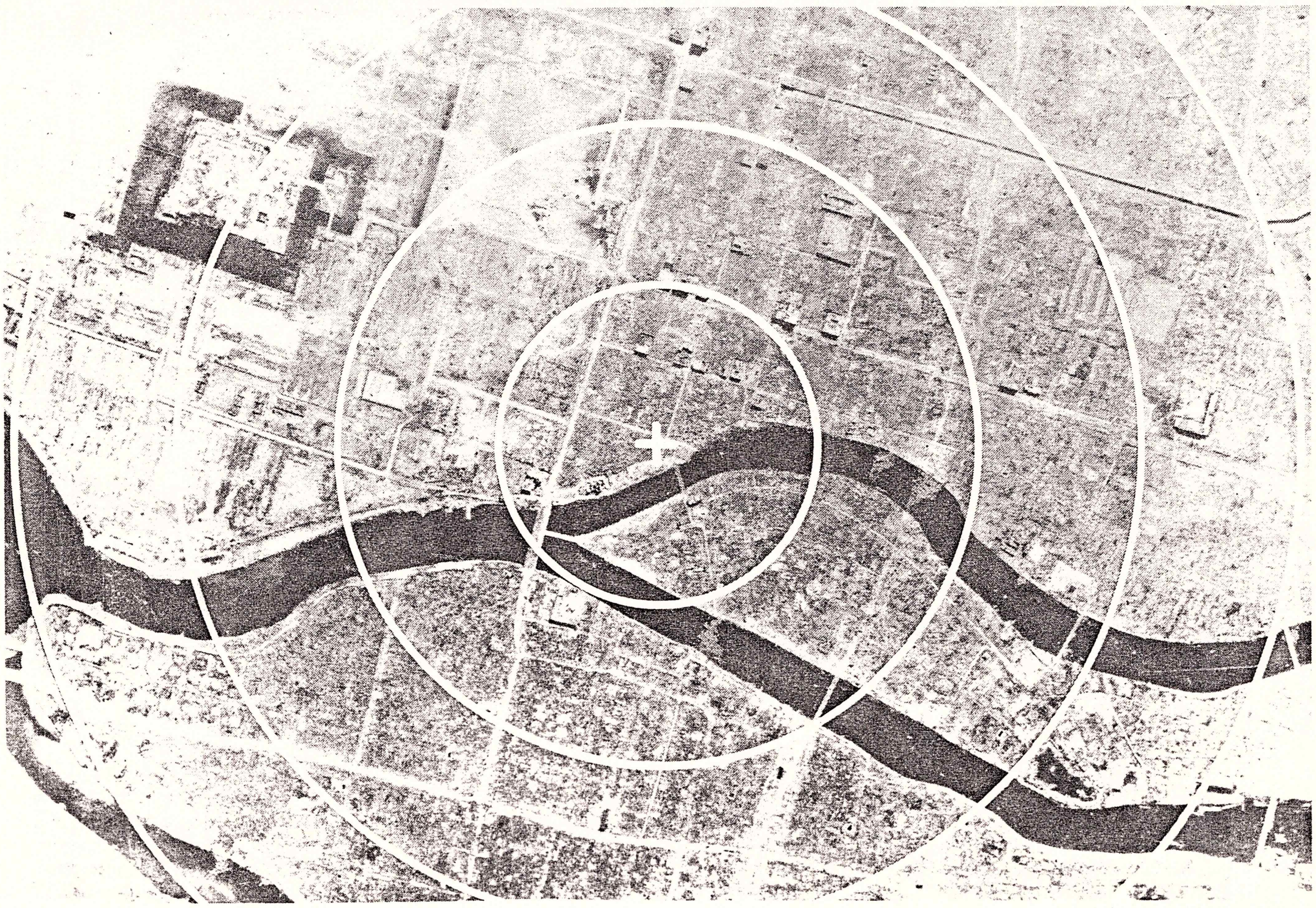
the fire could be deadly to the occupants. The heating of shelters, both by flames and by heated rubble (which could remain intolerably hot for days after the end of a fire), would jeopardize the occupants of shelters with an isolated atmosphere. In Dresden, where a firestorm ignited by chemical bombs killed more than 100,000 people in 1945, only those inhabitants who had left their shelters before the firestorm began were able to survive the twin threats of noxious gases and shelter heating.

After a nuclear attack many people would be disabled, trapped in wrecked buildings or prevented from fleeing the city because the streets were blocked by debris or fire. If mass fires were to form, which seems to be the probable result of multiple megaton bursts, the survivors among those who had escaped prompt incapacitation might be few. If mass fires were to begin in the Boston area, for example, the number of fatalities could be increased by 500,000.

