ANNEX 3

BIOLOGICAL EFFECTS OF NUCLEAR WAR

ACUTE EFFECTS OF RADIATION; THE LD-50 VALUE

by

T. Ohkita and J. Rotblat

Bases for estimates of LD-50 in man

Whole-body exposure to high doses of radiation gives rise to acute effects, i.e. the prodromal syndrome (radiation sickness), which may manifest itself within hours, or even minutes, after the exposure, and - if the dose is sufficiently large - death within a few weeks.

At high doses, above 10 gray, mortality is 100%, but the time of death is a function of the dose. The general trend of this function, compiled mainly from mammalian data,[1] is shown on Fig. 1. At very high doses death may occur within hours, but with decreasing dose the time of death extends to weeks.

At doses below 10 gray there is a chance of survival, particularly if medical treatment is available. The syndrome causing death in the range 1 to 5 gray is damage to the haemopoietic system (and the relevant dose is therefore that received by the bone marrow). A bone marrow transplant - if not rejected by the body - can prevent death in some cases, but such treatment is most unlikely to be available under war-time conditions. For this reason, even a dose to the bone marrow of less than 5 gray may produce 100% mortality within 60 days after exposure. At lower doses there is an increasing chance of survival. The probability of death is a sigmoid function of the dose. An example of such a function, obtained in experiments with mice, is shown in Fig. 2.

The chief characteristic of such curves is the LD-50 value, that is the dose that causes 50% mortality in a population exposed to it. A remarkable feature of the curve is its steepness, which means that estimates of radiation casualties are very sensitive to the LD-50. As seen from Fig. 2, an error of ± 30% in the LD-50 value can make all the difference between practically 100% survival and practically 100% mortality. For humans the curve is less steep, but an accurate value of the LD-50 is still necessary for an estimate of casualties.

The problem is that while there are plenty of such data for animals, there are practically none for man. Early data[2] from a group of patients with cancer, which indicated a bone marrow LD-50 of 2.5 gray, were dismissed as not being applicable to the general population. Estimates of the LD-50 in man were based mainly on the very small number of people exposed to large doses of radiation in accidents that have occurred before the Chernobyl disaster. Like in Chernobyl, most of the victims of the earlier accidents received intensive medical treatment, that included barrier nursing, antibiotics, platelet and red blood cell concentrates, and bone marrow transplants.[3] As already mentioned, such treatment enables people to survive much higher doses, nevertheless, it was assumed that this does not affect the LD-50 value. For example, in the United Kingdom an effective LD-50 of 6 gray to bone marrow - deduced mainly from the people exposed to radiation in accidents - is being used to estimate radiation casualties in a nuclear war.[4]

In Hiroshima and Nagasaki a large number of people were exposed to radiation under war-time conditions, but these data have not been utilized because of the alleged difficulty in separating mortalities caused by radiation from those caused by blast or heat.[5] However, recent surveys carried out in Japan in connection with the reassessment of the dosimetry for long-term effects (see Annex 1) provided an opportunity for another look at the acute effects of radiation. Under the auspices of the World Health Organization a survey was carried out on a large number of people in Hiroshima,[6] which provides suitable material for an estimate of radiation casualties under war-time conditions.

The Hiroshima Reconstruction Survey[6]

During the period 1969-71, the Hiroshima City jointly with the Research Institute for Nuclear Medicine and Biology of the University of Hiroshima, conducted a reconstruction survey focused on the central bombed area, and based on information available in the A-bomb survivor population file of the above Institute. From a list of 21 540 people who lived in 56 machi (residential areas), to the east, west and south of the hypocentre, at distances from about 500 metres to 1300 metres, 3215 people were selected for analysis, the basis for the selection being confirmed evidence that they were inside Japanese-style wooden houses during the explosion. A detailed questionnaire, with some 60 searching questions in it, provided information about the location of the survivors and the number of people who died during the first two months after the bomb.

It should be noted that this survey did not contain information about families whose members had all perished and who had no relatives or friends to provide data. This means that the actual mortality was greater than that recorded in the survey. In an analysis of mortality versus dose, the loss of data at the high mortality end of the curve generally results in an underestimate of the LD-50 value.

The data provided by the survey are listed in Table 1. There were numerous deaths during the first day, 6 August 1945, due to people being pinned under the houses which collapsed by the pressure of the blast wave, or were burned from the heat wave or in secondary fires.

Apart from the distance from the hypocentre and date of death, the survey also classified the material by age and sex. The age and sex distribution of the people in the survey reflected the war-time conditions in Japan. As seen from Table 2, the percentage of males in the middle age groups is considerably lower than of females, presumably because many men were called up for military service. For this reason, the total number of females is nearly double the number of males.

Suitability of the survey for the determination of the LD-50 value

Some of the people in the survey who have died during the two months have probably suffered injuries and/or burns, apart from being exposed to radiation. Therefore, the question arises whether the material in the survey is suitable for a determination of the LD-50 for radiation exposure.

To answer this question a detailed study has been made[7] using data from a part of the survey compiled earlier (from the areas on the east and west of the hypocentre) and comprising a total of 1215 people. The study was based on two types of analysis: the variation of mortality as a function of time after the exposure, and as a function of distance from the hypocentre. For both of these analyses, the observed occurrence of death after the first day was compared: (a) with that to be expected if the people were in the open and thus subject to the blast and heat effects, in addition to radiation; and (b) with data from laboratory experiments, in which radiation was the only cause of death from acute exposure of animals. The analysis has revealed a striking difference from the conditions under (a), but very good agreement with (b). In other words, the pattern of the observed mortality was that to be expected in a population subject predominantly to the trauma of radiation exposure. The same pattern was subsequently found in the complete survey.

Determination of the 50% mortality distance and effect of age and sex[8]

Fig. 3a shows the observed mortality as a function of distance from the hypocentre for all the subjects in the reconstruction survey who survived the first day. In order to facilitate a comparison with the customary sigmoid plot (mortality versus dose, as in Fig. 2), the horizontal scale gives distances increasing from right to left. The bars indicate one standard deviation.

An idea about the goodness of fit to a theoretical mortality curve can be obtained if the data are plotted on a probability scale instead of a linear scale, because the sigmoid curve is then transformed into a linear relation. Fig. 3b is such a plot of the data in Fig. 3a; as is seen the fit is very good. From this line, the distance at which the mortality is 50% comes out to be 903 $\pm$ 8 metres.

Similar calculations can be made for the two sexes separately, as well as for the different age groups. Naturally, dividing the total population into a number of small groups results in larger errors of the individual results. In Fig. 4, the distance at which the mortality is 50% is shown as a function of age, in 10-year intervals (the dashed horizontal line is the average for all ages). It should be noted that a larger 50% mortality distance means a greater sensitivity to radiation. As Fig. 4 shows, there is no significant difference in radiation sensitivity between the early years of life and middle age, but at older ages there is a definite increase in sensitivity; old people would die when exposed to doses which produce little mortality at a younger age. In Fig. 5, the age variation is plotted separately for the two sexes. A computer analysis has confirmed that the observed differences at the young and old age groups are statistically significant. As is seen, females are less sensitive to radiation than males when very young, but more sensitive at older age. The cross-over appears to occur at about 40 years of age. The males in the middle age group may have been exempt from military service for reasons of health; if so, in a normal population, the cross-over would occur at a younger age.

Calculation of the LD-50 values

In order to convert the distance at which there is 50% mortality to the radiation dose that reached the bone marrow, three parameters are necessary: (a) the variation of tissue kerma in air with distance; (b) the transmission factor for buildings; (c) the organ factor. As discussed in Annex 1, all these parameters underwent considerable changes in the revised dosimetry, carried out by the US-Japan Atom Bomb Radiation Dosimetry Committee. The new dosimetry system, DS86, will not be published until late in 1987, but based on results already published preliminary values of the LD-50 have been calculated.

Using the data from Annex 1 (Figs. 6a and b, Tables 6a and b) to estimate the contributions from the different components of the radiation at the distance at which 50% mortality was observed, the LD-50 value, averaged over all ages and both sexes, was calculated to be 1.5 gray. A recent publication,[9] more likely to represent the revised DS86 dosimetry, contains curves of kerma and shielding factors versus distance from the hypocentre. An analysis of these data leads to a bone marrow LD-50 value of 1.8 gray.[a]

Before the LD-50 can be applied to an estimate of radiation casualties in a nuclear war, when radiation exposure would come from radioactive fall-out rather than from the direct radiations, two points must be considered.

One is that the exposure to radiation in Hiroshima was practically instantaneous, while that from fall-out is spread out over hours or days. Since there is no directly relevant information about the effect this difference would make in man, data from animal experiments have to be used. From the literature[10] it can be inferred that, in larger mammals, if the same dose were delivered at a constant rate over 24 hours, the LD-50 would be increased by about 40%. However, in the case of fall-out the dose rate is not constant; it decreases rapidly. Calculations have shown that if the dose from the fall-out were received in 24 hours, the LD-50 would be increased by about 10%, making the LD-50 to bone marrow about 2.0 gray.

The second point is that in fall-out calculations, the dose at the surface of the body, and not to the bone marrow, is usually calculated. For this purpose the bone marrow dose must be divided by the organ factor, which for fall-out radiation is likely to be between 0.75 and 0.8. This gives an LD-50 at the surface of the body of about 2.5 gray.

This LD-50 value is two to three times lower than had been assumed before. It means that in a nuclear war the number of fatalities due to exposure to radiation would be considerably higher than thought hitherto (see Annex 4).

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[a] Results of another recent survey by S. Fujita, H. Kato and W. J. Schull (personal communication) indicate an LD-50 between 2.3 and 2.6 gray.

A factor contributing to this very low LD-50 value deduced from the Hiroshima survey is probably malnutrition that existed in the city both before and after the bomb, and which may have reduced the immune response of the organism.[11] Injuries from blast and heat have probably also contributed. In a stressed population, under war-time conditions, a low LD-50 value may be expected by the action of agents additional to that of malnutrition, namely physical trauma, burns and psychosocial stress, as discussed in the section on immunological consequences, in Annex 6.

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TABLE 1. HIROSHIMA RECONSTRUCTION SURVEY

Total number in survey	3 215
Died on 6 August 1945	1 085
Died between 7 August and 5 October	559

Data provided by the survey

Distance from hypocentre:	8 groups in 100 metre intervals, between 500 and 1300 metres.
Date of death:	Deaths that have occurred during the first two months are listed for each day.
Age:	18 groups in 5-year intervals between 0 and 85 plus.
Sex:	Data listed separately for males and females.

TABLE 2. AGE DISTRIBUTION IN SURVEY

(Percentage)

	Age group			
	0-14	15-59	60-	All
Male	14	18	3	35
Female	19	43	3	65

Fig. 1 Time of occurence of death from acute effects

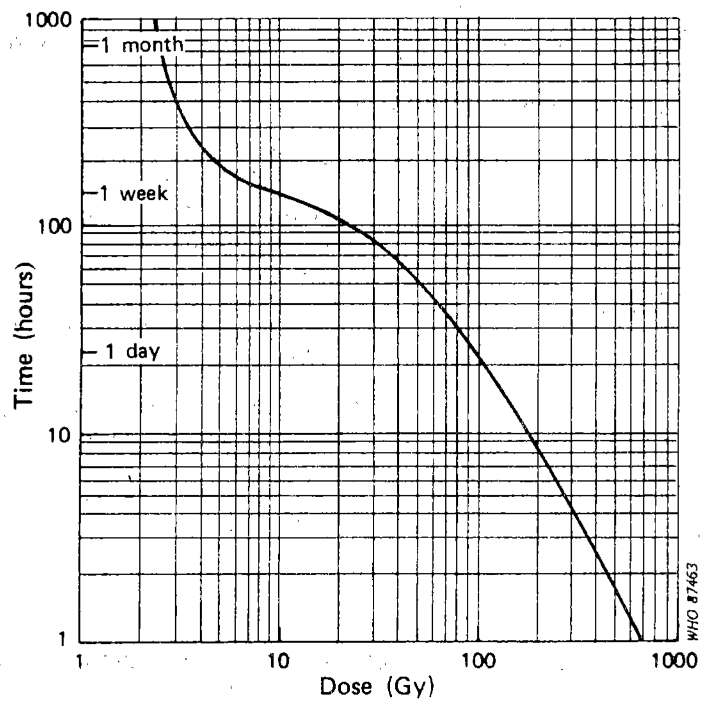


Fig. 2. Acute radiation mortality of mice as a function of dose

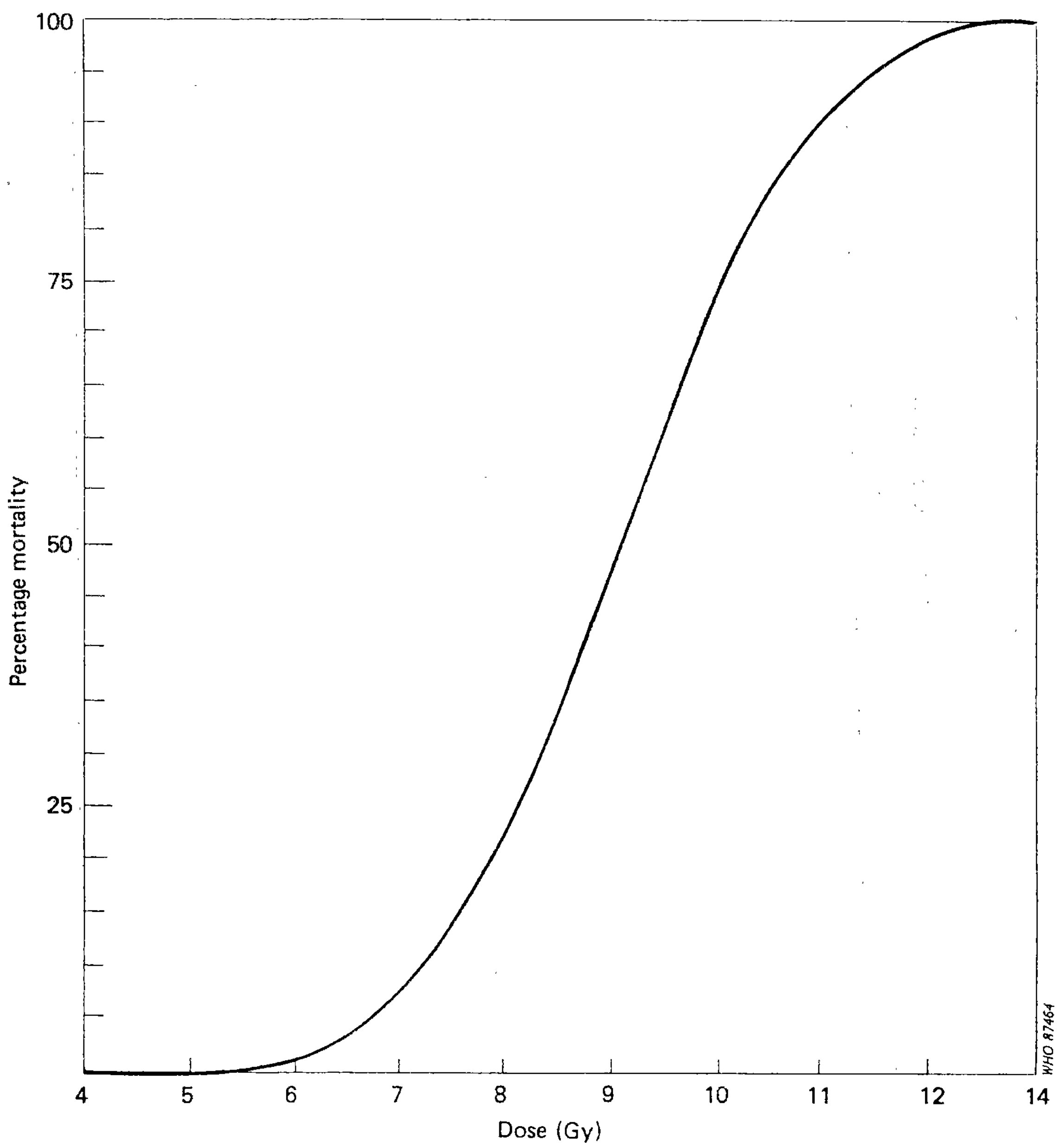


Fig. 3a. Percentage mortality as a function of distance from hypocentre in Hiroshima

