Chapter I

EXECUTIVE SUMMARY

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TABLES

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At the request of the Senate Committee on Foreign Relations, the Office of Technology Assessment has undertaken to describe the effects of a nuclear war on the civilian populations, economies, and societies of the United States and the Soviet Union.

Nuclear war is not a comfortable subject. Throughout all the variations, possibilities, and uncertainties that this study describes, one theme is constant—a nuclear war would be a catastrophe. A militarily plausible nuclear attack, even "limited, " could be expected to kill people and to inflict economic damage on a scale unprecetiented in American experience; a large-scale nuclear exchange would be a calamity unprecedented in human history. The mind recoils from the effort to foresee the details of such a calamity, and from the careful explanation of the unavoidable uncertainties as to whether people would die from blast damage, from fallout radiation, or from starvation during the following winter. But the fact remains that nuclear war is possible, and the possibility of nuclear war has formed part of the foundation of international politics, and of U.S. policy, ever since nuclear weapons were used in 1945.

The premise of this study is that those who deal with the large issues of world politics should understand what is known, and perhaps more importantly what is not known, about the likely consequences if efforts to deter and avoid nuclear war should fail. Those who deal with policy issues regarding nuclear weapons should know what such weapons can do, and the extent of the uncertainties about what such weapons might do.

FINDINGS

1 The effects of a nuclear war that cannot be calculated are at least as important as those for which calculations are attempted. Moreover, even these limited calculations are subject to very large uncertainties

Conservative military planners tend to base their calculations on factors that can be either control led or predicted, and to make pessimistic assumptions where control or prediction are impossible. For example, planning for strategic nuclear warfare looks at the extent to which civilian targets will be destroyed by blast, and discounts the additional damage which may be caused by fires that the blast could ignite. This is not because fires are unlikely to cause damage, but because the extent of fire damage depends on factors such as weather and details is of building construction that make it much more difficult to predict than blast damage. While it is proper for a military plan to provide for the destruction of key targets by the surest means even in unfavorable circumstances, the nonmilitary observer should remember that actual damage is likely to be greater than that reflected in the military calculations. This is particularly true for indirect effects such as deaths resulting from injuries and the unavailability of medical care, or for economic damage resulting from disruption and disorganization rather than from direct destruction.

For more than a decade, the declared policy of the United States has given prominence to a concept of "assured destruction:" the capabilities of U.S. nuclear weapons have been described in terms of the level of damage they

can surely inflict even in the most unfavorable circumstances. It should be understood that in the event of an actual nuclear war, the destruction resulting from an all-out nuclear attack would probably be far greater. In addition to the tens of millions of deaths during the days and weeks after the attack, there would probably be further millions (perhaps further tens of millions) of deaths in the ensuing months or years. In addition to the enormous economic destruction caused by the actual nuclear explosions, there would be some years during which the residual economy would decline further, as stocks were consumed and machines wore out faster than recovered production could replace them. Nobody knows how to estimate the likelihood that industrial civilization might collapse in the areas attacked; additionally, the possibility of significant long-term ecological damage cannot be excluded.

2. The impact of even a "small" or "limited" nuclear attack would be enormous. Although predictions of the effects of such an attack are subject to the same uncertainties as predictions of the effects of an all-out attack, the possibilities can be bounded. OTA examined the impact of a small attack on economic targets (an attack on oil refineries limited to 10 missiles), and found that while economic recovery would be possible, the economic damage and social dislocation could be immense. A review of calculations of the effects on civilian populations and economies of major counterforce attacks found that while the conse quences might be endurable (since they would be on a scale with wars and epidemics that nations have endured in the past), the number of deaths might be as high as 20 million. Moreover, the uncertainties are such that no government could predict with any confidence what the results of a limited attack or counterattack would be even if there was no further escalation.