Another factor not included in many assured-destruction calculations is radioactive fallout. Fallout results from the condensation of the radioactive byproducts of a nuclear explosion on materials fused by the intense heat of the fireball and (to a much smaller extent) from the conversion of nonradioactive materials into radioactive ones by the absorption of neutrons from the nuclear reactions of the explosion. If a nuclear weapon were to be exploded at or near the earth's surface, fallout would be an acute threat. Large amounts of debris would be scooped up into the rising cloud, later to fall out (or more likely be washed out) of the cloud in lethal amounts for hundreds of miles downwind. A dose of ionizing radiation measuring between 400 and 500 rems (an index of the biological effects of different types of radiation on man) delivered over a period of several days would kill half of the people who had been exposed. A dose of between 200 and 300 rems would kill somewhat fewer than 20 percent (assuming prompt medical treatment), but severe radiation-related blood symptoms, including diminished immunological response, could add extra fatalities by contributing to lethal infections. If 10 one-megaton weapons were exploded at ground level (to maximize fallout rather than blast and thermal effects), as many as a million New England residents who were not exposed to the immediate blast and thermal effects of the nuclear explosions would be subjected to dangerous levels of radiation. Even with optimistic assumptions about the availability of shelter and provisions, the fallout fatalities that would be added to the Boston-area toll could be as many as 500,000. An attack of this type might well mix airbursts and ground bursts to create maximum levels of both kinds of damage.

The number of fatalities from fire and radiation would grow steadily after such an attack, in part because medical facilities and personnel would be destroyed. Burn victims would present an exceptional medical problem, since serious burn cases require intensive and immediate treatment if they are to survive. The ability of any medical system to handle large numbers of such casualties is limited even in peacetime. The influx of some 50 survivors of the collision of two jet airliners on Tenerife in the Canary Islands a few years ago put a strain on burn centers in the U.S., which have a maximum capacity of about 130 patients. After a nuclear attack, of course, the number of burn cases would be orders of magnitude greater, and access to medical treatment would be far more difficult.

Existing medical services would be further burdened by the incidence of injuries well beyond areas of widespread mortality. The danger of injury from projected missiles (mainly shards of glass from shattered windows) would exist more than eight miles out from the

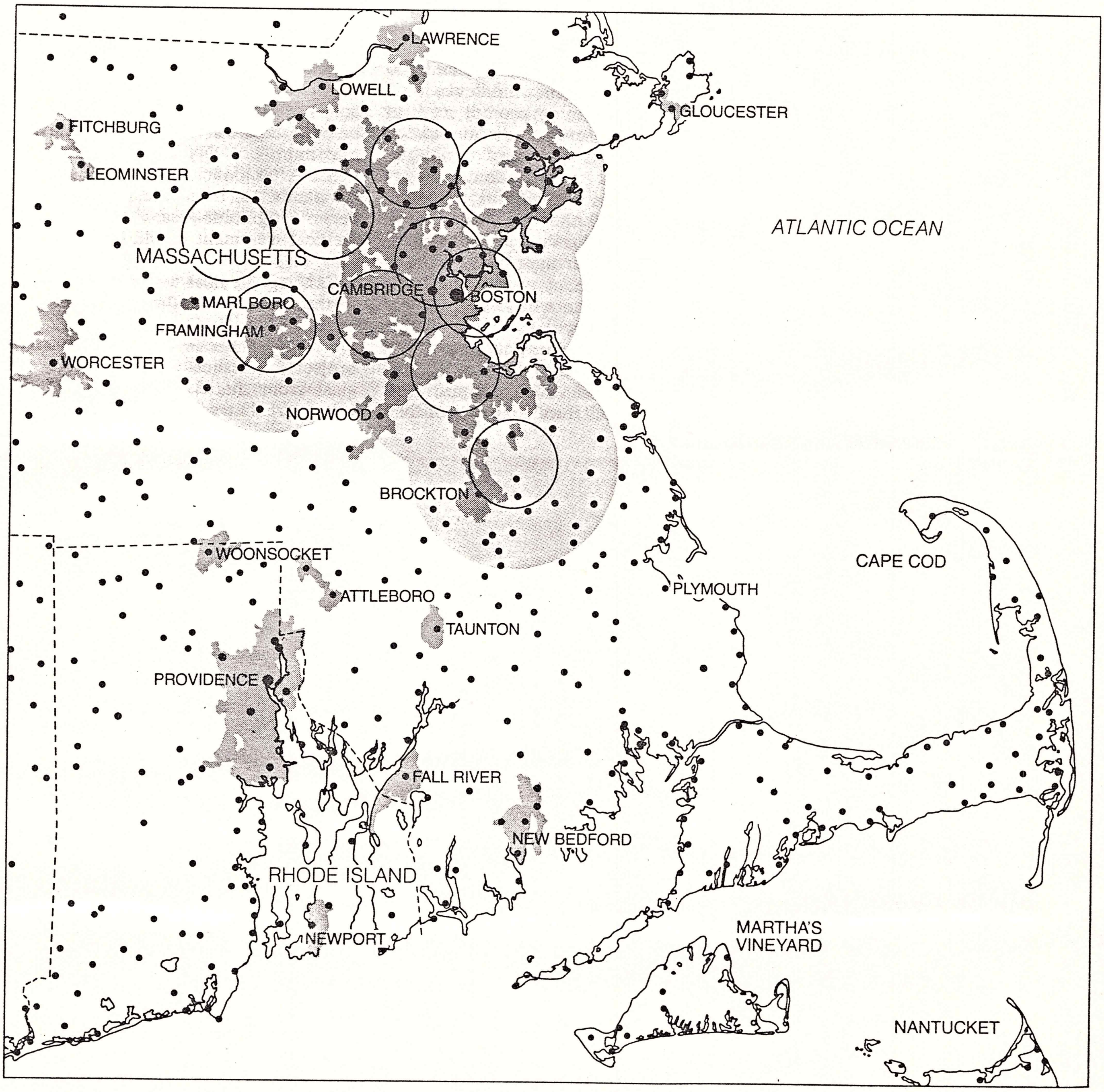


concentric circles are at 1,000-foot intervals. The firestorm following the prompt effects of the explosion lasted for about six hours and totally destroyed 4.4 square miles of the city. The explosive yield of the weapon that caused this devastation was on the order of 15 kilotons.

center of a one-megaton blast, and severe burns could be common out to nine miles, depending on weather conditions. Many victims of burns, radiation sickness and other mortal injuries who did not die immediately would require intensive (but under the circumstances unavailable) medical care. The management of less severely injured people and the very young, the very old and those with special medical needs would be complicated by the scarcity of food, shelter and medicine.