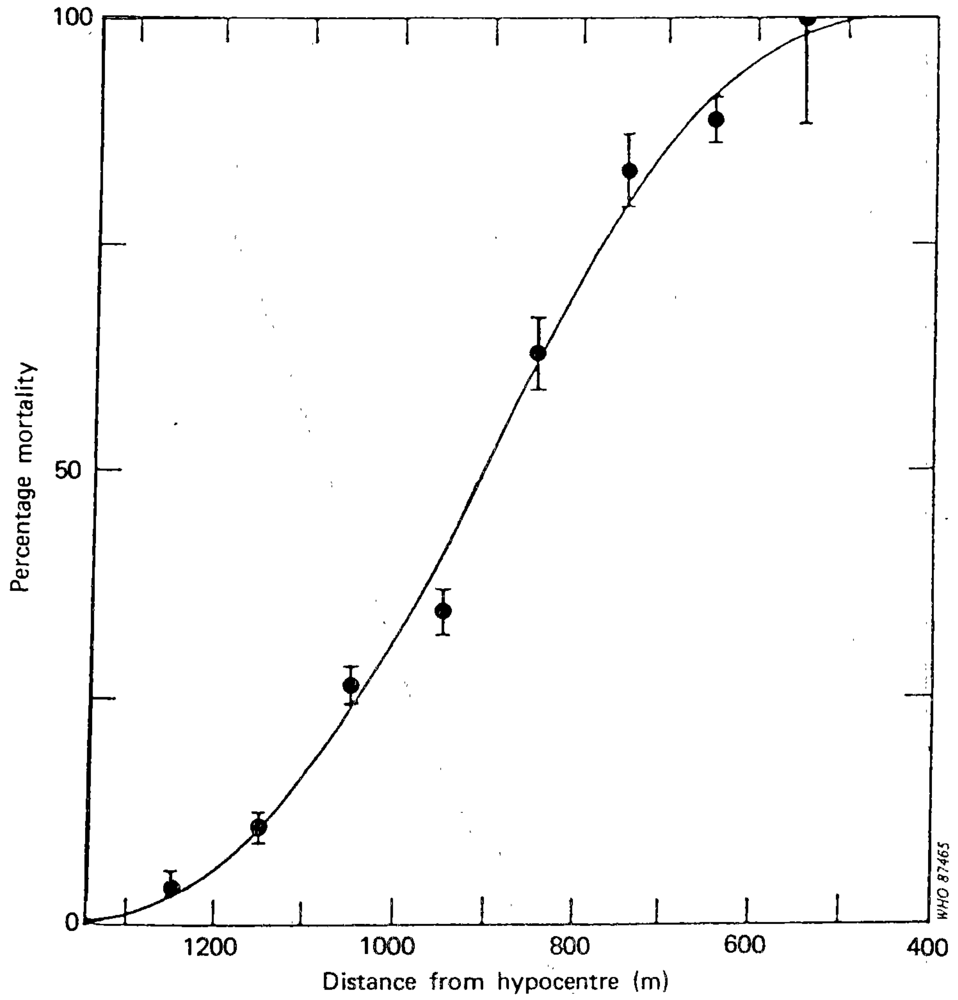


Fig. 3b. Percentage mortality as a function of distance from hypocentre in Hiroshima (note the probability scale)

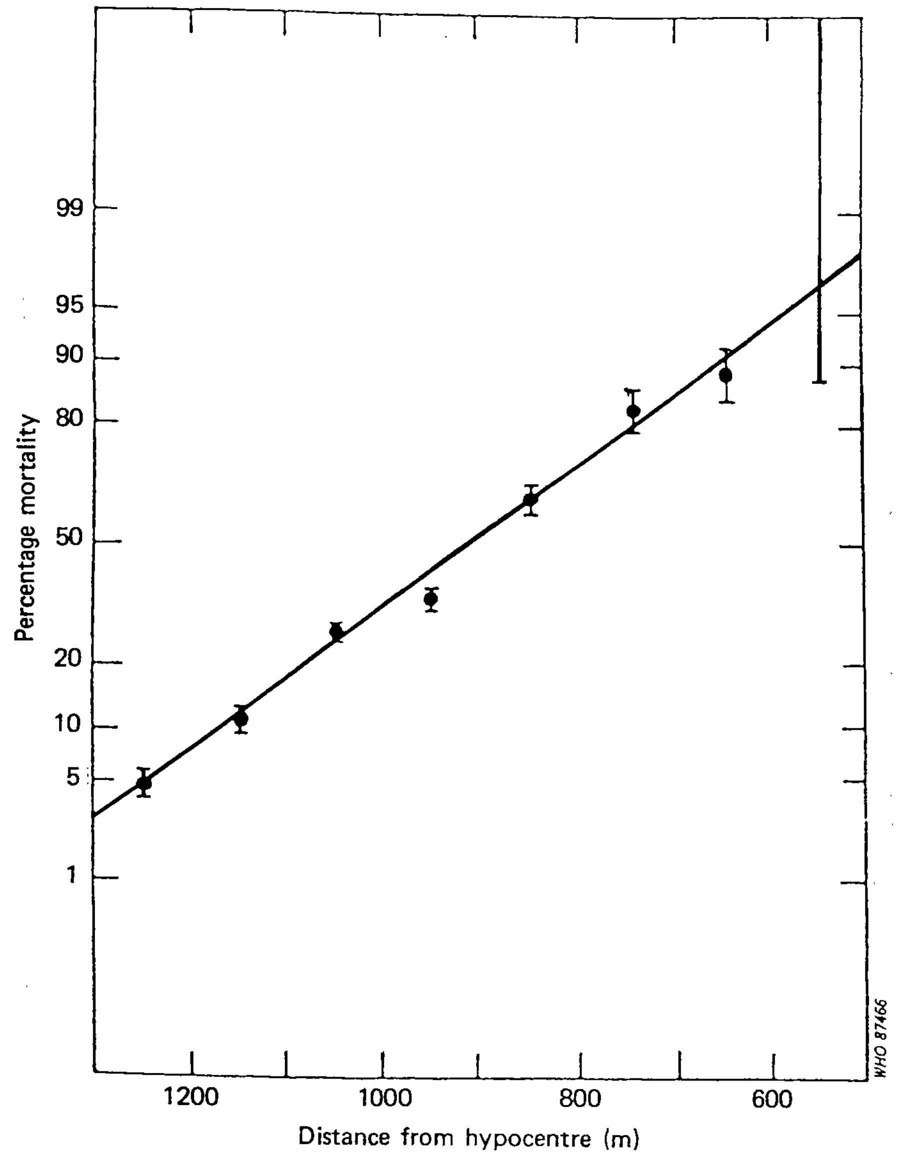
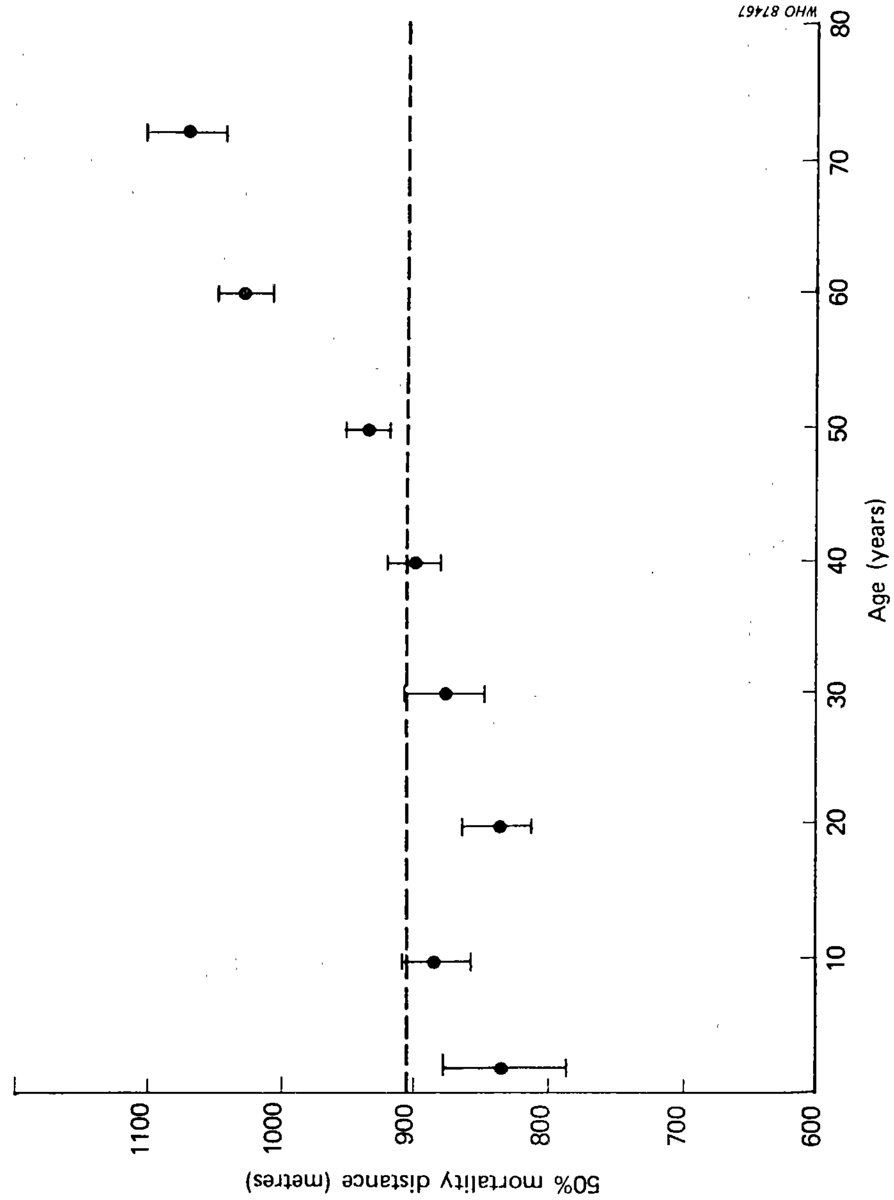


Fig. 4. Variation of the 50% mortality distance with age at exposure in Hiroshima (both sexes)



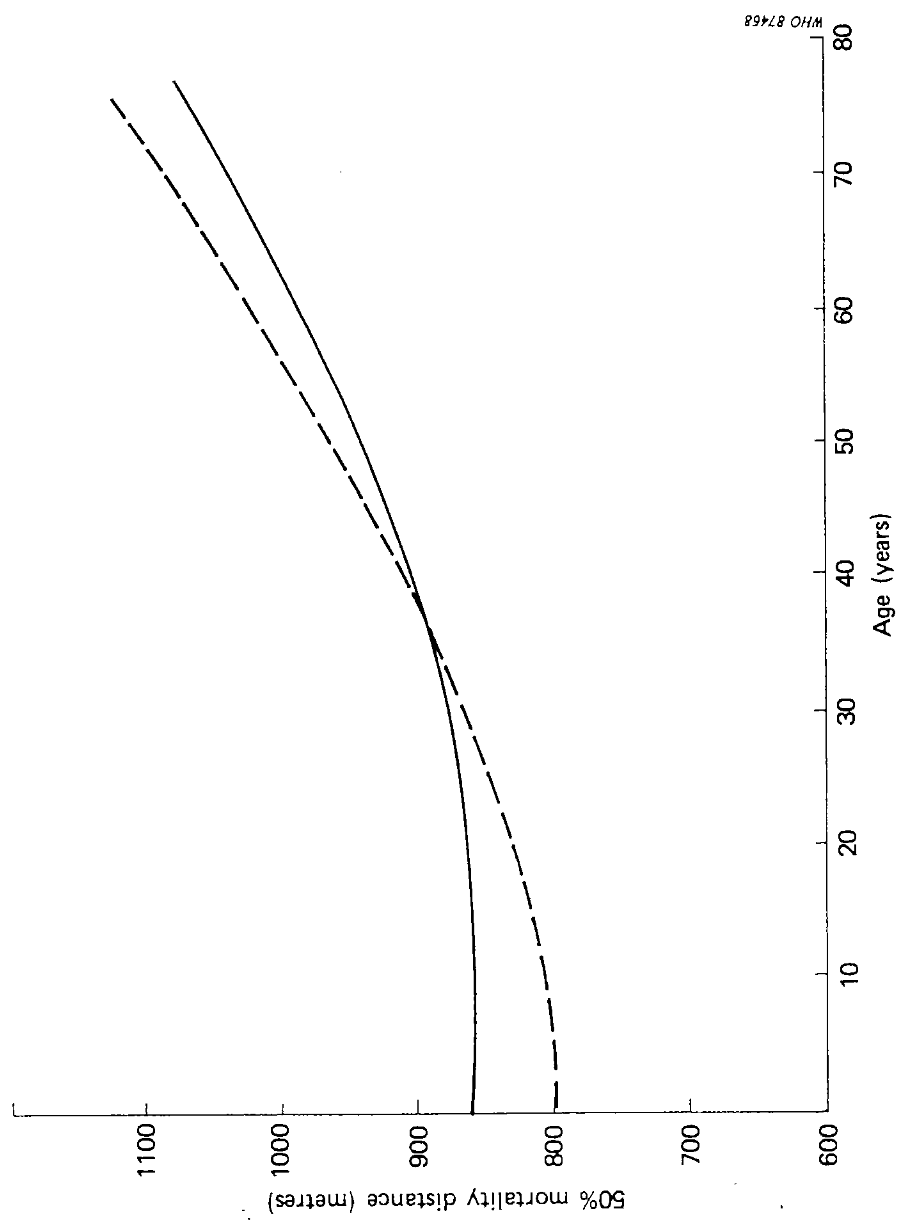


Fig. 5. Variation of the 50% mortality distance with age
Solid curve: males. Dashed curve: females

ANNEX 4

NUCLEAR WAR SCENARIOS

by

J. Rotblat

Introduction

The WHO report of 1983 contained an analysis of the various parameters that contribute to the uncertainties in estimating the casualties in a nuclear war.[1] The two main categories of these parameters are: (1) assumptions about the purpose and scale of the attack; (2) assumptions about the physical and biological effects of the explosions. Since 1983 there have been considerable developments in both these categories. Annexes 1, 2 and 3 discuss the new information relating to the second category of parameters. This Annex is concerned with the first category; it discusses several types and scales of attack, and the casualties arising in specific scenarios.

Much of the discussion in the last four years was centred on the climatological effects of nuclear war; a variety of scenarios were considered in this respect. In the "TTAPS" Report[2] 10 different scenarios were analysed, ranging from 100 megatons in a city attack to 25 000 megatons in a "future war"; the baseline scenario was a nuclear weapon exchange with 5000 megatons being exploded. A Lawrence Livermore Laboratory study[3] was based on a USA-USSR exchange involving 5300 megatons. A report from the US National Research Council[4] considered a scenario with 6500 megatons. In the very extensive SCOPE study[5] the scenario was based on 6000 megatons in a variety of targets and stages. All these scenarios do not differ significantly in scale from the "all-out nuclear war" scenario in the WHO report.[1] The casualty figures arrived at in that report - about 1100 million fatalities with a similar number of injured persons - were frequently quoted in the literature, but there was also some criticism about the assumption that the nuclear bombardment would in a considerable degree extend to non-nuclear weapon states; this was thought to lack credibility.[6]

The question of credibility can be applied to all "all-out" nuclear scenarios. Resort to a full-scale attack, even if only on one's adversary, is in itself incredible, since it is bound to be suicidal. Nevertheless, the majority of analysts believe that once a nuclear exchange has taken place, it is very likely to escalate into an "all-out" nuclear war. Though lacking in credibility, the possibility of a full-scale nuclear exchange cannot be ruled out. As the SCOPE Report puts it: "Although the concept of nuclear warfare involving the use of many nuclear weapons seems incredible and even irrational, the weapons for conducting such a war have been deployed and elaborate plans for action exist. It is unacceptable simply to dismiss the potential for global nuclear conflict on philosophical grounds. The deployment of nuclear warheads implies, in a very real sense, the possibility of their use".[7]

However, much discussion revolves round the concept of "limited" nuclear war, limited mainly in the selection and type of targets. This follows the remarkable improvement in the performance of nuclear weapons achieved in the recent years, namely the much greater accuracy of hitting a target. Nuclear weapons are now seen as instruments of fighting rather than deterrence. It is alleged that specific targets, such as military installations, could be destroyed and the enemy's retaliation potential greatly reduced in strictly limited attacks, which would bring the nuclear war quickly to an end without much collateral damage, e.g. civilian casualties.