3. It **is therefore reasonable to suppose that the extreme uncertainties about the effects of a nuclear attack, as well as the certainty that the minimum consequences would be enormous, both play a role in the deterrent effect of nuclear weapons.**

4. There are major differences between the United States and the Soviet Union that affect the nature of their vulnerability to nuclear attacks, despite the fact that both are large and diversified industrial countries. Differences between the two countries in terms of population distribution, closeness of population to other targets, vulnerability of agricultural systems, vulnerability of cities to fire, socioeconomic system, and political system create significant asymmetries in the potential effects of nuclear attacks. Differences in civil defense preparations and in the structure of the strategic arsenals compound these asymmetries. By and large, the Soviet Union is favored by geography and by a political/economic structure geared to emergencies; the United States is favored by having a bigger and better economy and (perhaps) a greater capacity for effective decentralization. The larger size of Soviet weapons also means that they are likely to kill more people while aiming at something else.

5. **Although it is true that effective sheltering and/or evacuation could save lives, it is not clear that a civil defense program based on providing shelters or planning evacuation would necessarily be effective.** To save lives, it is not only necessary to provide shelter in, or evacuation to, the right place (and only extreme measures of dispersion would overcome the problem that the location of safe places cannot be reliably predicted), it is also necessary to provide food, water, medical supplies, sanitation, security against other people, possibly filtered air, etc. After fallout diminishes, there must be enough supplies and enough organization to keep people alive while production is being restored. The effectiveness of civil defense measures depends, among other things, on the events leading up to the attack, the enemy's targeting policy, and sheer luck.

6. **The situation in which the survivors of a nuclear attack find themselves will be quite unprecedented.** The surviving nation would be far weaker—economically, socially, and politically— than one would calculate by adding up the surviving economic assets and the numbers and skills of the surviving people. Natural resources would be destroyed; surviving equip-

ment would be designed to use materials and skills that might no longer exist; and indeed some regions might be almost uninhabitable. Furthermore, prewar patterns of behavior would surely change, though in unpredictable ways. Finally, the entire society would suffer from the enormous psychological shock of having discovered the extent of its vulnerability.

7. From an economic point of view, and possibly from a political and social viewpoint as well, conditions after an attack would get worse before they started to get better. For a period of time, people could live off supplies (and, in a sense, off habits) left over from before the war. But shortages and uncertainties would get worse. The survivors would find themselves in a race to achieve viability (i. e., production at least equaling consumption plus depreciation) before stocks ran out completely. A failure to achieve viability, or even a slow recovery, would result in many additional deaths, and much additional economic, political, and social deterioration. This postwar damage could be as devastating as the damage from the actual nuclear explosions.

APPROACH

The scope of this study is both broader and narrower than that of most other studies on this subject. It is broader in three respects:

1. it examines a full range of possible nucle ar attacks, with attacking forces ranging in extent from a single weapon to the bulk of a superpower's arsenal;
2. it deals explicitly with both Soviet attacks on the United States and U.S. attacks on the Soviet Union; and
3. it addresses the multiple effects of nuclear war, indirect as well as direct, long term as well as short term, and social and economic as well as physical.

Those effects that cannot be satisfactorily calculated or estimated are described qualitatively. But this report's scope is narrower than most defense analyses because it avoids any consideration of military effects; although it hypothesizes (among other things) missile attacks against military targets, only the "collateral" damage such attacks would inflict on the civilian society are examined.

The approach used was to look at a series of attack "cases," (table 1) and to describe the various effects and overall impact each of them might produce. By analyzing the impact of the same attack case for both a U.S. attack on the Soviet Union and a Soviet attack on the United States, the report examines the significance of the different kinds of vulnerabilities of the two countries, and offers some insights about the consequences of the differences between the two countries' nuclear weapon arsenals. The cases were chosen primarily to investigate the effects of variations in attack size and in the kinds of targets attacked. It is believed that the analysis is "realistic," in the sense that the hypothetical attacks are possible ones. Patterns of nuclear explosions were examined that are not very different from those that, OTA believes, the existing nuclear forces would produce if the military were ordered to make attacks of the specified size on the specified targets.