The survivors of an all-out nuclear attack would include many who would be permanently incapacitated by crippling injuries, blindness and other causes. Any medical effort would be further degraded by the destruction of public-health facilities and personnel, the proliferation of disease-causing organisms (which tend to survive high radiation levels) and other difficulties, such as the seemingly insoluble problem of disposing of the dead. The total regional casualties following an attack on the Boston area with both airburst and groundburst nuclear weapons could well exceed two million dead, with roughly the same number wounded or sick.

The assured-destruction concept also ignores certain strategic issues. It is typically argued that the U.S.S.R. is pursuing two types of program that would enable it to blunt the effectiveness of a U.S. retaliatory attack. The first program seeks to reduce the number of U.S. warheads arriving at their targets by de-

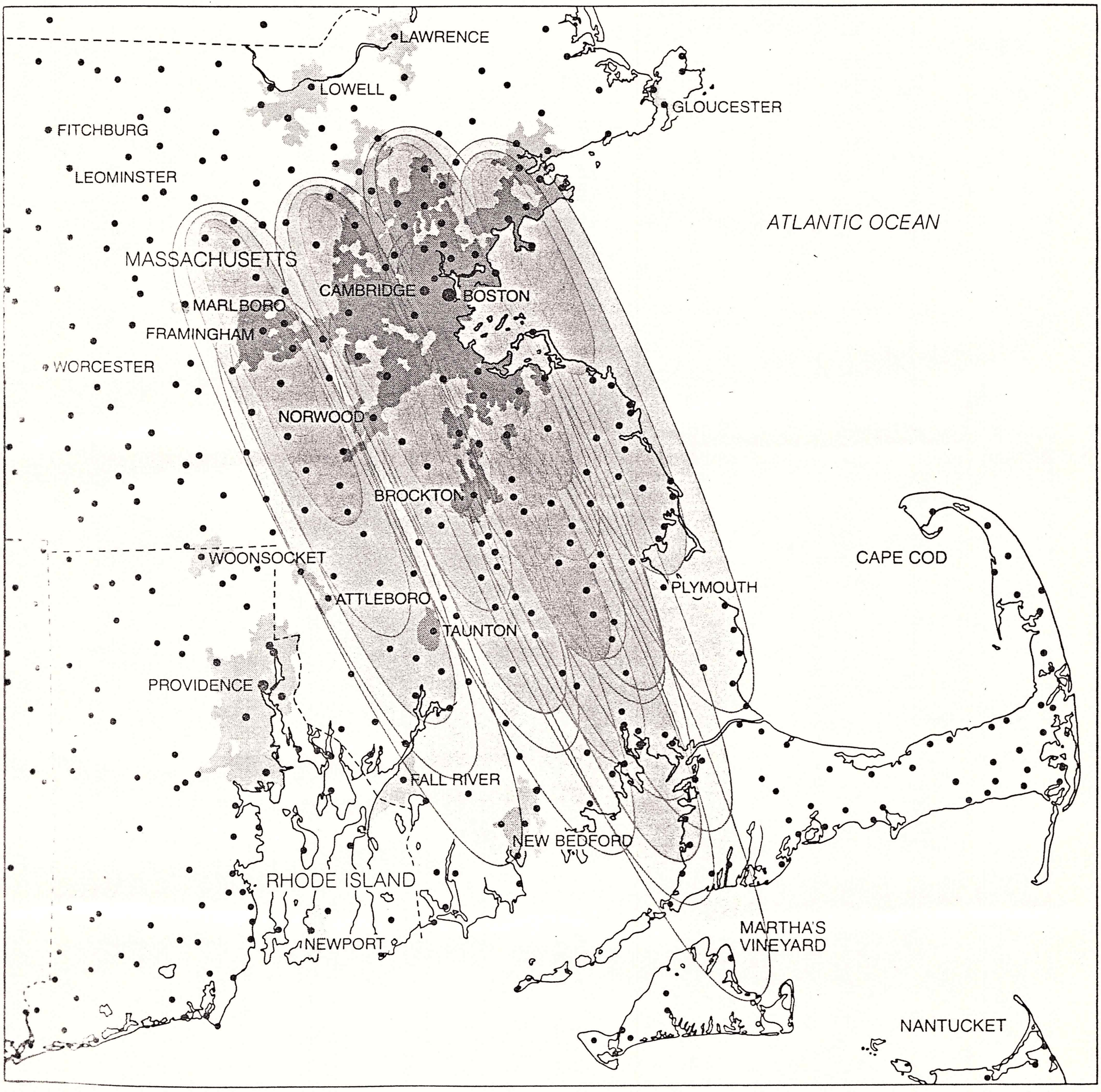


HYPOTHETICAL ATTACK on the greater Boston metropolitan area, which is outlined on these two pages, serves to contrast the prompt and delayed effects of multiple nuclear explosions. In both cases shown the attack consists of the detonation of 10 one-megaton nuclear warheads, which are aimed at local economic and military targets. In the illustration at the left it has been assumed that all the weapons have been detonated at an altitude that has been selected to maximize blast and thermal effects. Black circular outlines in the illustration correspond to regions exposed to an overpressure of at least 5 p.s.i.; each of these areas is 4.3 miles in radius. The colored areas represent the regions exposed to severe fire and burn risk on a clear day; each area in this case has a radius of 10 miles. The principal delayed effect of the attack suggested by the illustration is the risk of a regionwide firestorm or conflagration, which could add 500,000 fatalities to the assured-destruction estimate of 1.3 million killed by the prompt blast and thermal effects of the explosions. In the illustration

stroying U.S. strategic forces in a surprise attack and by intercepting as many surviving warheads as possible before they reach their targets in the U.S.S.R. The second program seeks to minimize the damage done by arriving U.S. weapons by evacuating urban residents and by dispersing and hardening industrial sites. Because the Russians could thereby "deny" important urban and economic targets to U.S. attack it is maintained that U.S. forces would fail to satisfy the assured-destruction damage levels, and that the U.S.S.R. would retain the industrial base, personnel and administration necessary for a rapid postwar recovery.

In spite of the alleged success of the U.S.S.R. in these endeavors, neither strategy could effectively reduce the devastation of an all-out nuclear war. Furthermore, neither effort would appreciably enhance the potential of the U.S.S.R. for recovery. On the contrary, such schemes only appear to reduce U.S. retaliatory capabilities in the perspective of the narrow and arbitrary definition of assured destruction discussed above.

Such analyses ignore the fact that even under the worst circumstances the U.S. would be able to mount a more than adequate retaliatory attack. Any Russian plan to degrade the U.S. assured-destruction capability would face the formidable task of reducing U.S. forces substantially below the level of 400 deliverable equivalent megatons. (Actually the task might be even more