Whether the postulate of containing a nuclear attack is valid or not, it is of interest to know the scale of civilian casualties in such attacks. This is the reason for the several studies carried out recently, using computer models. One study, of the casualties resulting from different "limited" nuclear attacks on the United States, was carried out by a group in Princeton.[8] An extension of this study to an attack on the Soviet Union was recently made by the same group, with partial support from WHO, and is described in Part B of this Annex. Another study, of the consequences of a "limited" nuclear war in Europe - also with partial support from WHO - was carried out in Milan and is described in Part C of this Annex.

One of the scenarios discussed in the 1983 WHO Report was a single one-megaton bomb on London. The consequences of an attack on this city was the subject of a recent very detailed study,[9] and the following is a review of this study.

ANNEX 4 . A

LONDON UNDER ATTACK

by

J. Rotblat

Scales of attack on London

The Greater London Area War Risk Study (GLAWARS) was commissioned by the Greater London Council in 1984; this arose from the United Kingdom Civil Defence Regulations which place the responsibility for civil defence on local authorities. Six Commissioners were appointed to supervise the study which comprised 12 separate task areas for investigation, and represents the most detailed analysis of the consequences of a nuclear attack on a major city. A summary of the reports of the task areas, prepared by a rapporteur, was published by the Commissioners.[9]

The GLAWARS study did not consider an attack on London alone, but rather the effects on London of nuclear attacks on the United Kingdom as a whole. To allow for different contingencies, five scenarios with increasing scales of nuclear attack were treated as a follow-on to a conflict started with conventional weapons. In the first scenario, only United Kingdom, or United-Kingdom-based, nuclear capabilities, such as cruise missile bases, were the targets, none of them in London. The second scenario extended the attack to command and control centres, and included seven bombs on the periphery of London. The third scenario was a more substantial attack, involving non-nuclear military targets, such as air force and naval bases, and included eight bombs on the periphery plus a ninth dropped in error on a point nearer to the centre of London. In all these three scenarios the bombs used were 150-350 kilotons. Scenarios 4 and 5 approached an all-out nuclear war, and extended to urban and industrial targets. They included all the weapons used in scenario 3, with the addition of a number of one-megaton bombs, some of them on London itself. The scales of the attack in the five scenarios are summarized in Table 1. The explosions were a mixture of ground and air bursts. Of those dropped on London itself only a small proportion (13% in scenario 4, 6% in scenario 5) were ground bursts. This maximizes the blast damage but minimizes radiation casualties.

Models for the calculation of casualties

The casualties resulting from the different scenarios in the GLAWARS study were calculated using a computer model originally developed for a study of the effects of a nuclear attack on Great Britain.[10] This model used census data to determine the population distribution in a grid of 1 km^2. An extension of this model was applied to the assumptions made in the GLAWARS scenarios.[11]

The methods described by Glasstone and Dolan[12] and the Office of Technology Assessment[13] were mainly used to determine the effects of heat, blast and fallout. For each scenario, the casualties due to the thermal flash were calculated first; the blast effect was then applied to the survivors, and finally the fallout casualties were calculated. The effect of superfires, as envisaged by the conflagration model (see Annex 1) was not included. For this reason, the numbers of prompt fatalities are underestimated.

Different atmospheric conditions were taken into account by inserting values for four wind directions and two wind velocities. A single LD_{50} value of 4.5 Gy was assumed. This again probably underestimates the radiation fatalities. A range of values of protection factors, from 1 to 16, was considered, in a grading system that depended on the degree of damage due to blast, namely, smaller protection factors were allocated to people in houses that suffered structural damage or broken windows.

Casualties from attacks on London

Table 2 summarizes the results of the calculation of casualties. Part A gives the fatalities (in thousands) in the five scenarios; the last column expresses them as a percentage of the total population. The night-time population of London (i.e. excluding commuters) was taken as 6 417 500. Part B gives the total casualties (fatalities plus injuries).

As is seen, the casualties come predominantly from the blast effect. This is so, because the over-pressure model was used. The conflagration model would have increased the fatalities in scenarios 2 and 3, but would make little difference to the total casualties in scenarios 4 and 5. Another important difference from other nuclear war scenarios is the low casualty rate from fallout relative to the prompt casualties. This is the result of postulating a small proportion of ground bursts. In another study[14] of the effect on London, in which ground bursts were assumed, it was found that - with similar parameters - the number of radiation fatalities was the same as from the prompt effects in the case of a single one-megaton bomb on the centre of London, and double the number of prompt fatalities in an attack with several bombs on the periphery of London.

Because of the small contribution of fallout casualties, the effect of varying the atmospheric conditions and protection factors are relatively small, as is seen in Table 3.

The effect of the attacks on London on its health services is discussed in Annex 5.

In their summary, the GLAWARS Commissioners reached the following conclusions: "If nuclear weapons were ever used, attempts to restrict their use to military targets would be likely to fail. Should this happen, London would be destroyed ... (In) The two most severe attacks considered ... at least 85 per cent of Londoners would be killed or seriously injured ... It would take London's pre-attack house-building industry more than 185 years to rebuild London's homes. Even a much less severe attack .. would destroy about one-third of the city. As a result, London might enter a spiral of decline from which it would never recover".

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TABLE 1. SCALES OF ATTACK ON LONDON

Scenario	Attack on United Kingdom		Attack on London	
	No. of warheads	Total megatons	No. of warheads	Total megatons
1	38	8.05		
2	56	13.00	7 (3 x 0.2 + 4 x 0.35)	2.00
3	207	31.05	9 (0.15 Mt)	1.35
4	241	65.05	13 (9 x 0.15 + 4 x 1)	5.35
5	266	90.05	18 (9 x 0.15 + 9 x 1)	10.35

TABLE 2. SHORT-TERM CASUALTIES IN THE LONDON AREA

A. Fatalities (thousands)

Scenario	Thermal flash	Blast	Radiation	Total	Percentage
1	0	0	0	0	0
2	14	529	95	638	9.9
3	75	496	166	737	11.5
4	606	3 336	399	4 341	67.6
5	1 093	4 370	338	5 801	90.4

B. Total casualties

Scenario	No. of injured	Total casualties	Percentage
1	0	0	0
2	357	995	15.5
3	739	1 476	23.0
4	1 109	5 450	84.9
5	423	6 224	97.0

TABLE 3. SENSITIVITY TESTS OF CASUALTY ESTIMATES

(Percentage of London population)

Scenario	Mean value	Atmospheric conditions Range	Protection factors Range
2	15.5	15.5 - 30	
3	23.0	20.5 - 33	21.5 - 25
4	84.9	82 - 88	82.5 - 86.5
5	97.0	95.5 - 97.5	96.5 - 97

ANNEX 4 . B

LIMITED ATTACKS ON THE UNITED STATES AND THE SOVIET UNION

by

B. Levi and F. von Hippel

Update since the 1983 WHO study

Focus on consequences of "limited" nuclear attacks

This section reports on calculations carried out at Princeton University of the consequences of so-called "limited" nuclear attacks by the USA and the USSR on one another - primarily because such scenarios seem to be motivating the acquisition of new nuclear weapons. Although the USA and USSR have recognized since the early 1960s that neither one can escape from their mutual hostage relationship by making a disarming "first strike" on the other, they continue to acquire nuclear weapons as if it might be possible to fight a nuclear war. In particular, both sides are moving towards weapons with improved capabilities - such as greater accuracy - for attacks against military targets, especially hardened underground ballistic missile silos and command posts.

Attacks on military targets are frequently described as "limited", because they are restricted to specific targets. In recent years, however, many have questioned whether such attacks can remain "limited" in view of the vulnerability of centralized control systems to nuclear weapons effects. The governments of nuclear weapons states might feel pressure to make maximum use of their arsenals before they lost control. Others have questioned whether counterforce attacks can remain "limited" in terms of civilian casualties. The estimates that are reviewed below allow one to compare the human toll to the more frequently discussed military value of the limited nuclear attacks that are most often discussed: attacks by the USA or the USSR against the nuclear weapons systems of the other.

This section also reviews recent calculations of the consequences of very limited attacks - of about 100 Mt each. These calculations examine the results of directing weapons against urban areas of the USA and USSR. They illustrate the damage - and hence the deterrent effect - of the use of only about 1% of the current Soviet and American nuclear arsenals. They also relate to the current debate over the possibility of defence against nuclear attacks. The key question, in the case of population defence, is how good such defences would have to be before they could reduce an attack below civilization-destroying levels.

Princeton studies of "limited" nuclear attacks on the USA and USSR

The Princeton group studied[1] the direct casualties from five different hypothetical "limited" nuclear attacks on the USA - one large attack on USA strategic nuclear facilities with approximately 3000 nuclear warheads and 4 smaller attacks on facilities in USA urban areas with approximately 100 1-Mt warheads each. The calculated numbers of short-term casualties ranged from 10 to 71 million for the 100-Mt attacks (100-700 thousand per megaton) and from 23 to 45 million for the large-scale counterforce attacks, with the variation being due to different assumptions concerning targets, winds and casualty models. The Princeton group has also estimated[2] the casualties from an attack with approximately 4000 warheads on military facilities in the Soviet Union. They find that the short-term casualties might range from 25 to 54 million. Both of these studies are discussed in more detail below.

New questioning of the assumptions that enter into such calculations

All of these consequence studies differ from one another in their detailed assumptions about the nature of the hypothetical nuclear attacks. They also differ in the many detailed assumptions one must make to estimate the casualties that result. These sets of assumptions comprise the "casualty models". Past calculations have all tended to adopt fairly similar casualty models. However, two recent studies have suggested modifications of two of these "standard" assumptions. The first study[3] shows that the current method for estimating casualties from blast and burns fails to account for the very large "superfires" that might be ignited in cities by today's large-yield nuclear weapons. Such large fires might result in many more deaths than predicted by the standard extrapolation from the casualties at Hiroshima and Nagasaki. The second study[4] indicates that the susceptibility of populations to death from radiation illness may be much greater under wartime conditions than is ordinarily assumed. The Princeton studies have found that these changes might result in large increases in the numbers of casualties due to both fires and radioactive fallout from nuclear attacks.

Casualty models

Casualties from blast and heat effects

All methods for estimating casualties produced by the combined effects of the blast and thermal pulse from a nuclear explosion rely on the observed probabilities of death and injury at various distances from ground zero at Hiroshima and Nagasaki. The methods differ in the way they extrapolate these data to weapons of higher yields. The standard method in the past has been to assume that the probability of death or injury at a particular location is associated with the peak blast overpressure at that location. This was a plausible assumption in the case of blast casualties and it was generalized because the radial distributions of casualties from all causes at Hiroshima and Nagasaki were quite similar to those due to blast.[5] The resulting simple "overpressure-casualty model" has been in almost universal use for years.[6]

As is discussed in Annex 1. , recent work by Postol[3] and by Brode & Small[7] has highlighted the likelihood that "superfires", ignited by nuclear weapons with significantly higher yield than those exploded over Hiroshima and Nagasaki, would cause high fatality rates over a much larger area than the standard extrapolation from those experiences would predict. The reason is that the lethality of fires caused by a nuclear explosion may grow much more rapidly as a function of the explosion's power than the area subjected to a given level of overpressure.

In an attempt to explore the potential effect of such superfires on casualty estimates, the Princeton group has developed a casualty model called the "conflagration model" which assumes that a circular mass fire would develop around ground zero and cause 100% lethalities for all those not within 2 km of its edge. Within the outer 2 km, the average rates of fatality and serious injury would be 50% and 33% respectively - the same as within the 2-km radius Hiroshima fire zone. Outside the fire zone, the same casualty rates were assumed as in the overpressure model.

Because of uncertainty about the growth of the area of the fire zone with the power of the explosion, the Princeton group adopted three versions of this conflagration model, corresponding to three different parameterizations of the radius of the fire zone. These parameterizations range from the assumption that the edge of the fire zone would occur at the same line of peak overpressure as at Hiroshima (about 20 kPa) to the assumption that the area of fire would grow in almost direct proportion to the power of the explosion. For a 1-Mt airburst at a 2-km altitude, this corresponds to a range of predicted conflagration radii of 8 to 15 km.

Figures 1a and 1b show the fatality and serious injury rates predicted by the overpressure model and an intermediate-radius (12-km) conflagration model for the case of a 1-Mt explosion at a 2-km altitude as a function of distance from ground zero.[8] It will be seen that the conflagration model predicts much higher numbers of fatalities than the overpressure model. Lower numbers of injuries are also predicted because many of those who would be predicted to be injured by the overpressure model are predicted to be fatalities by the conflagration model.

Casualties from radioactive fallout

If a nuclear explosion exploded so low that the fireball contacted the ground, large amounts of lethal radioactive fallout would result. There are many uncertainties that enter into calculations of casualties from such fallout. These include: the fraction of the energy of the nuclear explosion that comes from fission (the so-called "fission fraction"), the distribution of the fallout by the winds, the level of radiation protection of the population in the fallout zone, and the sensitivity of the population to the effects of radiation. The first three of these uncertainties will be briefly discussed here. The last is discussed in other annexes.

Fission fraction. The fission fractions of specific weapons are not publicly known. Published casualty estimates therefore ordinarily assume a fission fraction of 0.5 for strategic weapons. This is close to the estimated cumulative fission fraction of 0.4 for all atmospheric nuclear tests to date.[9]

Distribution of fallout. The distribution of the fallout would depend upon the wind pattern prevailing at the time of the explosion, the initial height distribution of the radioactivity produced by the explosion and the size and density distribution of the particles to which the radioactivity was attached. Since the radioactivity from a surface-burst weapon would be carried to a range of heights and the wind blows in different directions at different altitudes, quite complex patterns can result. A number of different computer models have been developed to predict these patterns and, because of the number of parameters and the relatively small amount of data available for fixing them, there is a considerable variation between their predictions. For example, the Livermore KDFOC2 fallout model, which was used in a recent report on the environmental consequences of nuclear war,[10] produces fallout areas about one half as large as other commonly used models. The reason seems to be that much of the local fallout in this model is assumed to come down very quickly, creating a very intense radioactive "hot spot" near ground zero. Even given a perfect model, however, estimates of the potential consequences of hypothetical nuclear attacks would be uncertain because of uncertainties about the wind patterns on the day of the attack.

Radiation protection factors. Computer programmes for calculating fallout radiation doses ordinarily calculate in an intermediate step the dose rates to which the population downwind would be exposed if they were standing outside on a perfectly flat surface. The unshielded dose rate received by a person inside is divided by a so-called "protection factor", which takes into account the shielding afforded by both the outside surface features and buildings. Unevenness of the terrain is ordinarily assumed to result in a protection factor for people standing outside of 1.4. The interiors of buildings above ground might offer an average protection factor of 5, and basements, below ground, 10 or higher. However, even if one knew the protection factor for every location, there would still be considerable uncertainty about the distribution of population protection factors, because one could not predict the behaviour of the population during the post-attack period. This behaviour would be particularly important when the radiation level was most intense during the hours immediately after the fallout arrived. For example, for fallout arriving two hours after an explosion, one hour's exposure outdoors would give the same dose as would be accumulated over the following two weeks in a shelter with a protection factor of 10. Therefore, activities such as attempting to escape from the contaminated zone, looking for missing family members, or trying to gather survival supplies would have a critical bearing on the actual reduction of population radiation dose by shielding. The effective protection factor would also be reduced when people emerged from their shelters after days or weeks to seek food, medical attention, etc.