Case 1: In order to provide a kind of tutorial on what happens when nuclear weapons are

Table 1. –Summary of Cases

Case	Description
1 (pp. 27-44)	Attack on single city: Detroit and Leningrad; 1 weapon. or 10 small weapons.
2 (pp. 64-80)	Attack on oil refineries, limited to 10 missiles.
3 (pp. 81-94)	Counterforce attack; includes attack only on ICBM silos as a variant.
4 **(pp. 94-106)**	Attack on range **of military and economic targets using large fraction of existing arsenal.**

For each case the first section describes a soviet attack on the United States and the following section a U S attack on the Soviet Union

detonated, the study describes the effects of the explosion of a single weapon. Then it examines the effects of such an explosion over a single U.S. city (Detroit) and single Soviet city (Leningrad) of comparable size. The base case was the detonation of a l-megaton weapon (1 Mt = energy released by one million tons of TNT), since both the United States and the Soviet Union have weapons of roughly this size in their arsenals. Then, in order to look at the ways in which the specific effects and overall impact would vary if other weapons that might be available were used, the effects of a 25-Mt weapon over Detroit, the effects of a 9-Mt weapon over Leningrad, and the effects of 10 weapons of 40 kilotons (kt) each over Leningrad are described. An attempt was made to describe as well the effects of a small weapon in a large city (such as a terrorist group might set off) but was unsuccessful because the effects of such a weapon in a metropolitan setting cannot be inferred from the existing body of knowledge regarding military weapons. This is explained in the body of the report.

The casualties from such attacks could range from 220,000 dead and 420,000 injured to 2,500,000 dead and 1,100,000 injured (many of the injured would wind up as fatalities), depending on the details of the attack and the assumptions made regarding conditions. The discussion in chapter II shows how the time of day, time of year, weather conditions, size of weapon, height of burst, and preparation of the population could all make a great difference in the number of casualties resulting from such an attack. The extent of fire damage is a further uncertainty, Even if only one city is attacked, and the remaining resources of a nation are available to help, medical facilities would be inadequate to care for the injured. A further imponderable is fallout (if the attack uses a surface burst), whose effects depend on the winds.

Case 2: In order to examine the effects of a small attack on urban/industrial targets, the study examines a hypothetical attack limited to 10 SNDVs (strategic nuclear delivery vehicles, the term used in SALT to designate one missile or one bomber) on the other superpower's oil refineries. In "planning" this attack, which is not analogous to any described in recent U.S. literature, it was hypothesized that the political leadership instructed the military to inflict maximum damage on energy production using only 10 SNDVs without regard to the extent of civilian casualties or other damage, It was assumed that the Soviets would attack such targets with SS-18 missiles (each carrying 10 multiple independently targetable reentry vehicles, or MIRVs), and that the United States would use 7 MIRVed Poseidon missiles and 3 MIRVed Minuteman III missiles.

The calculations showed that the Soviet attack would destroy 64 percent of U.S. oil refining capacity, while the U.S. attack would destroy 73 percent of Soviet refining capacity. Calculations were also made of "prompt fatalities," including those killed by blast and fallout, assuming no special civil defense measures: they showed about 5 million U.S. deaths and about 1 million Soviet deaths. The results were different for the two countries for several reasons. Soviet oil refining capacity is more concentrated than U.S. oil refining capacity, so that a small attack can reach more of it. At the same time, Soviet refineries tend to be located away from residential areas (the available data on population location deals with where people live rather than with where they work) to a greater extent than U.S. refineries. A further difference is that a limitation on the number of delivery vehicles would lead each side to use weapons with many MIRVs, so the United States would attack most of the targets with Poseidon missiles which have small warheads, while the Soviets would use SS-18 intercontinental ballistic missiles (ICBMs) which carry much larger warheads, and large warheads cause more damage to things not directly targeted (in this case, people) than do small warheads.

One can only speculate about the consequences of such extensive destruction. There would have to be drastic changes in both the U.S. and Soviet economies to cope with the sudden disappearance of the bulk of oil refining capacity. Productivity in virtually every industrial sector would decline, and some sectors would be largely wiped out. There would

have to be strict allocation of the remaining available refined petroleum products. Some Soviet factory workers might end up working in the fields to replace tractors for which fuel was unavailable. The United States might have to ban commuting by automobile, forcing suburban residents to choose between moving and long walks to a bus stop. The aftermath of the war might lead to either an increase or a decrease i n the amount of petroleum products required by the military. Changes in people's attitudes are impossible to predict. Calm determination might produce effective responses that would limit the damage; panic or a breakdown in civic spirit could compound the effects of the attack itself.