at the right it has been assumed that all 10 of the warheads have been detonated at ground level in order to maximize the effects of radioactive fallout. (Typical January wind patterns have been assumed in drawing the contours.) The dark-colored areas are those that are covered by an amount of radiation that would be fatal to at least 80 percent of the exposed population. The medium-colored areas are those in which at least 50 percent of the exposed population would die of radiation sickness. The light-colored areas are the probable extent of the region in which clinical radiation symptoms would be evident in much of the exposed population, resulting in perhaps 20 percent fatalities. (Presumably the survivors would also be subjected to the effects of additional long-term radioactive fallout from attacks on neighboring regions.) The total number of casualties in the Boston region following an attack that made use of a suitable combination of airburst and ground-burst nuclear weapons could well exceed two million dead, with approximately the same number wounded or sick.

difficult, because a well-planned American attack of even 200 equivalent megatons could still promptly kill a fifth of the U.S.S.R.'s population and destroy more than two-thirds of its industry, thereby satisfying the requirements of assured destruction.)

It is extremely unlikely that a preemptive Russian first strike could achieve this goal. For one thing, 400 equivalent megatons is only a fraction of the current U.S. nuclear arsenal. More than half of the current U.S. arsenal of more than 6,000 equivalent megatons is carried by missile-launching submarines on station, by bombers on alert at Strategic Air Command bases and by silo-based missiles, all of which are capable of going into action within a few minutes of a Presidential order. The rest of the U.S. strategic forces consist mainly of bombers not on alert and submarines in port for maintenance. If a Russian surprise attack were to destroy many land-based U.S. missiles in their silos and all the nonalert bombers and submarines, more than 2,000 equivalent megatons would remain available for retaliatory action. Even if an unexpectedly large number of U.S. weapons were to malfunction or to be destroyed in flight, more than 1,500 equivalent megatons could still be delivered with high confidence. These figures assume "worst case" conditions from a U.S. perspective: if some warning were available prior to such a Russian attack, extra bombers and submarines could be alerted and the number of deliverable equivalent megatons would more than double.

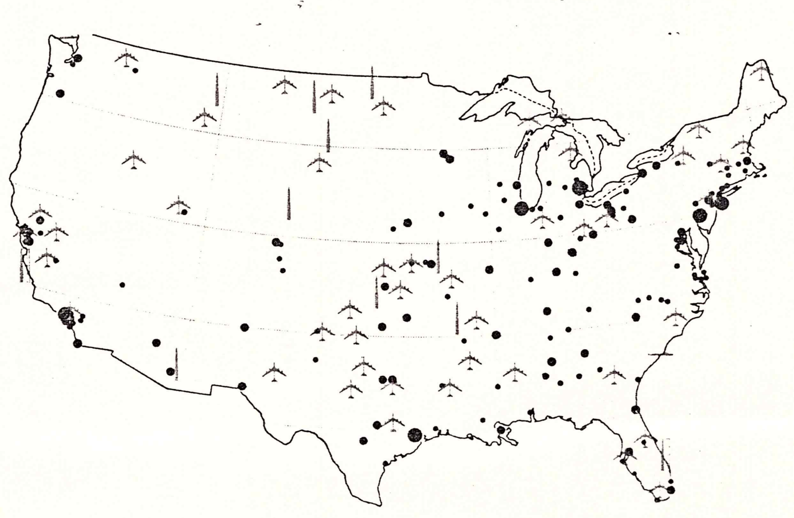
Because of the availability of what are sometimes described as "overkill" forces any effort to reduce the numbers or effectiveness of the arriving U.S. warheads is bound to fail. For example, Moscow is protected by an anti-ballistic-missile (ABM) system that is limited by treaty to 100 missile launchers. (Currently only 64 missiles are deployed in that system.) In the event of a missile attack those missiles could destroy a certain fraction of the incoming missiles. U.S. planners could easily compensate for this potential attrition by several strategies, one of which would be to allocate extra warheads to the "Moscow package" based on generous theoretical assumptions about the effectiveness of the Moscow ABM system.