The Princeton group assumed in its calculations that the population would be about equally divided between a group that spent most of its time inside houses but above ground, therefore having an effective protection factor of 3, and another group that spent most of its time in shelters below ground, which afford a protection factor of 10.

An additional uncertainty is how much additional dose might be received from contamination of indoor areas, clothes, skin, food and water. Contamination of clothes and skin would result in skin burns from short-range beta-rays and contamination of food and water would result in high doses to the inner surface of the gastrointestinal tract - also from beta-rays. These beta-doses are ordinarily not included in fallout dose calculations but they could significantly lower the resistance of the population to the whole-body doses that are calculated.

Population susceptibility to radiation illness. The standard assumption used in USA casualty models since World War II is that a gamma-radiation dose at the surface of the body of 4.5 grays (450 rads), delivered over a period of two weeks or less, would cause approximately 50% of a typical human population to die from radiation illness within 60 days. (Such a dose is termed the LD-50 dose.) Although the basis for estimating the LD-50 for humans to be 4.5 grays was never documented,[11] this value has nevertheless been widely used because the available human data from accidents and medical exposures is so sparse and its relevance to wartime conditions so questionable.

As is discussed in Annex 3. , however, a recent study of the data on mortality at Hiroshima and Nagasaki suggests that, under wartime conditions, high percentages of deaths from radiation illness could occur at much lower doses of ionizing radiation than previous casualty models have assumed. That study concludes that the LD-50 exposure for Hiroshima victims may have been a body surface dose of 2.3 grays.

In its study, the Princeton group investigated the sensitivity of their results to these different assumptions about the LD-50. They calculated casualties for three different values of the LD-50, corresponding to body surface exposures of 2.5, 3.5 and 4.5 grays, respectively. For each they made a simplifying assumption that the relationship between percentage mortality and absorbed dose was linear, with mortalities beginning at a dose 1.5 grays lower than the LD-50 and reaching 100% at a dose 1.5 grays higher than the LD-50. Persons who receive doses of the order of about 1 gray but who survive are typically expected to experience the prodromal syndrome of radiation sickness which may require medical treatment. The Princeton study classified as fallout illnesses survivors who received doses greater than a certain lower limit; they set that lower limit at 1.5 grays below the LD-50.

Casualty estimates for "limited" nuclear attacks

Attack on USA strategic-nuclear facilities

Targets. The Princeton group considered an attack whose goal would be to prevent the USA from retaliating with nuclear weapons. The assumed targets of the attack on USA strategic-nuclear forces and the assumed attacking weapons are shown in Table 1. They include:

- missile silos;
- ballistic-missile submarine bases;
- bomber bases;
- construction and maintenance facilities at which USA ballistic missiles may be found;
- actual and planned home ports for other USA naval ships which are equipped with nuclear-armed cruise missiles or aircraft;
- bases for the refuelling ("tanker") aircraft which would refuel USA bombers on the way to and from their targets in the Soviet Union;
- underground missile launch-control facilities which are dispersed among the missile silos housing USA operational intercontinental ballistic missiles;
- major nuclear weapons storage depots; and
- 30 early warning radars, strategic command posts and strategic radio transmitters.

In the hypothetical attack, each of these facilities is targeted with at least one airburst weapon. "Hard targets" (i.e., blast-resistant) would be attacked by an additional ground-burst weapon. In addition, it was assumed that the attacker, in an effort to destroy those aircraft that had been launched on warning of attack, would create a "pattern-attack" on strategic air bases by 14 warheads delivered by two multiple-warhead submarine-launched ballistic missiles. The assumed attack would be well within Soviet capabilities. Fig. 2 shows the fallout pattern from this attack, given typical February winds.

Casualties. The effects of changes in various assumptions on the numbers of short-term casualties and deaths estimated by the Princeton group for this attack are shown in Table 2. The indicated uncertainty ranges reflect the variation due to four different wind conditions which were tested: typical winds for February, May, August and October. It will be seen that:

- o the number of casualties from blast and fire effects are comparable to those from radioactive fallout;

- o the estimated number of deaths from blast and burns was more than doubled when the overpressure model was replaced by a conflagration model with a conflagration radius of 12 km but the total number of deaths plus injuries was increased by only one third;

- o the number of deaths from radiation sickness approximately doubled when the median lethal radiation dose was decreased from 4.5 to 2.5 grays.

Attack on Soviet strategic-nuclear facilities

Targets. Table 3 lists the targets of the hypothetical counterforce attack. In most cases, public information concerning the locations of these facilities is not as good as for the corresponding USA facilities. Generally, the information that is available comes from the USA intelligence community. Ordinarily, however, the locations of facilities are indicated only by giving the name of the nearest town or city. The most comprehensive public compilation of such information for nuclear-weapons related facilities worldwide may be found in W.M. Arkin & R.W. Fieldhouse, Nuclear Battlefields.[12]

In some cases, such as airfields and naval bases, the location of the nearest town was used as a guide to locate the facility itself on publicly available maps. In other cases, such as operational missile silos, mobile-missile bases, military headquarters and radio towers, the Princeton group was forced to make assumptions concerning actual locations.

Attacking weapons. The weapons assumed to be used in the hypothetical attack on Soviet strategic-nuclear forces differed somewhat from the weapons used for the counterforce attack on the USA because the two arsenals are different. Nevertheless, the order of magnitude of the two postulated attacks were similar, with 2839 warheads carrying 1342 megatons total yield involved in the attack on 1215 USA targets and 4108 warheads carrying 844 total megatons in the attack on 1740 targets in the USSR. The larger number of warheads used in the attack on the Soviet Union is principally due to the larger number of Soviet fixed land-based missiles. The smaller total yield of the attack is due to the lower estimated yields of the warheads on USA multiple-warhead ballistic missiles.

Civilian population distribution. A computerized population distribution for the Soviet Union was developed on a 20-mile grid by digitizing a contour map of the Soviet rural population density[13] and placing on it all Soviet cities and towns with a population greater than 2500. The 1983 populations of all Soviet cities larger than 50 000 were obtained from a Soviet publication.[14] The populations of smaller cities were obtained from a USA government listing that is not kept up to date - and thus are only approximate. Typical wind data for each month at five levels of the Northern Hemisphere atmosphere were obtained from a USA Department of Defence wind data tape.[15] The same distribution of population protection factors was assumed as for the counterforce attack on the USA (one half of the population with a protection factor of 3 and one half with 10). And the same values of population radiation sensitivities were tested.

Casualties. The estimated short-term deaths from the blast, burns and fallout radiation from the attack on Soviet strategic-nuclear forces can be seen from Table 4 to range from 15 to 32 million. The total casualties run from 25 to 54 million. These numbers are quite comparable to the results of the corresponding attack on the USA.

Table 4 shows that shifting from the standard overpressure model to a medium-radius conflagration model for calculating casualties from blast and burns results in an approximate doubling of the estimated numbers of deaths from this cause. It can also be seen that reducing the LD-50 of radiation from the standard value of 4.5 to 2.5 grays approximately doubles the estimated number of deaths from radiation illness. In one additional simulation to test the sensitivity of the results to assumptions about radiation, the Princeton group found that assuming an LD-50 equal to a body-surface exposure of 6.0 grays would lower the number of deaths and illnesses by about 2 million each.

The main contribution to casualties comes from the attacks on the missile silo fields - largely due to casualties from fallout. Fig. 3, which shows the calculated radiation patterns for typical February winds, shows that a large fraction of the fallout would come down in the most heavily populated areas of the Western Soviet Union.

"Limited" attacks on urban targets

The Princeton group also calculated the consequences of relatively small attacks on urban targets. Their motivation was two-fold: (i) to determine the sensitivity of the consequences to the exact nature of the targets - factories, military facilities or densely populated areas; and (ii) to determine the maximum casualties that might result from use of a very small percentage of the existing nuclear arsenals.

Attacks on USA urban areas. Table 5 shows the estimated casualties resulting from four hypothetical attacks with approximately 100 1-Mt warheads each, exploded at a height of 2 km over urban targets - four times the height of burst of the Hiroshima explosion. (At a 2-km height of burst, a 1-Mt explosion would give the same pattern of overpressures as a function of distance from ground zero as the Hiroshima blast.[16])

The four classes of targets chosen for these attacks were:

(1) Worst-case attack. The 100 most densely populated areas were targeted.

(2) City-centre attack. The centres of 100 of the largest USA cities were targeted.

(3) Military-industrial attack. 101 key USA facilities for the final assembly of major pieces of military equipment were targeted.

(4) Strategic-nuclear targets. All the targets of the previously described large attack on USA strategic-nuclear facilities except missile silos and missile launch-control centres were attacked. This remainder, including naval bases and construction facilities, military airfields, nuclear weapon storage depots, early warning radars, strategic command posts and strategic radio transmitters, totalled 99 targets.

Fig. 4 shows the cumulative deaths for the worst-case attack on USA cities as a function of the number of weapons used.

One hundred warheads would correspond to approximately 1% of the total number of warheads in the Soviet strategic arsenal and perhaps 2% of its total megatonnage. The casualties from these attacks therefore represent conceivable results if only 1% of the warheads currently deliverable by Soviet strategic forces survived a USA first strike and penetrated USA defences to reach USA urban areas in a retaliatory attack. It will be seen that tens of millions of deaths and injuries might still result.

Tens of millions of casualties could result even if the targets of the attacks were strategic-nuclear facilities (in this case, bomber and naval bases, nuclear storage depots and command and communication facilities) rather than densely populated areas. The reason is that many of the targets of all of these attacks are in any case located in heavily populated urban areas. This may be seen from Fig. 5, which compares the cumulative population within given distances of the: 100 city centres, 101 military-industrial facilities; and 99 strategic-nuclear targets and 99 strategic-nuclear facilities in the corresponding target lists. The range of deaths (casualties) varies from 3-11 (10-16) million for the attack on strategic nuclear targets to 25-66 (36-71) million for an attack on the most populated urban areas of the USA. Since the urban population of the USA totals about 167 million, it will be seen that a 100-Mt attack could kill or injure nearly one half of the USA urban population.

Attacks on USSR urban areas. The Princeton group has also made a calculation of the consequences of a limited nuclear attack on the urban areas of the Soviet Union. This is an attack with 100 1-Mt airbursts over the most populated urban regions of the USSR. These estimates are more speculative than those for the USA, because insufficient data are publicly available to determine the population distribution within Soviet cities. The Princeton group estimated the shapes of the 22 largest Soviet cities from maps and assumed that all other top cities were circular in shape. When the population density was not known, it was assumed to be 3300/km^2 - the average for cities whose population density was known. This population density was put on a 5-mile grid. The cumulative results as a function of numbers of 1-Mt warheads used are shown in Fig. 6. Thus, attacks on most populated Soviet urban centres might kill between 45 and 77 million residents and produce 73-93 million total casualties.

All-out nuclear war

In the previous section, it was reported that an attack on USA or Soviet urban areas with of the order of 1% of the nuclear warheads deliverable by the superpower strategic forces could kill or injure close to one half of the urban population of the attacked country. Since population and social and economic infrastructure have very similar distributions, the damage to the social support system of the USA or the USSR would be correspondingly vast and would probably destroy either nation as a modern society - leading to many additional deaths and illnesses.

Since the USA and Soviet populations combined are approximately 10% of the world population, it would seem, therefore, that of the order of 10% of the combined strategic-nuclear arsenals of the USA and Soviet Union could destroy civilization throughout the world - even without taking into account effects such as nuclear winter.

Of course, it is difficult to imagine attacks that would result in uniform bombardment of all the major urban areas of the world. It could be expected that the urban areas of the USA and Soviet Union and their allies would be more heavily attacked than the urban areas of other nations and that the international petroleum supply infrastructure on which the OECD nations depend might be destroyed as well. However, most of the industrialized countries belong to one or the other of the two major alliances and the rest of the world would suffer from the combination of: the loss of the agricultural chemicals and machinery, health supplies, etc. provided by these nations; the unavailability of oil imports; and climatic disturbances. These impacts could well cause the starvation of much of even that part of the world's human population outside targeted areas.[17]

Conclusions

1. The use of only a fraction of the destructive capacity in USA and Soviet nuclear arsenals could have catastrophic consequences to human kind.

2. Although the primary justification of the tens of thousands of nuclear warheads in USA and Soviet arsenals is their potential use against military targets, the most commonly discussed potential large-scale military uses of these weapons - in attacks against the nuclear weapons of the other side - would result in tens of millions of civilian casualties. Certainly, if a first strike resulted in such a huge civilian toll, there could be little assurance of restraint in the response of the country that was attacked.

3. The use of even 1% of the strategic arsenals of the USSR or the USA against the population, military industry or strategic-nuclear targets of the other nation could result in tens of millions of casualties.

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TABLE 1. COUNTERFORCE ATTACK ON US STRATEGIC-NUCLEAR FORCES

Target type	No. of targets	Mode of attack
Missile silos	1016	0.5-Mt groundburst + 0.5-Mt low-airburst
Missile launch-control facilities	100	0.5-Mt groundburst + 0.5-Mt low-airburst
Strategic bomber and tanker bases	34	1.0-Mt groundburst + 14x0.2-Mt airbursts (pattern)
Nuclear Navy bases	16	1.0-Mt groundburst + 1.0-Mt airburst
Nuclear weapon storage facilities	9	1.0-Mt groundburst + 1.0-Mt airburst
National command posts and alternate headquarters	5 2	1.0-Mt groundburst + 1.0-Mt airburst 1.0-Mt airburst
Early-warning radars	5	1.0-Mt airburst
Navy radio transmitters	10	1.0-Mt airburst
Strategic Air Command radio transmitters	7 2	1.0-Mt airburst 1.0-Mt groundburst + 1.0-Mt airburst
Satellite command trans.	9	1.0-Mt airburst
TOTALS	1215 targets, 2839 attacking warheads with 1342 Mt total yield	

Source: W. H. Daugherty, B. G. Levi & F. N. von Hippel, "The Consequences of 'Limited' Nuclear Attacks on the United States", International Security, Spring 1986, p. 30.

TABLE 2. ESTIMATED SHORT-TERM DEATHS AND INJURIES FROM A COUNTERFORCE ATTACK ON US STRATEGIC-NUCLEAR FORCES

	Deaths (millions)				
Cause:	Blast and fire	Radiation illness[a]			Total[b]
		Lethal exposure (Grays)			
		4.5	3.5	2.5	
Overpressure model	7	5-6	7-8	9-14	12-21
Conflagration model[c]	15	4-5	6-7	8-12	19-27

	Injuries (millions)		
Cause:	Blast and fire	Radiation illness	Total
Overpressure model	8	3-16	11-24
Conflagration model[c]	4	3-14	7-18

[a] The uncertainty range reflects the variation among four different wind patterns - typical winds for: February, May, August and October.

[b] The sum of the subtotals may differ from the sum of the totals because of rounding.

[c] Medium conflagration radius assumed. For a 1-Mt airburst (groundburst), the conflagration radius is assumed to be 12 (8.5) km and, for other values of yield, Y, it is assumed to scale as $Y^{0.42}$.

Source: W. H. Daugherty, B. G. Levi & F. N. von Hippel, "The Consequences of 'Limited' Nuclear Attacks on the United States", International Security, Spring 1986, p. 35 and unpublished results.