It is instructive to observe the asymmetries between the problems which the United States and the Soviets would face. Soviet agricultural production, which is barely adequate in peacetime, would probably decline sharply, and production rates would slow even in essential industries However, the Soviet system is well adapted for allocating scarce resources to high-priority areas, and for keeping everybody employed even if efficient employment is unavailable. The relative wealth and freedom of the United States brings both advantages and disadvantages: while agriculture and essential industry would probably continue, there would be a staggering organizational problem in making use of resources that now depend on petroleum — one must ask what the employees of an automobile factory or a retail establishment on a highway would do if there were virtually no gasoline for cars,

A major question relating to these results is how much they could vary with changed assumptions, The figures for fatalities were based on air bursts, which would maximize destruction of the refineries. (As an excursion, U.S. fatalities were recalculated on the assumption of surface bursts, and use of the best fallout shelters within 2 miles of where each person lives. This reduced fatalities by one-third,) There was no data available on the types of Soviet residential construction in the vicinity of oil refineries: treating it parametrically gave casualty figures of about *1,5OO,OOO* if the construction is all houses, and about 800,000 if it is al I apartment buildings. Perfect accuracy was assumed for missiles that are in fact somewhat inaccurate — some inaccuracy might reduce the extent of damage to the refineries, but it might well increase the number of deaths.

Case 3. I n order to examine the effects on civilian populations and economies of counterforce attacks, the study examined attacks on ICBM silos and attacks on silos, bomber bases, and missile submarine bases. Such attacks have received fairly extensive study in the executive branch in recent years, so OTA surveyed a number of these studies in order to determine the range of possible answers, and the variations in assumptions that produce such a range, An unclassified summary of this survey appears as appendix D of this volume. (The complete survey, classified secret, is available separately.)

A counterforce attack would produce relatively Iittle direct blast damage to civilians and to economic assets; the main damage would come from radioactive fallout, The uncertainties in the effects of fallout are enormous, depending primarily on the weather and on the extent of fallout sheltering which the population makes use of. The calculations made by various agencies of the executive branch showed a range in "prompt fatalities" (almost entirely deaths from fallout within the first 30 days) from less than 1 to 11 percent of the U.S. population and from less than 1 to 5 percent of the Soviet population. This shows just how great a variation can be introduced by modifying assumptions regarding population distribution and **shelter**

What can be concluded from this? First, if the attack involves surface bursts of many very large weapons, if weather conditions are unfavorable, and if no fallout shelters are created beyond those that presently exist, U.S. deaths could reach 20 m i l l ion and Soviet deaths more than 10 million. (The difference is a result of geography; many Soviet strategic forces are so located that fallout from attacking them would drift mainly into sparsely populated areas or into China.) Second, effective fallout

sheltering (which is not necessarily the same thing as a program—this assumes people are actually sheltered and actually remain there) could save many lives under favorable conditions, but even in the best imaginable case more than a million would die in either the United States or the U.S.S.R. from a counterforce attack. Third, the "limited nature" of counterforce attacks may not be as significant as the enormous uncertainty regarding their results.

There would be considerable economic damage and disruption as a result of such attacks. Almost all areas could, in principle, be decontaminated within a few months, but the loss of so many people and the interruption of economic life would be staggering blows. An imponderable, in thinking about the process of recovery, is the extent of any lasting psychological impacts.

Case *4:* In order to examine the kind of destruction that is generally thought of as the culmination of an escalator process, the study looked at the consequences of a very large attack against a range of military and economic targets. Here too calculations that the executive branch has carried out in recent years were used. These calculations tend to assume that Soviet attacks on the United States would be a first strike, and hence use most of the Soviet arsenal, while U.S. attacks on the Soviet Union would be retaliatory strikes, and hence use only those weapons that might survive a Soviet counterforce attack. However, the difference in damage to civilian populations and economies between a "first strike" and a "second strike" seems to lie within the range of uncertainty created by other factors.