The assured-destruction criterion implicitly assumes what may be the least probable scenario for a general nuclear war. It is extremely unlikely that an all-out war would begin with a massive surprise attack by either side on the other side's cities. Such a war would more probably follow an escalating crisis that might begin with limited nuclear strikes on military targets. These alternative scenarios imply that city populations would have ample warning of a possible or probable nuclear attack, with the result that evacuation and other tactics for reducing damage could be pursued. If this were to be the situation, the character of the city population would clearly have changed by the time of an attack. Since assured destruction is calculated according to peacetime population densities and the calculations rely on certain assumptions about the disposition of city dwellers and workers on a day-to-day basis, the programmed fatality levels may not be reached under realistic circumstances.

The assured-destruction criterion also assumes that a general nuclear war would consist of a single massive "countervalue" strike: a strike against both military and economic targets. Countervalue strikes might well, however, remain at a relatively low level of intensity for some time. A limited countervalue exchange might consist of attacks on industrial locations away from large cities in order to discourage escalation to attacks with the largest possible number of fatalities. (The Russians in particular have built some key installations in remote areas, where they could be attacked with a relatively low level of fatalities.) Strikes against cities might be preceded by a warning or an ultimatum, which would clearly encourage evacuation. A general war might even begin with a slow campaign of "city-trading." In other words, virtually any change in assumptions radically alters the context of the assured-destruction scenario and casts doubt on the accuracy of fatality estimates.

In fact, except in the circumstances of certain specialized scenarios, there will always be an opportunity for a country to evacuate its urban centers to some extent, regardless of the degree to which the country has prepared for such evacuation. (For example, on September 1, 2 and 3, 1939, the British government evacuated some 1.5 million women and children from Britain's major cities, and in the same three days an additional two million people moved out on their own initiative.) The wide availability of private-automobile transport in the U.S. probably more than compensates for any current Russian evacuation plans and training.

Nevertheless, allegations of evacuation planning in the U.S.S.R. have inspired much concern in the U.S. According to a recent report of the Central Intelligence Agency, if the Russians were to have at least one week to thoroughly evacuate their cities and shelter refugees against radioactive fallout, war-related casualties could be reduced to the "low tens of millions, about half of which would be fatalities." Some analysts have gone so far as to term these fatality levels "acceptable" in view of the fact that the U.S.S.R. suffered 20 million dead in World War II. Even if evacuation could reduce the number of prompt fatalities, however, the degree of damage the U.S. could inflict on the unprotectable economic resources of the U.S.S.R. would be so great that the U.S.S.R. would be eliminated as a major industrial power.



RELATIVE CONCENTRATIONS of potential population targets and military targets in the U.S. and the U.S.S.R. are suggested by these two maps. The black dots indicate the location of the largest cities in each country. The colored symbols designate strategic-weapons instal-

One purpose of any campaign of strategic bombardment is to reduce an enemy's potential for supporting armed forces in the field. In World War II factories, transportation systems and power plants were attacked. One goal of such bombing campaigns was to destroy industries on which other economic sectors relied, depriving those sectors of essential inputs and leading to an expanding industrial incapacitation. The bombing of Germany failed to have this effect, in part because of limitations on the size of chemical-explosive payloads. Attacks on a given target system had to be spread out over many raids, and so the surviving facilities could be "jury-rigged" to compensate for the damage done to certain parts of the industrial network. Civilians left homeless in attacks could be housed in nearby towns that had not been damaged. Even after the atomic bombing of Hiroshima and Nagasaki enough aid was available in surrounding communities to significantly aid the survivors.

The deployment of large numbers of nuclear weapons has radically changed the context of strategic bombing. The forces currently deployed by the U.S. and the U.S.S.R. are able to destroy the entire industrial structure of any nation. Moreover, this damage can be done all at once, so that little assistance would be available for those targets that had come under attack.

In both the U.S. and the U.S.S.R. a limited number of facilities comprise the bulk of the productive capacity in many major industries. The centrally planned economy of the U.S.S.R. in particular has many vulnerable bottlenecks and choke points. Hence the destruction of a single target or very few targets could disrupt production in many other industries. Because of this concentration 100 equivalent megatons, corresponding to the payload of the missiles carried by five or six Poseidon submarines, would be sufficient to destroy crucial industries without which the Russian economy could not sustain itself.