TABLE 3. COUNTERFORCE ATTACK ON SOVIET STRATEGIC-NUCLEAR FORCES

Target type	No. of targets	Mode of attack
Missile silos		
SS-4	112	0.1-Mt groundburst + 0.1-Mt low-airburst
SS-11	448	0.1-Mt groundburst + 0.1-Mt low-airburst
SS-13	60	0.1-Mt groundburst + 0.1-Mt low-airburst
SS-17	150	0.35-Mt groundburst + 0.17-Mt low-airburst
SS-18	308	0.35-Mt groundburst + 0.17-Mt low-airburst
SS-19	360	0.35-Mt groundburst + 0.1-Mt low-airburst
Missile launch-control centres		
SS-4, -11, -13	66	1.2-Mt groundburst + 0.17-Mt low-airburst
SS-17, -18	48	0.35-Mt groundburst + 0.17-Mt low-airburst
SS-19	36	0.35-Mt groundburst + 0.1-Mt low-airburst
ICBM test silos	27	0.1-Mt groundburst + 0.1-Mt low-airburst
Bases for mobile missiles		
SS-25 bases	3	1.2-Mt groundburst + 16 0.1-Mt airbursts (pattern)
SS-20 bases	16	1.2-Mt groundburst + 16 0.1-Mt airbursts
Anti-ballistic missile launcher sites		
Exo-Atmos. interceptors	2	0.1-Mt groundburst + 0.1-Mt low-airburst
Endo-Atmos. interceptors	7	0.1-Mt groundburst + 0.1-Mt low-airburst
Nuclear Navy bases		
Ballistic missile subs.	8	1.2-Mt groundburst + 1.2-Mt airburst
Other nuclear-capable ships	8	1.2-Mt groundburst + 1.2-Mt airburst
Naval yards	5	1.2-Mt groundburst + 1.2-Mt airburst
Bomber bases		
Long-range (Bison & Bear)	3	1.2-Mt groundburst + 16 0.1-Mt airbursts (pattern)
Arctic staging	5	1.2-Mt groundburst + 16 0.1-Mt airbursts
Intermed-range (Backfire)	10	1.2-Mt groundburst + 16 0.1-Mt airbursts
Medium-range (Badger, Blinder, Fencer)	6	1.2-Mt groundburst + 16 0.1-Mt airbursts
National and strategic rocket forces HQ		
Underground	19	0.1-Mt groundburst + 0.1-Mt low-airburst
Base for airborne command posts	1	1.2-Mt groundburst + 16 0.1-Mt airbursts
Communication facilities		
Early-warning and ABM radars	13	0.1-Mt airburst
Radio transmitters	19	0.1-Mt airburst
TOTALS	1740 targets, 4108 attacking warheads with 844 Mt total yield	

TABLE 4. ESTIMATED SHORT-TERM DEATHS AND INJURIES FROM A COUNTERFORCE ATTACK ON SOVIET STRATEGIC-NUCLEAR FORCES

	Deaths (millions)				
Cause:	Blast and fire	Radiation illness[a]			Total[b]
		Lethal dose (Grays)			
		4.5	3.5	2.5	
Overpressure model	5	10-13	13-17	19-24	15-29
Conflagration model[c]	11	9-12	11-16	16-22	20-32

	Injuries (millions)		
Cause:	Blast and fire	Radiation illness	Total
Overpressure model	7	3-18	10-25
Conflagration model[c]	4	3-18	7-22

[a] The uncertainty range reflects the variation among four different wind patterns. The largest values come from February and the smallest from August winds, with May and October results lying between these extremes.

[b] Rounding may cause the totals to differ from the sum of the subtotals.

[c] Medium conflagration radius assumed. For a 1-Mt airburst (groundburst), the conflagration radius is assumed to be 12 (8.5) km and, for other values of yield, Y, it is assumed to scale as $Y^{0.42}$.

Source: W. H. Daugherty, B. G. Levi, F. N. von Hippel and D. W. Thickens, Casualties from Limited Nuclear Attacks on the Soviet Union (Princeton University, Center for Energy and Environmental Studies report, to be published).

TABLE 5. ESTIMATED DEATHS AND TOTAL CASUALTIES
FROM FOUR "100-MEGATON" ATTACKS ON US URBAN AREAS[a]

	Deaths (millions)		Total casualties (millions)	
Model:	Overpressure	Conflagration	Overpressure	Conflagration
Attack				
Worst-case	25	66	36	71
City-centres	14	42	32	51
Military-industrial	11	29	23	35
Strategic-nuclear	3	11	10	16

[a] One-megaton explosions at 2-km altitude.

Source: W. H. Daugherty, B. G. Levi & F. N. von Hippel, "The Consequences of 'Limited' Nuclear Attacks on the United States", International Security, Spring 1986, p. 35.

Fig. 1. Fatality rates from a 1 Mt. explosion at 2 km altitude: predictions of two casuality models

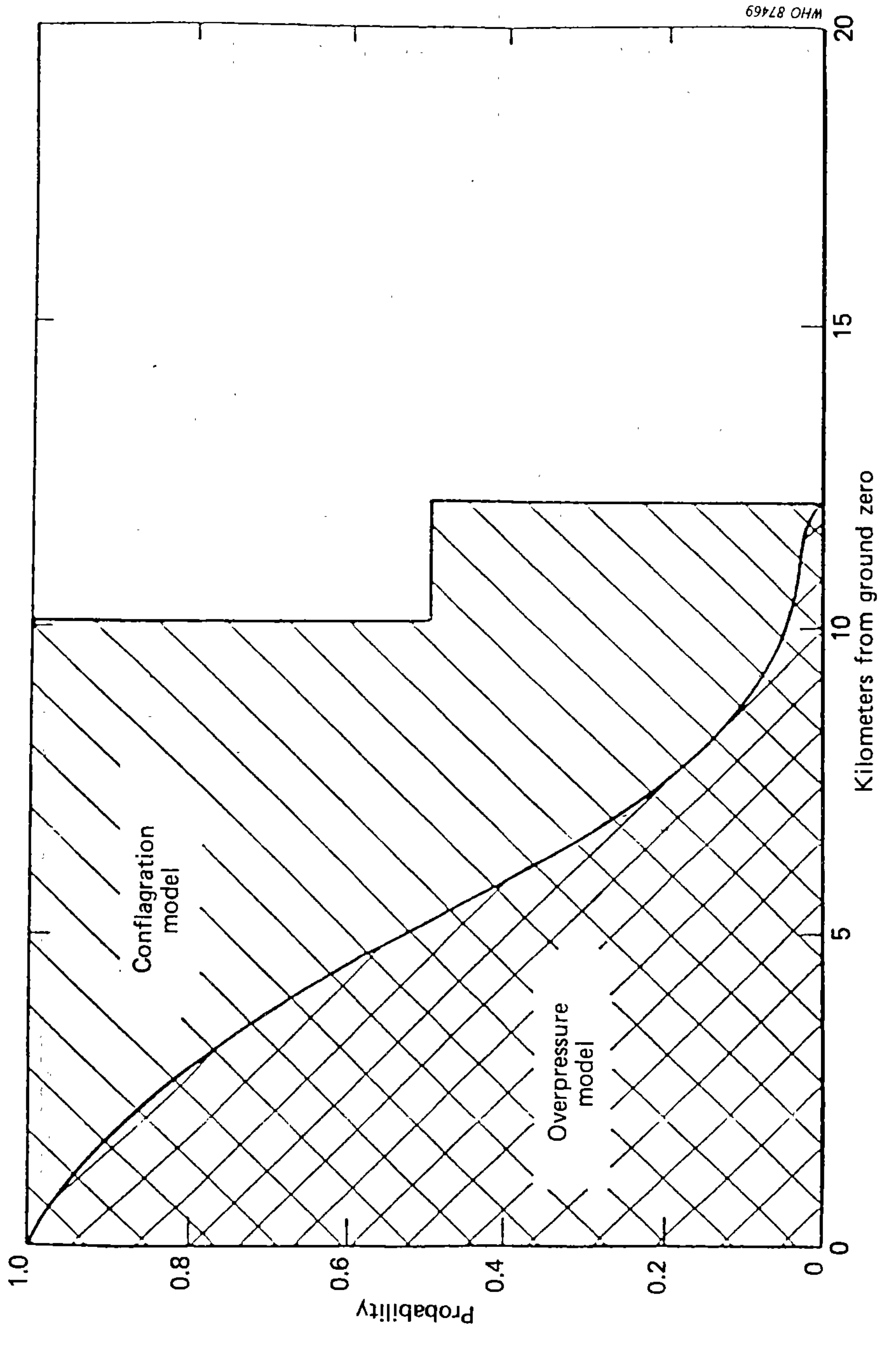
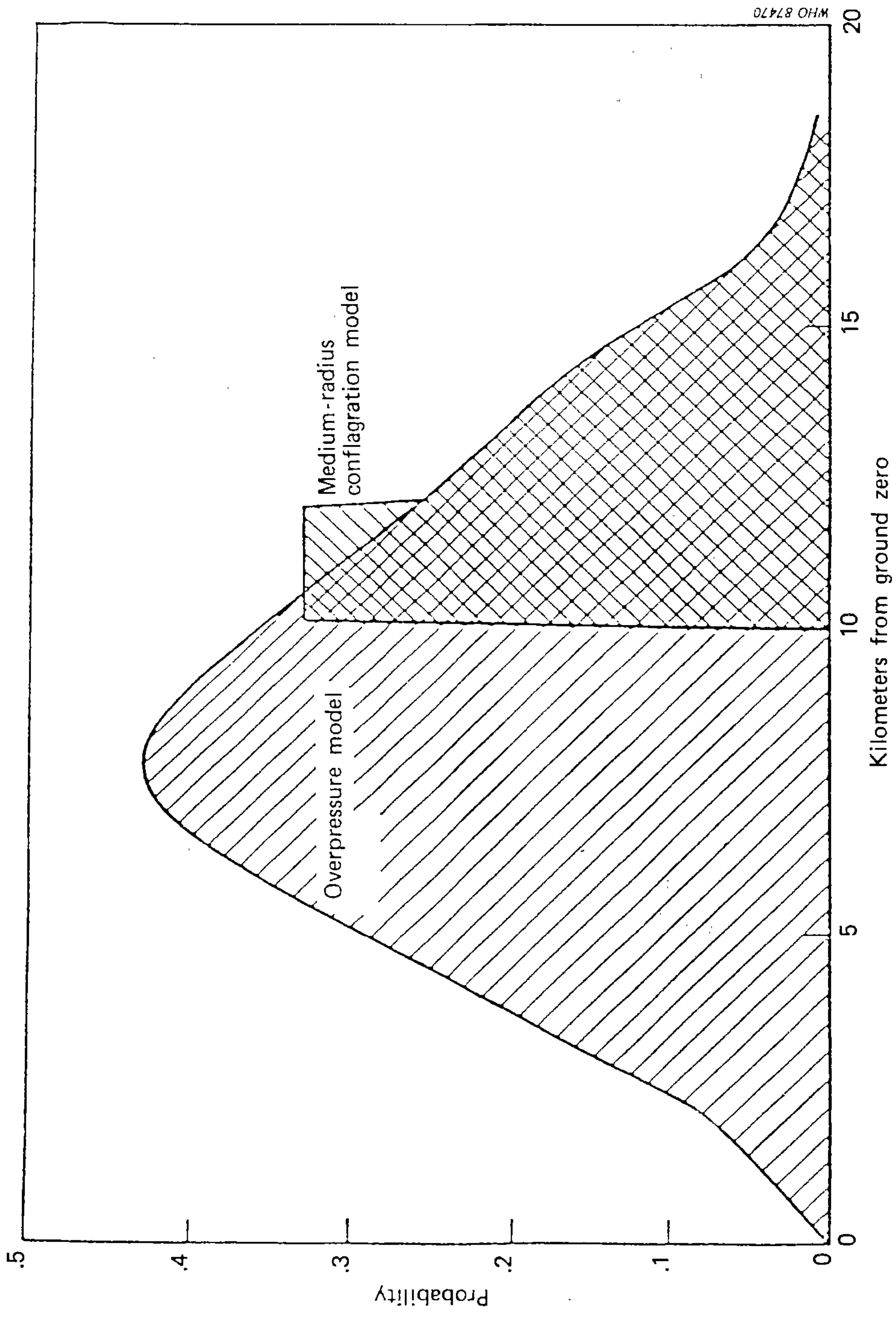


Fig. 1b. Injury rates from 1 Mt. airburst model assumptions.