The resulting deaths would be far beyond any precedent. Executive branch calculations show a range of U.S. deaths from 35 to 77 percent (i. e., from 70 million to 160 million dead), and Soviet deaths from 20 to 40 percent of the population. Here again the range reflects the difference made by varying assumptions about population distribution and sheltering, and to a lesser extent differences in assumptions about the targeting policy of the attacker. Soviet casualties are smaller than U.S. casualties because a greater proportion of the Soviet population lives in rural areas, and because U.S. weapons (which have lower average yields) produce less fallout than Soviet weapons.

Some excursions have been run to test the effect of deliberately targeting population rather than killing people as a side effect of attacking economic and military targets. They show that such a change in targeting could kill somewhere between 20 million and 30 million additional people on each side, holding other assumptions constant.

These calculations reflect only deaths during the first 30 days. Additional millions would be injured, and many would eventually die from lack of adequate medical care. In addition, millions of people might starve or freeze during the following winter, but it is not possible to estimate how many. Chapter V attempts to calculate the further millions who might eventually die of latent radiation effects.

What is clear is that from the day the survivors emerged from their fallout shelters, a kind of race for survival would begin. One side of the race would be the restoration of production: production of food, of energy, of clothing, of the means to repair damaged machinery, of goods that might be used for trade with countries that had not fought in the war, and even of military weapons and supplies. The other side of the race would be consumption of goods that had survived the attack, and the wearing-out of surviving machines. If production rises to the rate of consumption before stocks are exhausted, then viability has been achieved and economic recovery has begun. If not, then each postwar year would see a lower level of economic activity than the year before, and the future of civilization itself in the nations attacked would be in doubt. This report cannot predict whether this race for economic viability would be won. The answer would lie in the effectiveness of postwar social and economic organization as much as in the amount of actual physical damage. There is a

controversy in the literature on the subject as to whether a postttack economy would be based on centralized planning (in which case how would the necessary data and planning time be obtained?), or to individual initiative and decentralized decision making (in which case who would feed the refugees, and what would serve for money and credit?).

An obviously critical question is the impact that a nuclear attack would have on the lives of those who survive it. The case descriptions discuss the possibilities of economic, political, social, and psychological disruption or collapse. However, the recital of possibilities and uncertainties may fail to convey the overall situation of the survivors, especially the survivors of a large attack that included urban-industrial targets. In an effort to provide a more concrete understanding of what a world after a nuclear war would be like, OTA commissioned a work of fiction. It appears as appendix C and presents some informed speculation about what life would be like in Charlottesville, Va., assuming that this city escaped direct damage from the attack. The kind of detail that such an imaginative account presents—detail that proved to be unavailable for a comparable Soviet city–adds a dimension to the more abstract analysis in the body of the report.

Civil Defense: Chapter 11 I provides some basic information about civil defense measures, discusses the way in which they might mitigate the effects of nuclear attack, and discusses the uncertainties regarding their effectiveness. There is a lively controversy among experts as to the effectiveness of existing Soviet civil defense programs, and another controversy as to whether existing U.S. programs ought to be changed. The major points in dispute were identified, but no attempt was made to assess the merits of the arguments. For the purposes of this study, it was assumed that the existing civil defense programs, as described in this report, would be in effect, and that a full-scale preattack evacuation of cities (sometimes called “crisis relocation”) would not take place. This assumption was made because it appeared to be the only way to describe existing vulnerabilities while avoiding predictions about the course of events leading up to a nuclear war. While both the U.S. and the Soviet Governments profess to believe that urban evacuation prior to an attack on cities would save lives, ordering such an evacuation would be a crisis management move as well as a civil defense precaution.

Long-Term Effects: While the immediate damage from the blasts would be long term in the sense that the damage could not be quickly repaired, there would be other effects which might not manifest themselves for some years after the attack. It is well established that levels of radiation too low (or too slowly absorbed) to cause immediate death or even illness will nevertheless have adverse effects on some fraction of a population receiving them. A nuclear attack would certainly produce both somatic effects (largely cancer) and genetic effects, although there is uncertainty about the numbers of victims. OTA calculated the ranges of such effects that might be produced by each of the attack cases analyzed. Cancer deaths and those suffering some form of genetic damage would run into the millions over the 40 years following the attack. For the comprehensive attack (Case 4), it appears that cancer deaths and genetic effects in a country attacked would be small relative to the numbers of immediate deaths, but that radiation effects elsewhere in the world would appear more significant. For counterforce attacks, the effects would be significant both locally and worldwide.