For example, a study conducted recently by the Office of Technology Assessment of Congress showed that a U.S. attack on petroleum refineries in the U.S.S.R. could, with only some 40 low-yield nuclear warheads, destroy about three-fourths of the U.S.S.R.'s entire refining capacity. Comparatively few warheads could also destroy the transportation, energy, maintenance and management resources needed for any postwar economic recovery. The Russian energy system is particularly vulnerable to attack and is crucial for recovery. For instance, nearly all the intercity freight in the U.S.S.R. is shipped over electrified rail networks, whereas much of it in the U.S. goes by truck.

These kinds of figures should not be taken as evidence that the U.S. economy is somehow less vulnerable than that of the U.S.S.R. The Russians have more than enough warheads to cover similar U.S. targets. Rather, it is instructive to remember, as the CIA report noted, that "the coordination of requirements with available supplies and transportation is a complex problem for Soviet planners even in peacetime, let alone following a large-scale nuclear attack on the U.S.S.R."

Even if the Russian evacuation plans were successful, they would only defer, not prevent, the impact of the war on civilians. A nation's fixed medical, technical and educational base would, after all, be destroyed in a nuclear war. Recovery stockpiles and facilities could also be targeted. If some food, pharmaceuticals, clothing, equipment and spare parts did survive, there would be neither the administrative structure to allocate the goods nor the transport to ship them where they were needed. The destruction of refineries and electric-power stations could interdict resupply, and shortages could develop quickly. Perishable goods, including many foods and drugs, would be lost if electric power were cut off. The devastation of housing would make summer life difficult and winter existence intolerable. This would be particularly true in the U.S.S.R., where outside cities there are few alternative forms of shelter such as hotels. In short, civil defense might protect some people, but it could not prevent the widespread destruction of property essential to the support of life. The economic interdependence of an industrialized nation is a vulnerability that cannot be defended.

A nation's administrative and social structure would also be disrupted by nu-

lations: major airfields, missile-submarine bases, land-based-missile launching sites and missile-testing sites (*see key at bottom left*). In addition to the installations shown here the U.S. has a variety of strategic forces stationed elsewhere in the world (mainly on the island of Guam and in Alaska). In general suitable targets for nuclear attack are more concentrated in the U.S.S.R. than they are in the U.S.

clear attack to the point that a political system might be shattered beyond reconstitution. Although special bunkers are being constructed to protect the bureaucratic and internal-security apparatus of the Soviet government in the event of war, the U.S. does not lack the means to attack those shelters.

The delayed effects of a nuclear war between the U.S. and the U.S.S.R. would propagate far beyond the borders of the antagonists and their allies. Worldwide effects would result mainly from the fact that the stem and cloud of most nuclear explosions would penetrate the stratosphere and deposit several kinds of radioactive material in it. Unlike the lower part of the atmosphere, the stratosphere lacks the moisture and shear motions needed to quickly sort out particulate and gaseous matter. Since such materials would remain in the stratosphere for a long time, their effects would be diluted. One consequence of this long residence time, however, would be wide dispersion. Thus although stratospheric effects would be less intense than lower-atmospheric ones, they would last longer and be more widespread.

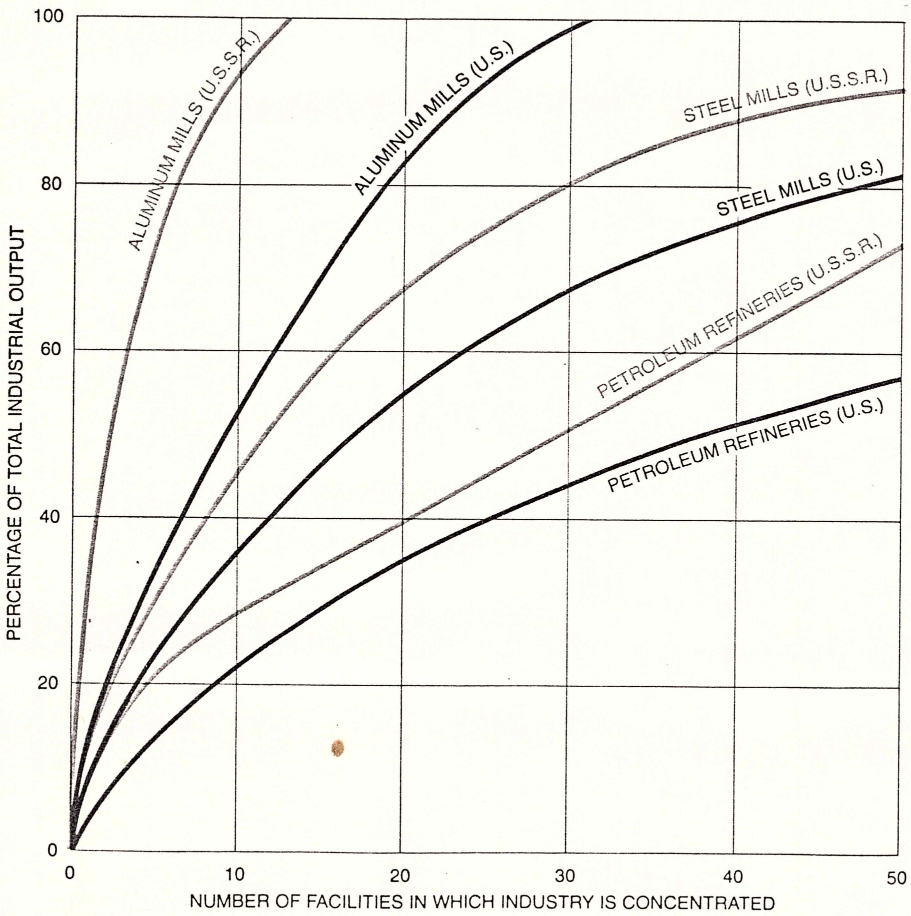
A report issued by the National Academy of Sciences in 1975 listed three effects of nuclear war that might have adverse worldwide impacts. First, stratospheric ozone might be depleted, because nitrogen oxides made from atmospheric nitrogen and oxygen by the heat of nuclear explosions would be injected into the stratosphere, where they would aid in the conversion of ozone into molecular oxygen. Second, the deposition of large amounts of dust in the upper atmosphere could alter the amount of solar radiation arriving at the earth's surface. Third, hazardous radioactive isotopes could be dispersed through the stratosphere, falling out slowly on a worldwide scale.