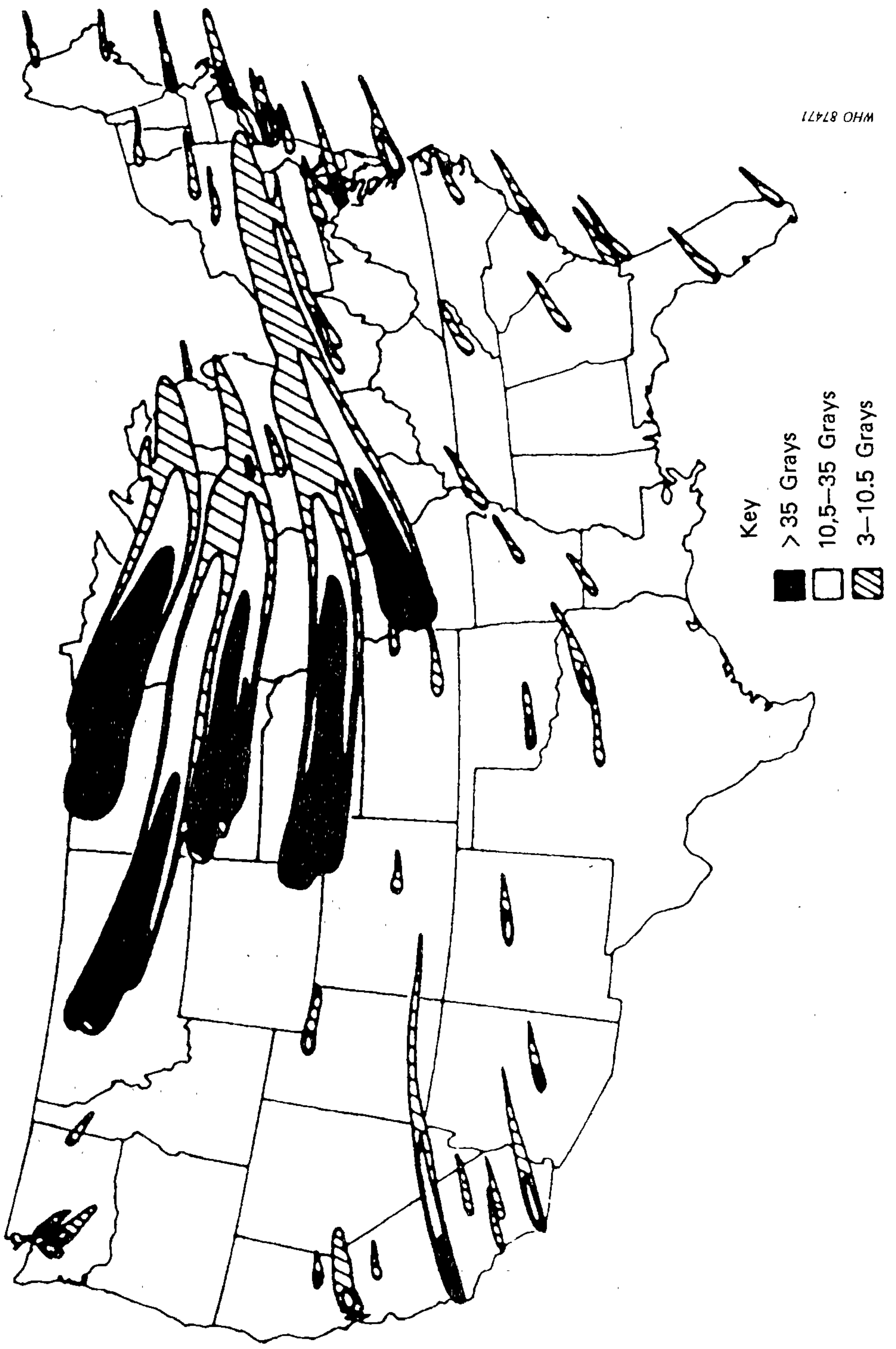
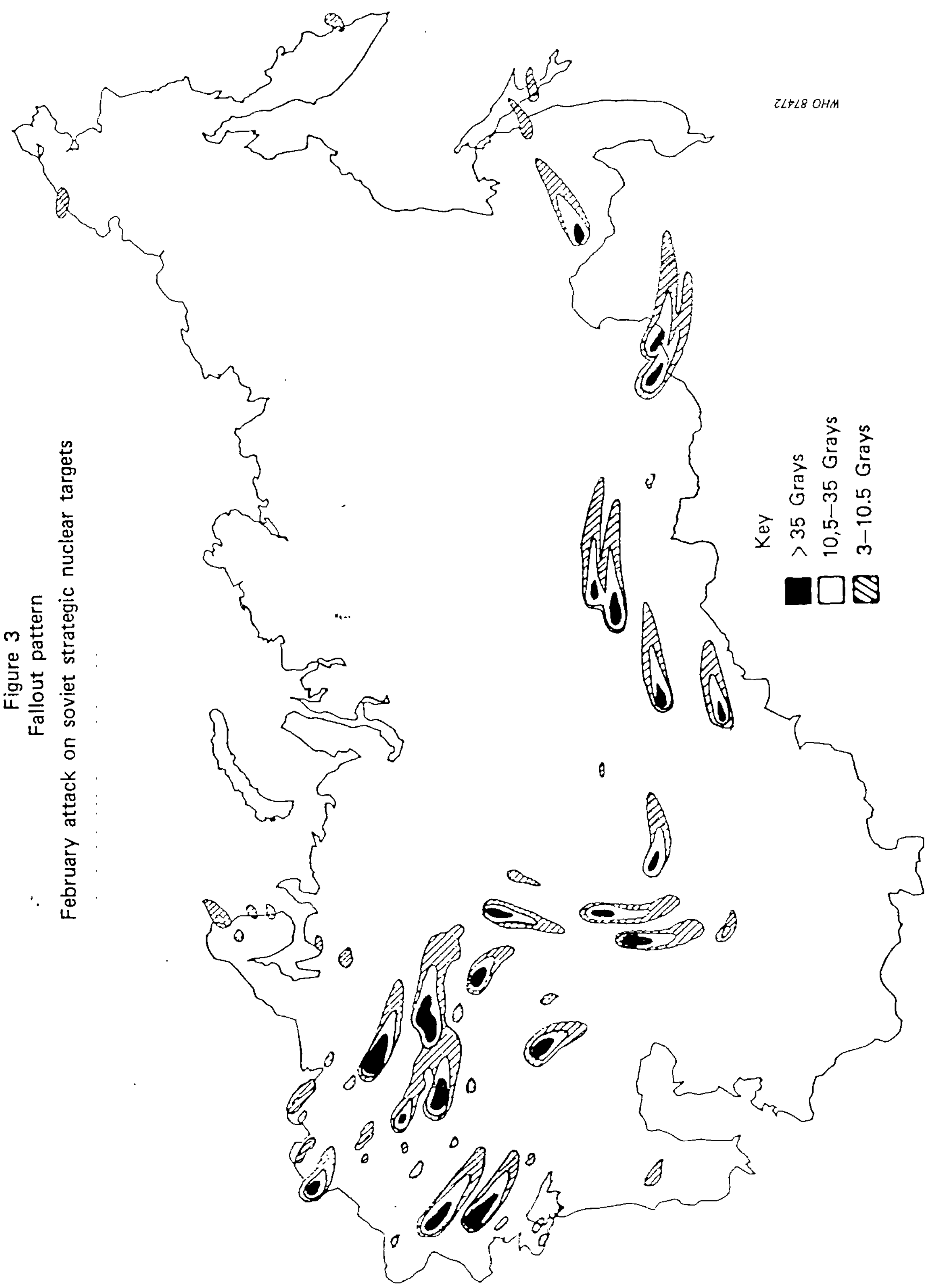


Figure 2

Fallout pattern

February attack on US strategic nuclear targets

Figure 3
Fallout pattern
February attack on soviet strategic nuclear targets



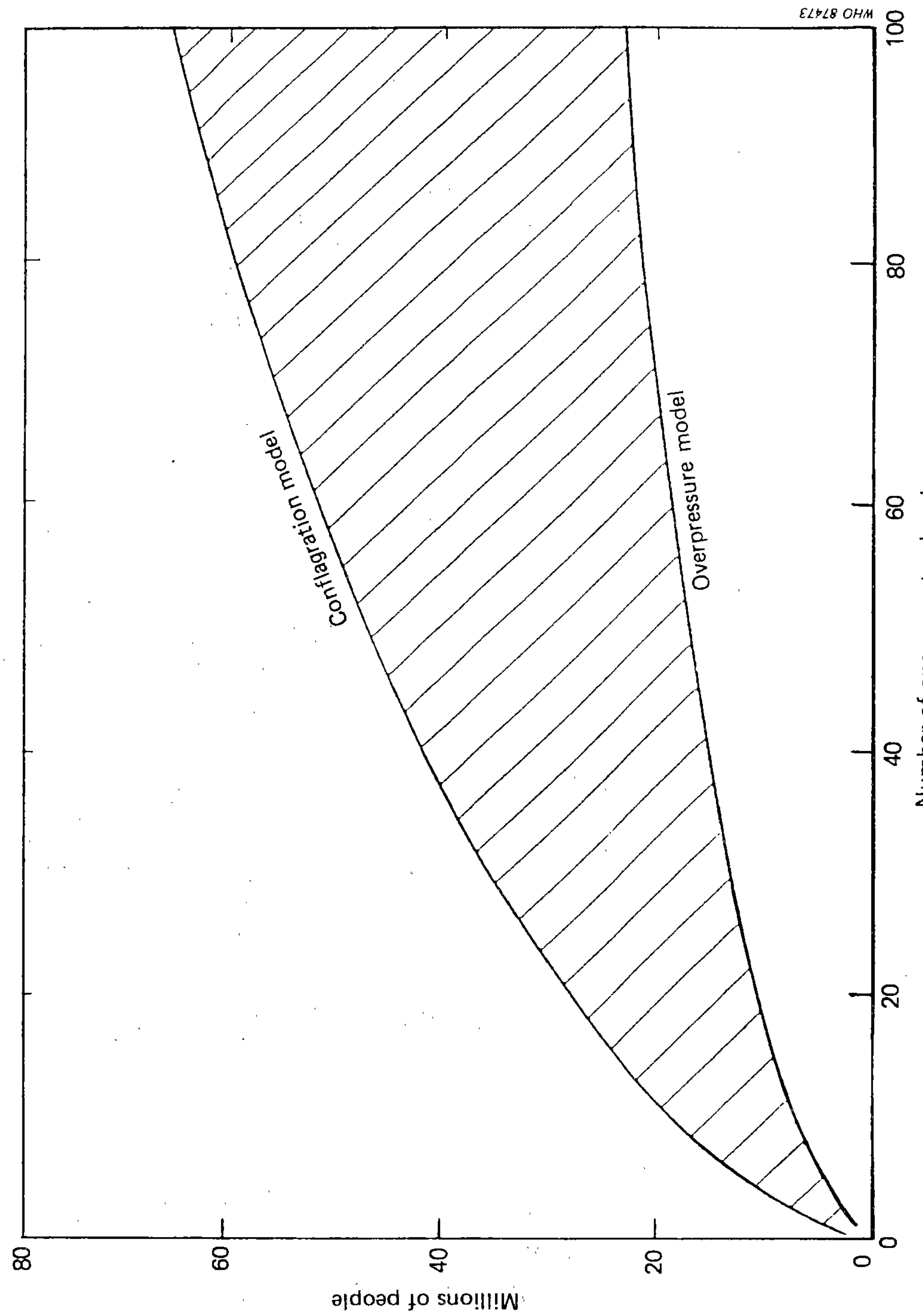


Fig. 4. Fatalities from a worst-case city attack

Fig. 5. Cumulative population around ground-zeros for 100 Mt. attacks

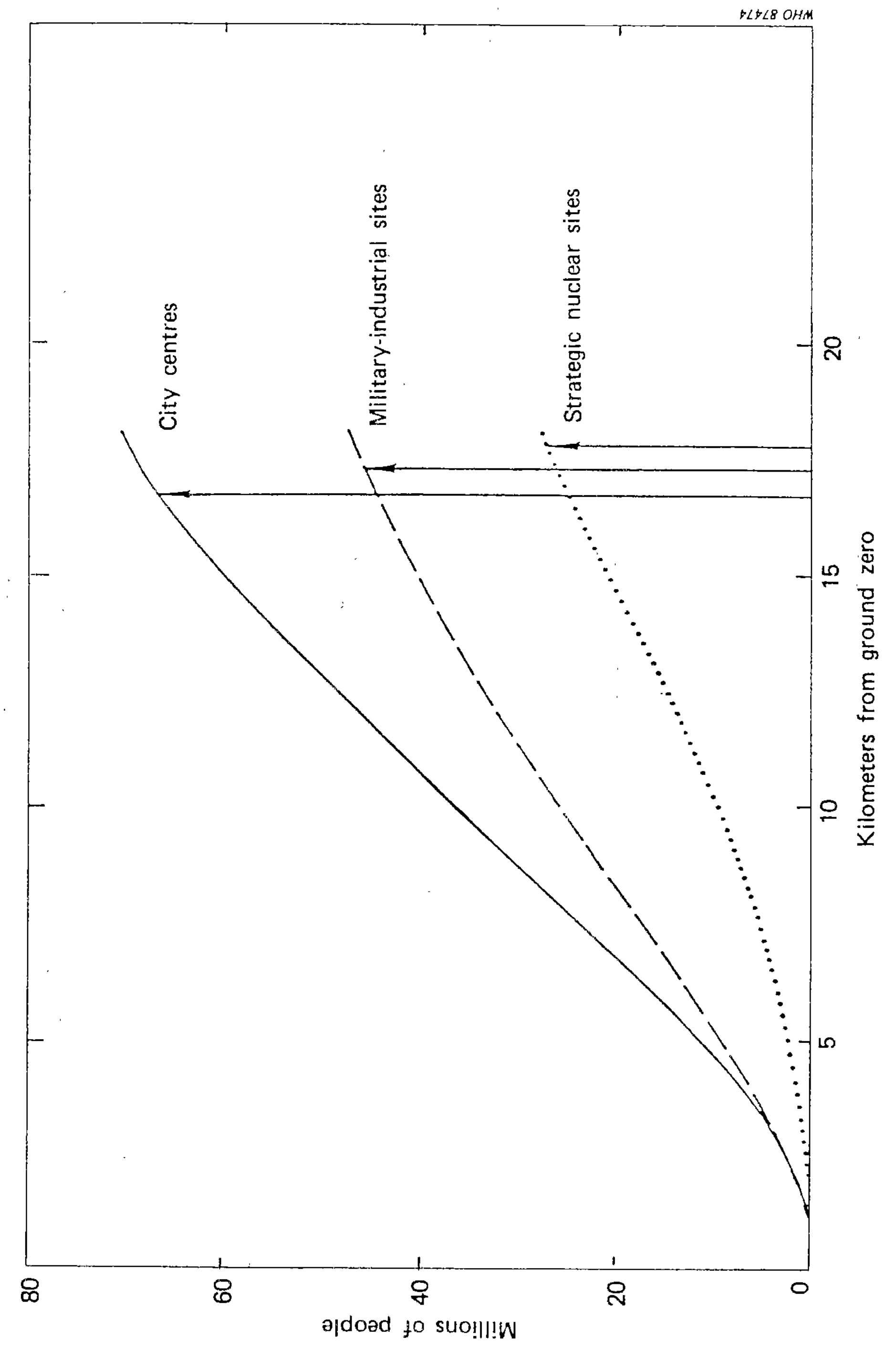
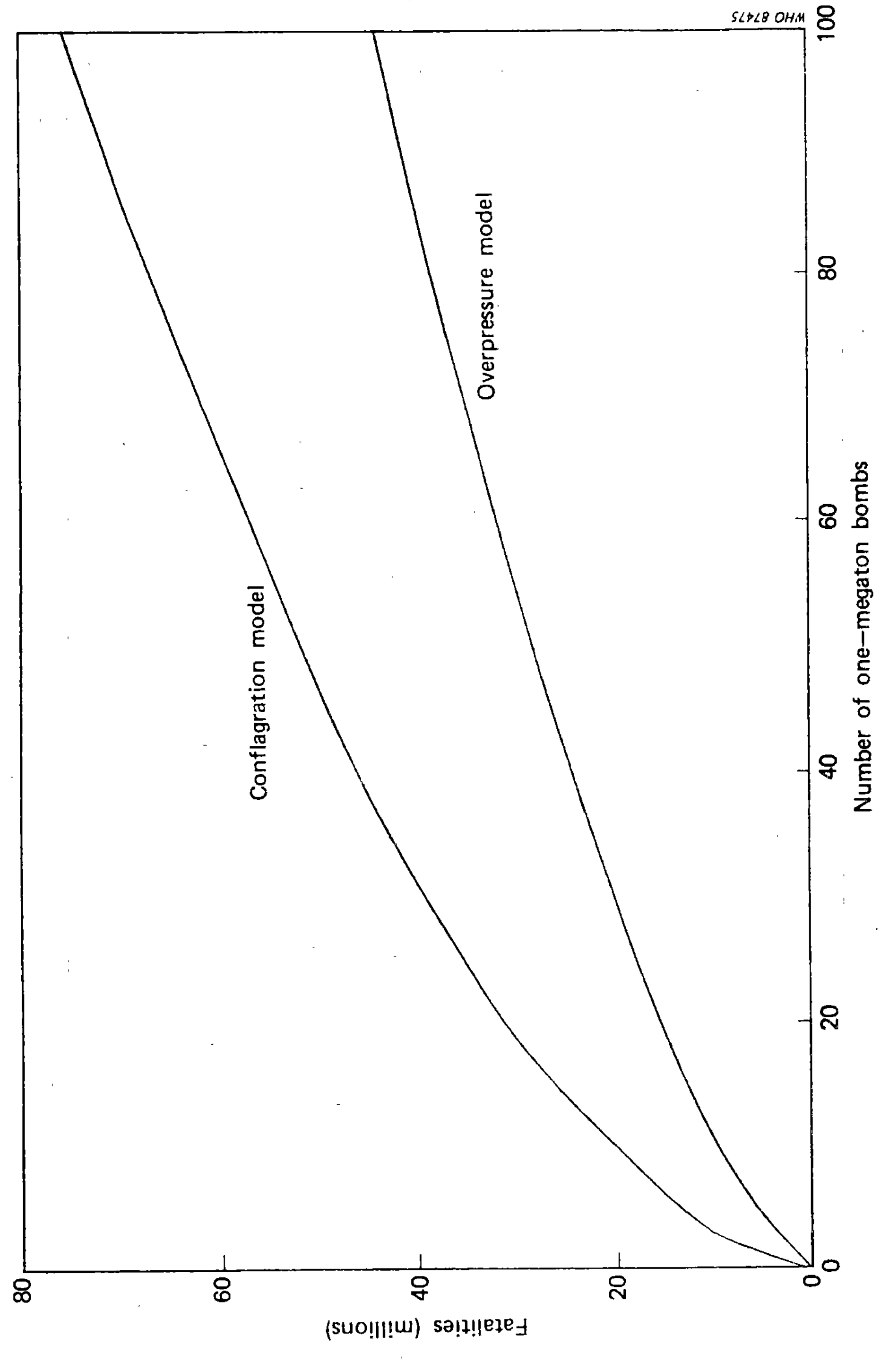


Fig. 6. Maximum-casualty attacks on soviet urban areas



ANNEX 4 . C

LIMITED NUCLEAR WAR IN EUROPE

by

Andrea Ottolenghi

Simulation of the short-term effects of a limited nuclear exchange in Europe

In Part B of this Annex the consequences are discussed of "limited" nuclear attacks on the United States and the Soviet Union. Many nuclear strategists believe that a nuclear exchange is likely to take place in Europe, following military action with conventional weapons. There are more than 9000 nuclear warheads deployed in Europe, or facing Europe,[1] and a small fraction of these arsenals might be used initially in an exchange aimed entirely at military targets, thus minimizing collateral damage, that is, civilian casualties.