A 1975 study by the National Academy of Sciences (NAS)[1] addressed the question of the possibility of serious ecological damage, and concluded that while one cannot say just how such damage would occur, it cannot be ruled out. This conclusion still stands, although the NAS report may have been more alarmist about the possibility of damage to the ozone layer than recent research would support.

Table 2 summarizes the results of the case studies.

[1] *Long-Term Worldwide Effects of Multiple Nuclear-Weapons Detonations* **(Washington, D.C.: National Academy of Sciences, 1 975).**

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Table 2. –Summary of Effects

Case	Description	Main causes of civilian damage	Immediate deaths	Middle-term effects	Long-term effects
1 **(pp. 27-44)**	Attack on single city: Detroit and Leningrad; 1 weapon or 10 small weapons,	Blast, fire, & loss of infrastructure, fallout is elsewhere,	*200,00-2,000,000*	Many deaths from injuries; center of city difficult to rebuild,	Relatively minor
2 **(pp. 64-80)**	Attack on oil refineries, limited to 10 missiles,	Blast, fire, secondary fires, fallout, Extensive economic problems from loss of refined petroleum,	1,000,000-*5,000,000*	Many deaths from injuries; great economic hardship for some years; particular problems for Soviet agriculture and for U.S. socioeconomic organization	Cancer deaths in millions only if attack involves surface bursts
3 (pp. 81-94)	Counterforce attack: Includes attack only on ICBM silos as a variant	Some blast damage if bomber and missile sub marine bases attacked	1,000>000-*20,000,000*	Economic impact of deaths, possible large psychological impact	Cancer deaths and genetic effects in millions, further millions of effects outside attacked countries
4 **(pp. 94-106)**	Attack on range of military and economic targets using large fraction of existing arsenal	Blast and fallout, subsequent economic disruption; possible lack of resources to support surviving population or economic recovery, Possible breakdown of social order. Possible Incapacitating psychological trauma.	*20,000,000*-160,000,000	Enormous economic destruction and disruption, If Immediate deaths are in low range, more tens of millions may die subsequently because economy is unable to support them Major question about whether economic viability can be restored–key variables may be those of political and economic organization Unpredictable psychological effects,	Cancer deaths and genetic damage in the millions; relatively Insignificant in attacked areas, but quite significant elsewhere in the world. Possibility of ecological damage.

For each case, the first section describes a Soviet attack on the United States, and the following section a U.S. attack on the Soviet Union

UNCERTAINTIES

There are enormous uncertainties and imponderable involved in any effort to assess the effects of a nuclear war, and an effort to look at the entire range of effects compounds them. Many of these uncertainties are obvious ones: if the course of a snowstorm cannot be predicted 1 day ahead in peacetime, one must certainly be cautious about predictions of the pattern of radioactive fallout on some unknown future day. Similar complexities exist for human institutions: there is great difficulty in predicting the peacetime course of the U.S. economy, and predicting its course after a nuclear war is a good deal more difficult. This study highlights the importance of three categories of uncertainties:

- Uncertainties in calculations of deaths and of direct economic damage resulting from the need to make assumptions about matters such as time of day, time of year, wind, weather, size of bombs, exact location of the detonations, location of people, availability and quality of sheltering, etc.
- Effects that would surely take place, but whose magnitude cannot be calculated. These include the effects of fires, the shortfalls in medical care and housing, the extent to which economic and social disruption would magnify the effects of direct economic damage, the extent of bottlenecks and synergistic effects, the extent of disease, etc.
- Effects that are possible, but whose likelihood is as incalculable as their magnitude. These include the possibility of a

long downward economic spiral before viability is attained, the possiblity of political disintegration (anarchy or regionalization), the possibility of major epidemics, and the possibility of i reversible ecological changes.

One major problem in making calculations is to know where the people will be at the moment when the bombs explode. Calculations for the United States are generally based on the 1970 census, but it should be borne in mind that the census data describes where people's homes are, and there is never a moment when everybody in the United States is at home at the same time If an attack took place during a working day, casualties might well be higher since people would be concentrated in factories and offices (which are more likely to be targets) rather than dispersed in suburbs. For the case of the Soviet population, the same assumption is made that people are at home, but the inaccuracies are compounded by the unavailability of detailed information about just where the Soviet rural population lives. The various calculations that were used made varying, though not unreasonable assumptions about population location.