Stratospheric ozone plays an important role in life on the earth by screening out harmful ultraviolet radiation. The NAS report estimated that a 10,000-megaton nuclear war could destroy half of the ozone in the Northern Hemisphere and about 30 percent of the ozone in the Southern Hemisphere. As opponents of the supersonic transport aircraft and fluorocarbon spray-can propellants have contended, the depletion of the ozone layer could lead to a variety of medical and environmental problems. Higher cancer rates and harmful effects on plants, including crop plants, could result. The destruction of stratospheric ozone on this scale could upset the thermal structure of the upper atmosphere and lead to worldwide temperature changes. After such a war ozone levels might not return to normal levels for many years.

A single one-megaton surface burst would also project thousands of tons of fine dust into the stratosphere. The dust could absorb, reflect and scatter radiation arriving from the sun or reflected from the earth, and there have been suggestions that this effect could lead to a change in the weather at the earth's surface. According to the NAS study, however, a 10,000-megaton war would inject no more dust into the stratosphere than was thrown up by the explosion of the volcano Krakatoa in 1883. By extrapolating from such volcanic events the NAS report concluded that only a slight change in surface weather conditions might result.

Radioactive isotopes would be distributed worldwide by stratospheric transport processes. Since these isotopes would have a relatively long residence time in the stratosphere, many of the dangerous short-lived ones would decay before they could reach the ground. Nevertheless, some hazardous isotopes, such as strontium 90, cesium 137, iodine 131 and carbon 14, would persist and might enter the food chains of the biosphere. The NAS report did not suggest that this fallout would have the kind of worldwide lethal consequences for human life that are depicted in novels such as Nevil Shute's *On the Beach.* Regional concentrations of fallout in the combatant nations (and neighboring nations) could nonetheless present an acute radiation hazard to many evacuees and rural residents who might not have been directly imperiled during an attack on cities. Less intense "hot spots" could appear at greater distances, with adverse biological consequences. Few parts of the attacked country would escape the threat of fallout, since a thorough attack would cover economic and military targets nationwide, leaving most areas contaminated.

Atmospheric phenomena are complex, and it is not clear how a 10,000-megaton nuclear war might influence climate. Although the NAS study estimated that the effects of ozone depletion and dust loading probably would not have an irreversible impact on global weather patterns, the report did indicate that changes of a much more serious nature could not be excluded. The possibility of synergistic actions among these various effects cannot be ignored. For example, it has been noted that a global cooling of only one degree C. could eliminate all wheat growing in Canada.



KEY INDUSTRIAL TARGETS are also more concentrated in the U.S.S.R. than they are in the U.S., as these three pairs of curves demonstrate. As a consequence fewer nuclear warheads would be needed to cripple the U.S.S.R.'s production of such vital materials as steel, petroleum and nonferrous metals. In addition the economies of both countries are characterized by crucial bottlenecks. For example, only one plant at Pavlodar in the U.S.S.R. does work essential to 65 percent of the aluminum industry of the country. By the same token close to 80 percent of the iron ore shipped in the U.S. travels through one set of locks at Sault Sainte Marie.