The probability of containing the nuclear exchange to very small numbers of warheads is disputed by many analysts, who believe that once started there is a great likelihood of an escalation to an all-out nuclear war. Nevertheless, it is of interest to calculate the civilian casualties even in a very limited nuclear exchange.

The Research Group on Nuclear Weapons and Arms Control of the University of Milan has developed a computer model to estimate the short-term consequences of such an exchange. The results of the first study, a counterforce attack on Italy, have been published;[2] this study has now been extended to the whole of Europe, but excluding the Soviet Union. In the scenario used, about 470 European military installations are attacked by 150-kiloton nuclear weapons, of a total yield less than 100 megatons. A full description of this scenario is in the course of publication;[3] this Annex summarizes the basic assumptions and presents the results. These show that even an attack on a very limited scale, and restricted to military objectives, could lead to more than 100 million casualties.

The model

After postulating the military parameters of the scenario, i.e. selected targets, the number and yield of the weapons, and the altitude of the bursts, the estimates of the short-term casualties resulting from the exchange - for a range of values of other parameters - are made according to a base model. In this model, the probability of death and injury from the prompt effects of the explosions, namely thermal radiation and blast wave, are first calculated. The initial nuclear radiation (gamma-rays and neutrons) is ignored, since its range of action falls well within the range of damage from heat and blast for 150-kt bombs. The effect of fallout is then considered and added to the combined prompt effects.

To obtain the number of casualties, the whole area of Europe (exclusive of the Soviet Union) was divided into squares of 1 kilometre side. Within each square an average value was assumed for the several variables, i.e. population density, thermal blast effects, and radiation exposure from fallout. The total number of fatalities was obtained by summing the deaths in all squares. A similar procedure was adopted in the calculation of the number of injuries, with the qualification that persons suffering injuries from both prompt and fallout effects, or those injured by more than one explosion, are counted as fatalities.

Mathematical formulae or computer programmes were developed to establish the magnitude of the physical phenomena and their effects on the population.

Prompt effects. For the blast effect the overpressure model was used, mainly based on scaling laws as discussed in Glasstone & Dolan.[4] For the thermal radiation, the two parameters: radiation fluence and rate of delivery, were combined into one parameter by defining the effective radiation fluence related to the experience from Hiroshima. Fig. 1

shows the calculated probability of death from heat and mechanical effects, as a function of distance from the hypocentre, for a 150-kt bomb in a ground burst and in an air burst (at a height of 1180 m).

Fallout. To estimate the effects of local fallout a model is needed that describes the spatial distribution and the rate of the radioactive debris, as a function of the characteristics of the explosion and the meteorological conditions. During the 1970s, detailed models had been developed which considered the meteorological conditions point by point over the contaminated area for weapons of the order of 100 kilotons. The complexity of these models requires such a large amount of data and computer time that it makes their use difficult for a simulation of multiple explosions over a territory. However, starting from one of such detailed models (DELFIC, 1979),[5] its author, H. G. Norment, has developed a simplified model (DNAF-I, 1981)[6] and this model was used in this simulation. The adequacy of this model was confirmed by the agreement between predicted and observed fallout patterns following several United States test explosions.

The number of casualties from radiation exposure depends greatly on the assumed value of the LD-50. Many of the standard casualty models used an LD-50 (measured at the surface of the body) of 4.5 Gy. But a recent survey of a large group of persons inside their houses during the explosion in Hiroshima, reported by Rotblat,[7] indicates a much lower LD-50 value under wartime conditions. Consequently, two LD-50 values, 3.5 and 2.5 Gy, were used in the calculation of the number of fatalities. Persons exposed to sublethal doses, but who may die due to their susceptibility to infection resulting from the lowering of their immune response, were considered as radiation injuries. The calculation of the probability of death as a function of the dose D was made from the formula:

$$1 - e^{-\ln 2 \left(\frac{D}{Do}\right)^3}$$

with Do values of 3.5 and 2.5 Gy. Similarly, the probability of radiation injury is calculated from the formula:

$$1 - e^{-\ln 2 \left(\frac{D}{Do}\right)^{3.5}}$$

with Do being 1.0 and 0.75 Gy. Figs. 2 and 3 show the probability of death or injury, based on these calculations. To allow for the fact that exposure to fallout radiation takes place over a period of time, the concept of the maximum effective biological dose was used, that is the equivalent of the dose that, if absorbed within a few minutes, would produce the same effect as that from fallout.

Protection factors. The behaviour of people after the beginning of the attack makes a big difference to the risk of radiation exposure. In this connection it must be pointed out that the first hours after fallout deposition are the most dangerous, since the activity decreases very rapidly with time. Computation of an individual's average protection factor must take into account that it is very unlikely that people would shut themselves into basements or shelters (if available) right after the beginning of the conflict. In fact, experiences from disasters of various kinds - including accidents with release of radioactive debris - show that most people try to reach their relatives and accumulate stocks of food and water, which means staying outside during the most dangerous period. This is especially so in the case when there is lack of communication and information on the dimension of the conflict and the level of involvement of the area. The experience of Chernobyl has shown that even in peacetime and at a low level of radioactivity the information about the real situation was dramatically inadequate.

Considering that in Europe very few countries have a sheltering programme for civilians, the following distribution of protection factors (P.F.) was assumed:

Percentage of population	Protection factors					
	0.7	1.4	2	3	5	10
Case 1	5	30	30	20	10	5
Case 2 (better protection)	5	20	20	30	15	10
Case 3 (worse protection)	5	40	30	15	10	0

Two other distributions are given: one for better (case 2) and the other for worse protection levels (case 3). (The apparently meaningless value of 0.7 was introduced to allow for an increase of radiation dose from beta-rays.)

In order to compare the results with those of the Princeton studies (Part B of this Annex), a further distribution of protection factors was considered which assumes a much greater protection of the population than case 2, namely, a P.F. of 3 for half the population and 10 for the other half. In Tables 1 and 2 this is denoted as case 4.

It should be noted that in all cases, in areas damaged by blast and heat, it was assumed that 90% of the population had a P.F. of 1 and 10% a P.F. of 2. All those already injured by blast or heat were considered to have a protection factor of 1.

Meteorological conditions. The meteorological data were provided by the Global Weather Central (U.S.A.), in the form of typical monthly winds; speeds and directions were given at different levels over each point of a grid covering the northern hemisphere. The calculation of casualties was made for typical winds in four months, February, May, August and November.

The scenario

The following assumptions were made:

- The conflict is characterized by a counterforce nuclear exchange.
- The European countries directly involved in the nuclear exchange are those belonging to NATO and the Warsaw Pact.
- The targets include the bulk of the nuclear forces of the two sides.
- The targeting list includes the main European nuclear installations and facilities, chosen from among the following:
  - missile bases;
  - command sites;
  - communication sites;
  - nuclear storage sites;
  - air-bases;
  - naval nuclear bases.

With very few exceptions, the following military installations were not attacked: nuclear and non-nuclear weapons research and production centres; training centres; nuclear test sites; nuclear artillery; ADM (Atomic Demolition Munition); SAM (Surface-to-Air Missiles); nuclear storage sites and command centres devoted to control the military installations; military installations in or near large cities; political headquarters; airports devoted to VIP transport; the hotline system.

All military targets are attacked using 150-kt warheads. This represents an average of the different yields that might actually be used. All targets are attacked by one ground burst, with the following exceptions:

- "Soft" targets like antennas are attacked by one air burst at the "optimum" height of 1180 m in order to maximize the area subjected to a peak overpressure larger than 70 kPa.
- The main command centres and a few missile sites are attacked by a cluster of three 150-kt warheads.
- The most important airports - chosen from the ones where strategic nuclear bombers are allocated - are attacked by a cluster of three 150-kt warheads.

According to these criteria, the targets attacked were as follows:

94 targets (3 in the Eastern countries and 91 in the Western countries):	by one 150-kt air burst;
285 targets (94 in the Eastern countries and 191 in the Western countries):	by one 150-kt ground burst;
91 targets (11 in the Eastern countries and 80 in the Western countries):	by one cluster of three 150-kt ground bursts;

In total, about 98 Mt (652 x 0.150) are used to attack 470 military installations.

The distribution of the targets is shown on Fig. 4.

The casualty toll

The number of fatalities due to the blast and thermal effects was found to be 7.4 million. The total casualties from these effects (deaths plus injuries) amounted to 15.6 million.

Tables 1 and 2 give the total numbers, including the effects of fallout for four different wind conditions and two values of the LD-50: 3.5 Gy in Table 1, and 2.5 Gy in Table 2. The fallout patterns for the months of May and November are shown on Figs. 5 and 6.

It should be pointed out that high as the casualty toll is, the numbers in the Tables may underestimate the actual numbers, since only short-term and predictable effects have been taken into account. Other effects, including long-term and the consequences of climatic disturbances, are discussed in other Annexes.

In summary, the simulation of a very limited nuclear exchange in Europe - against military targets only and using less than 1% of the existing nuclear arsenals - has shown that it could result in the death or injury of more than 100 million people; a catastrophe of unimaginable dimension.

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3. A. Ottolenghi: Simulation of the short-term effects of a "Limited" Nuclear War in Europe (to be published, 1987).

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7. J. Rotblat: "Acute Radiation Mortality in a Nuclear War", in The Medical Implications of Nuclear War, National Academy Press, Washington D.C. (1986), pp. 233-250.

TABLE 1. NUMBER OF FATALITIES AND CASUALTIES (FATALITIES + NON-FATAL INJURIES) FROM THERMAL AND BLAST EFFECTS; AND FROM FALLOUT, ASSUMING AN LD-50 OF 3.5 Gy

(Millions)

Protection Factor Distribution	February	May	August	November
Case 1:				
Fatalities:	67.3	70.6	67.7	64.0
Casualties:	93.7	96.3	92.5	91.0
Case 2:				
Fatalities:	62.2	65.5	62.6	58.3
Casualties:	88.6	91.2	87.5	85.2
Case 3:				
Fatalities:	71.0	74.2	71.3	68.1
Casualties:	97.1	99.7	95.7	94.9
Case 4:				
Fatalities:	48.9			
Casualties:	72.3			

TABLE 2. NUMBER OF FATALITIES AND CASUALTIES (FATALITIES + NON-FATAL INJURIES) FROM THERMAL AND BLAST EFFECTS, AND FROM FALLOUT, ASSUMING AN LD-50 OF 2.5 Gy

(Millions)

Protection Factor Distribution	February	May	August	November
Case 1:				
Fatalities:	78.7	81.8	79.0	77.1
Casualties:	104.8	108.1	103.0	103.2
Case 2:				
Fatalities:	72.9	76.0	73.3	70.2
Casualties:	99.1	102.3	97.5	96.5
Case 3:				
Fatalities:	82.9	86.0	83.1	82.0
Casualties:	108.6	112.0	106.6	107.7
Case 4:				
Fatalities:	57.2			
Casualties:	80.7			

FIG. 1. PROBABILITY OF DEATH - DUE TO THERMAL AND MECHANICAL EFFECTS - AS A FUNCTION OF THE DISTANCE FROM GROUND ZERO, FOR A YIELD OF 150 kt

Solid curve: air burst. Dashed curve: ground burst

Source: Andrea Ottolenghi

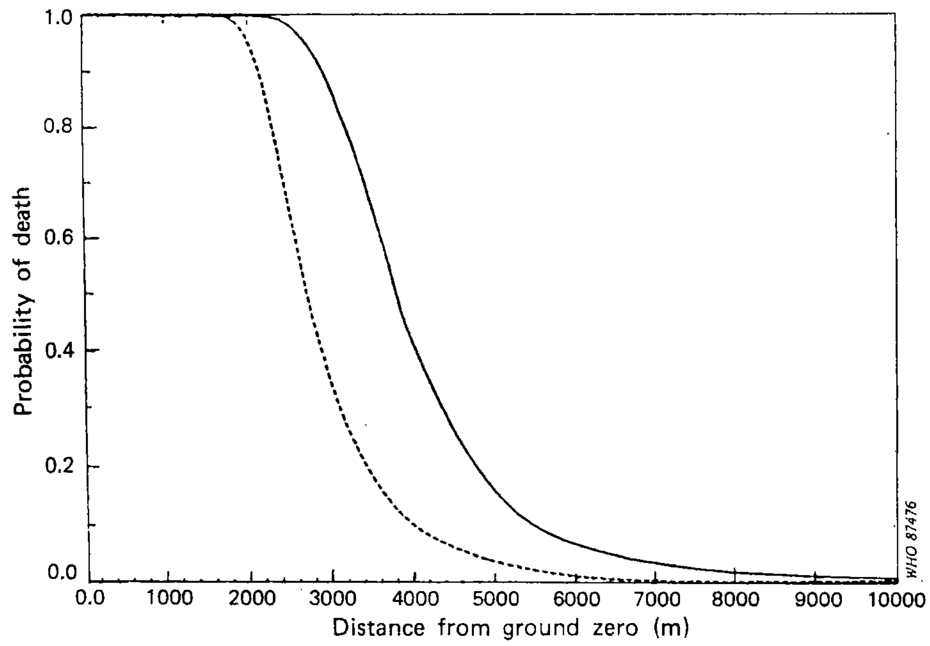


FIG. 2. PROBABILITY OF DEATH (A) AND RADIATION ILLNESS (B) AS A FUNCTION OF THE DOSE, ASSUMING Do VALUES OF 3.5 AND 1.0 Gy (see text)

Source: Andrea Ottolenghi

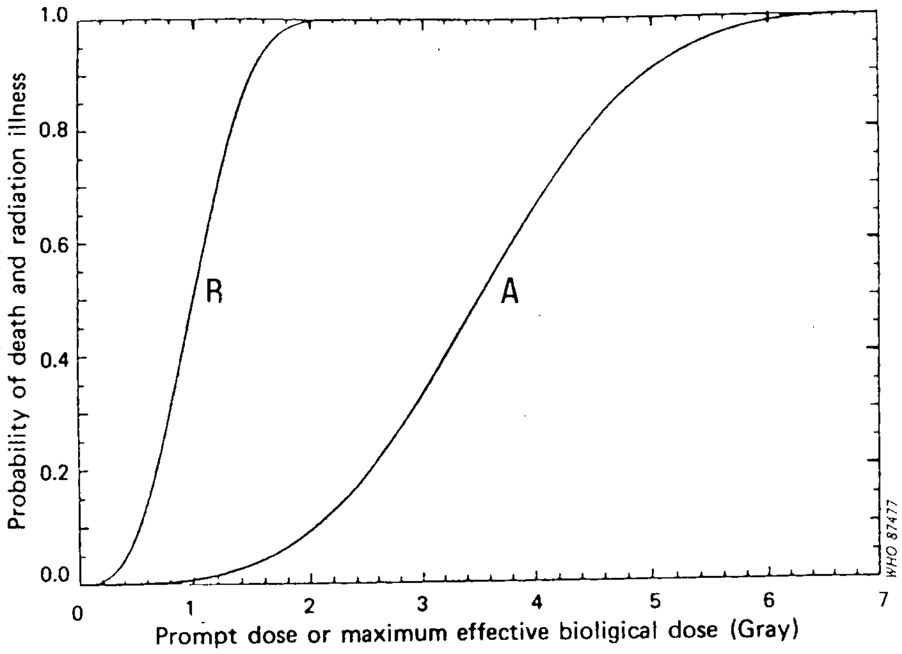


FIG. 3. PROBABILITY OF DEATH (A) AND RADIATION ILLNESS (B) AS A FUNCTION OF THE DOSE, ASSUMING Do VALUES OF 2.5 AND 0.75 Gy (see text)