A second uncertainty in calculations has to do with the degree of protection available. There is no good answer to the question: "Would people use the best available shelter against blast and fallout?" It seems unreasonable to suppose that shelters would not be used, and equally unreasonable to assume that at a moment of crisis all available resources would be put to rational use, (It has beep pointed out that if plans worked, people behaved rationally, and machinery were adequately maintained, there would be no peacetime deaths from traffic accidents.) The Defense Civil Preparedness Agency has concluded from public opinion surveys that in a period of severe international crisis about 10 percent of all Americans would leave their homes and move to a "safer" place (spontaneous evacuation); more reliable estimates are probably impossible, but it could make a substantial difference to the casualty figures

A third uncertainty is the weather at the time of the attack at the various places where bombs explode. The local wind conditions, and especially the amount of moisture in the air, may make an enormous difference in the number and spread of fires. Wind conditions over a wider area determine the extent and location of fallout contamination. The time of year has a decisive effect on the damage that fallout does to agriculture–while an attack in January might be expected to do only indirect damage (destroying farm machinery or the fuel to run it), fallout when plants are young can kill them, and fallout just before harvesttime would probably make it unsafe to get the harvest in. The time of year also has direct effects on population death — the attack in the dead of winter, which might not directly damage agriculture, may lead to greater deaths from fallout radiation (because of the difficulty of improvising fallout protection by moving frozen dirt) and from cold and exposure.

The question of how rapid and efficient economic receovery would be— or indeed whether a genuine recovery would be possible at all — raises questions that seem to be beyond calculation. I t is possible to calculate direct economic damage by making assumptions about the size and exact location of bomb explosions, and the hardness of economic assets; however, such calculations cannot address the issues of bottlenecks and of synergy. Bottlenecks would occur if a key product that was essential for many other manufacturing processes could no longer be produced, or (for the case of a large attack) if an entire industrial sector were wiped out. I n either case, the economic loss would greatly exceed the peacetime value of the factories that were actually destroyed. There does not appear to be any reliable way of calculatin$_g$ the likelihood or extent of bottlenecks because economic input/output models do not address the possibility or cost of substitutions across sectors. Apart from the creation of bottlenecks, there could be synergistic effects: for *example, the* fire that cannot be controlled because the blast destroyed fire stations, as actually happened at Hiroshima. Here, too, there is no reliable way to

estimate the likelihood of such effects: would radiation deaths of birds and the destruction of insecticide factories have a synergistic effect? Another uncertainty is the possibility of organizational bottlenecks. In the most obvious instance, it would make an enormous difference whether the President of the United States survived. Housing, defined as a place where a productive worker lives as distinct from shelter for refugees, is another area of uncertainty. Minimal housing is essential if production is to be restored, and it takes time to rebuild it if the existing housing stock is destroyed or is beyond commuting range of the surviving (or repaired) workplaces. It should be noted that the United States has a much larger and more dispersed housing stock than does the Soviet Union, but that American workers have higher minimum standards.

There is a final area of uncertainty that this study does not even address, but which could be of very great importance. Actual nuclear attacks, unlike those in this study, would not take place in a vacuum. There would be a series of events that would lead up to the attack, and these events could markedly change both the physical and the psychological vulnerability of a population to a nuclear attack. Even more critical would be the events after the attack. Assuming that the war ends promptly, the terms on which it ends could greatly affect both the economic condition and the state of mind of the population. The way in which other countries are affected could determine whether the outside world is a source of help or of further danger. The post-attack military situation (and nothing in this study addresses the effects of nuclear attacks on military power) could not only determine the attitude of other countries, but also whether limited surviving resources are put to military or to civilian use.

Moreover, the analyses in this study all assume that the war would end after the hypothetical attack. This assumption simplifies analysis, but it might not prove to be the case. How much worse would the situation of the survivors be if, just as they were attempting to restore some kind of economy following a massive attack, a few additional weapons destroyed the new centers of population and of government?