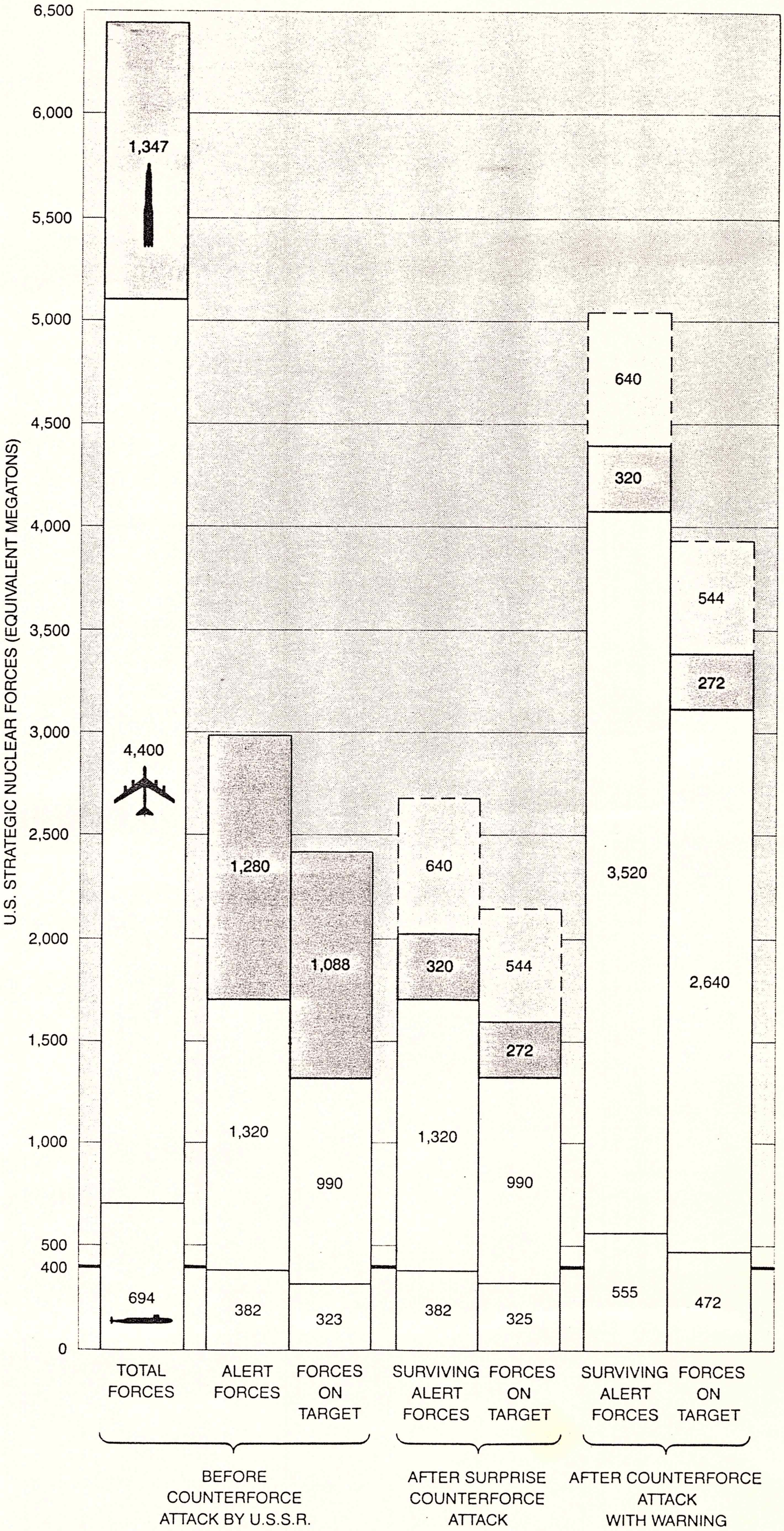
Direr possibilities include the expansion or melting of polar ice.

The NAS report did not examine possible changes in continental weather resulting from effects such as fires. A single 10-megaton airburst could ignite a forest fire covering thousands of square miles. The burning of the broad grasslands and forests of the U.S. and the U.S.S.R. could defoliate the natural ground cover, thereby changing the reflectivity of the earth's surface and giving rise to weather changes. Particulate combustion products thrown into the atmosphere by forest fires would absorb and reflect solar radiation, and they would also act as nucleation centers for the formation of water droplets and ice crystals, thereby increasing the cloud cover and altering the distribution of precipitation. Such local effects could exacerbate the worldwide phenomena cited above.

Finally, just as the various components of a national economy are interlocked, so nations themselves are interdependent. The destruction of the economies of the major powers by a nuclear war would be a massive blow to the economies of nations dependent on those powers for the exchange of commodities and technology. The less developed countries in particular would suffer, since at this stage of their development they need to import technology from more developed countries.

In sum, the cumulative effects of an all-out nuclear war would be so catastrophic that they render any notion of "victory" meaningless. The formal methodologies of the assured-destruction scenarios do not reveal the full extent of these effects. Moreover, arguments that throw doubt on the sufficiency of the deterrent capability of the U.S. exclude some of the most profound and long-lasting of these effects. When the delayed effects of all-out war are taken into consideration, it should become clear that no countermeasure would significantly lessen the degree of devastation that would surely occur. Even if a highly efficient program for the evacuation of cities could substantially reduce prompt fatalities, it could not prevent the delayed social consequences of industrial and economic devastation. The magnitude of either the prompt disaster or the delayed one would be so great that neither disaster could ever be considered tolerable.

There are many steps that could be taken by both sides to diminish the likelihood of an all-out nuclear war. Many of them are now the subject of strong disagreement. One step in the right direction would be to reframe the currently misleading concept of assured destruction in more realistic terms to reflect the full extent of the catastrophe that would be represented by a nuclear war.



U.S. STRATEGIC ARSENAL would retain far more deliverable nuclear weapons than would be necessary to accomplish the assured-destruction mission, even after an all-out surprise attack by the U.S.S.R. on strategic military targets in the U.S. If there were any warning available before such an attack, the number of U.S. nuclear weapons that could be delivered on targets in the U.S.S.R. would increase considerably. The heavy black line across the bottom of the chart indicates the 400 equivalent megatons thought to be sufficient to kill 35 percent of the people in the U.S.S.R. Strategic forces above this level are referred to as overkill capability.