Source: Andrea Ottolenghi

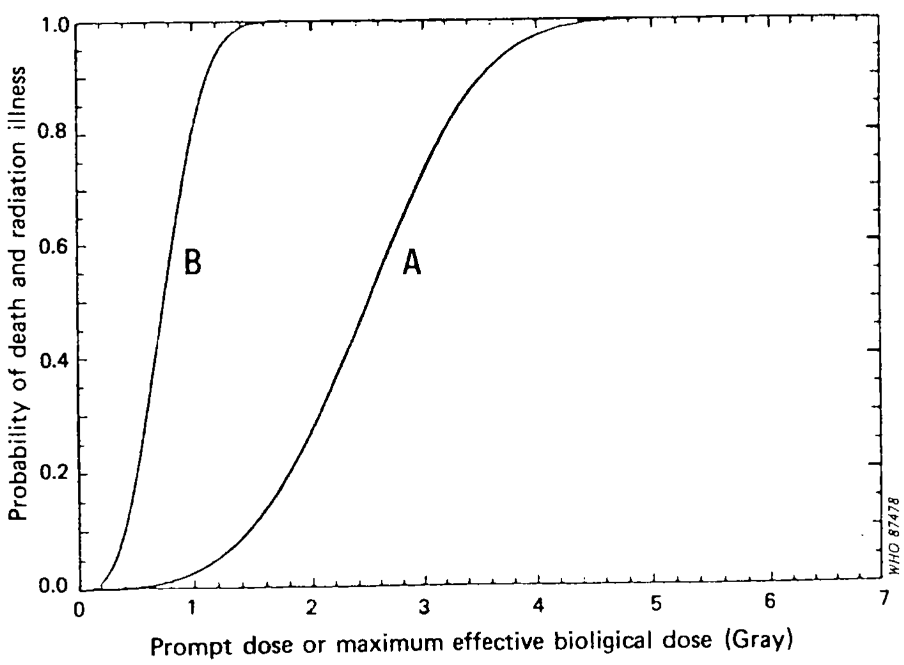


FIG. 4. MILITARY TARGETS IN EUROPE (EXCLUDING THE SOVIET UNION) ATTACKED IN THE SIMULATION

Source: Andrea Ottolenghi

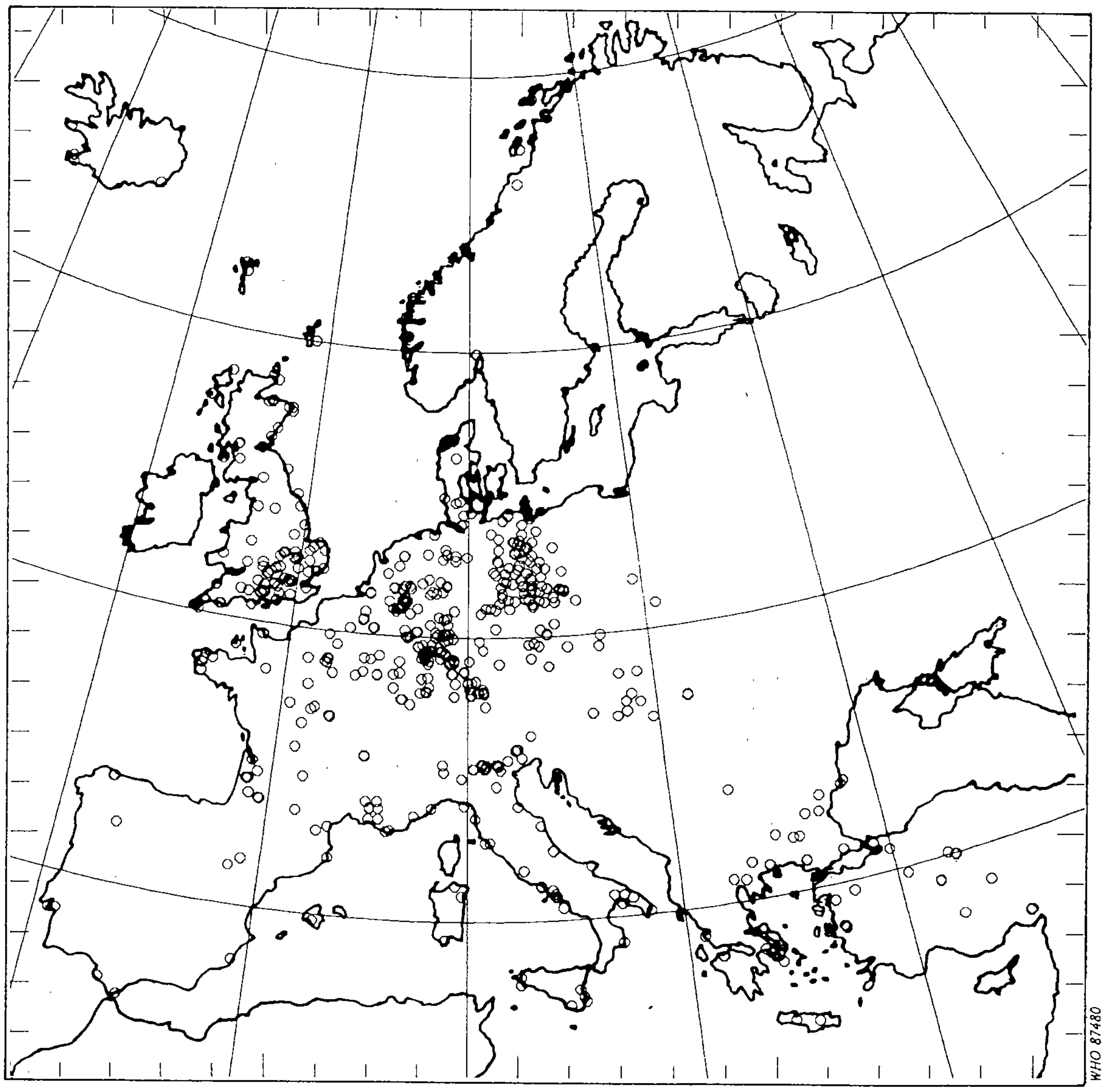


FIG. 5. FALLOUT PATTERN FROM A LIMITED NUCLEAR WAR IN EUROPE, ASSUMING TYPICAL MAY WINDS. CONTOURS OF "MAXIMUM EFFECTIVE BIOLOGICAL DOSE".

Black: more than 3.5 Gy. Grey: between 0.5 and 3.5 Gy

Source: Andrea Ottolenghi

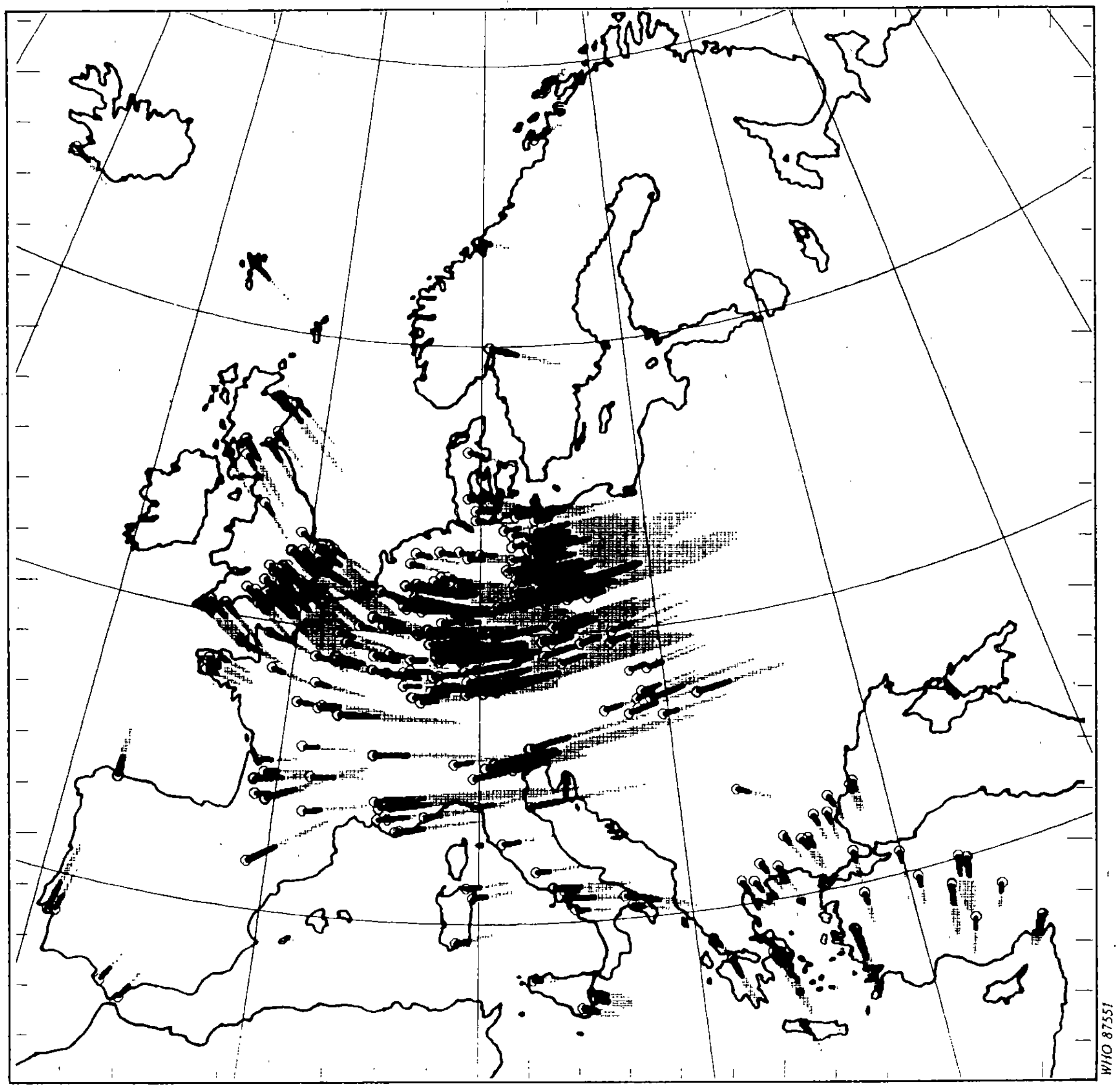
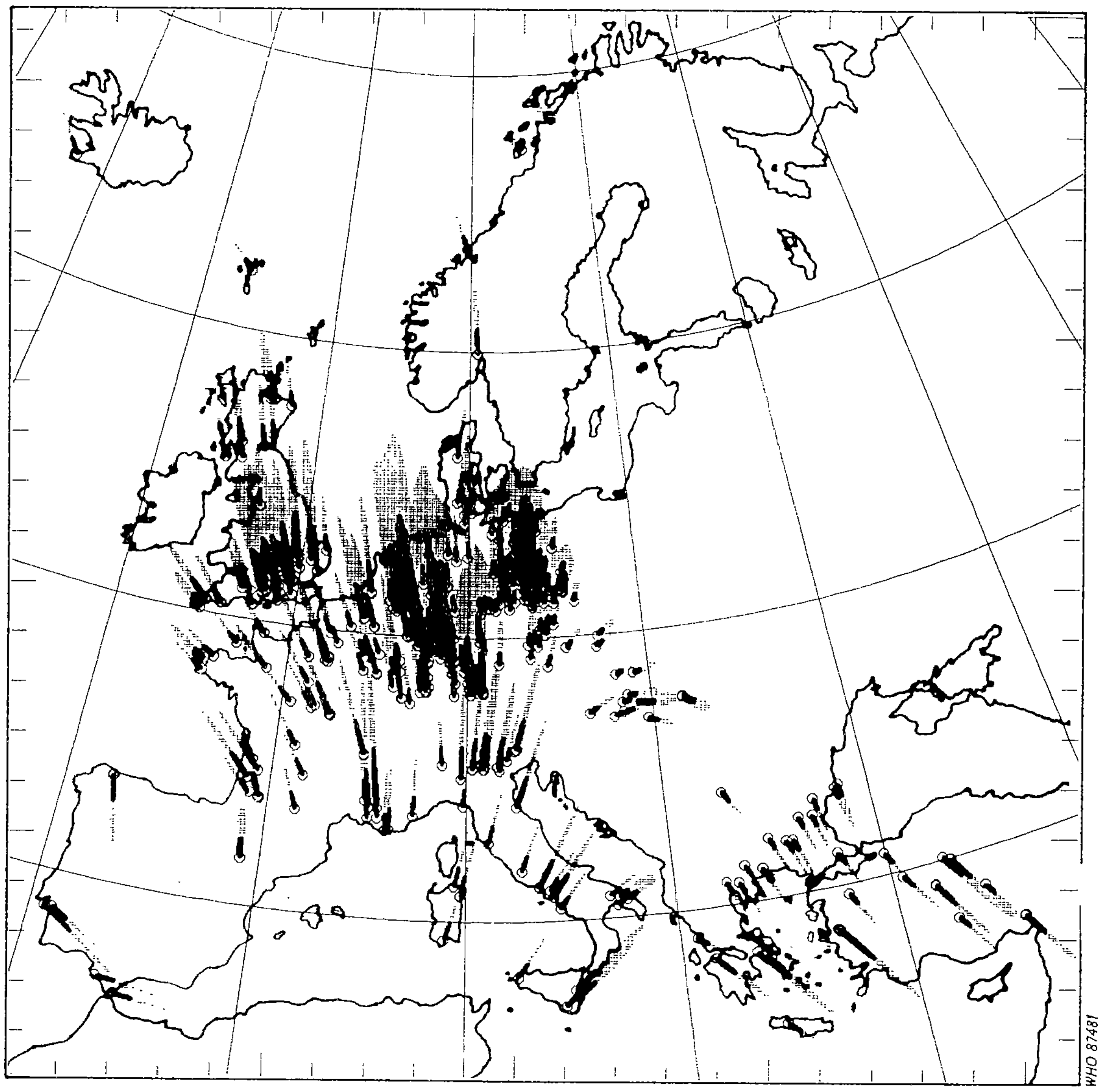


FIG. 6. FALLOUT PATTERN FROM A LIMITED NUCLEAR WAR IN EUROPE, ASSUMING TYPICAL NOVEMBER WINDS. CONTOURS OF "MAXIMUM EFFECTIVE BIOLOGICAL DOSE.

Black: more than 3.5 Gy. Grey: between 0.5 and 3.5 Gy.

Source: Andrea Ottolenghi



ANNEX 5

THE PSYCHOSOCIAL ASPECTS OF NUCLEAR THREAT AND NUCLEAR WAR: ANALOGIES FROM DISASTER RESEARCH

by

J. Thompson

1. Introduction

No disaster experienced in recorded history resembles the potential destruction of major nuclear war. Nonetheless, past disasters can give us pointers to the likely responses of those who survive the immediate effects, though it will always be necessary to interpret the findings carefully with due allowance for the differences which restrict the applicability of the comparison.

Localized disasters such as explosions and fires give a partial view of likely reactions, which in the case of nuclear war would be repeated across whole continents. Earthquakes and floods give a better understanding of large-scale and generalized destruction, though it is correspondingly more difficult to comprehensively evaluate how everyone reacted. All these disasters differ from the nuclear case in that there is always an undamaged outside world able to offer some help and assistance. Further, the imponderable effects of radiation will impose a delay on rescue attempts, since most people will be unable to establish when it is safe to come out from what remains of their shelter. Electromagnetic pulse is likely to have severely damaged the communication networks on which all effective relief operations depend. Most of all, the likely extent of the physical destruction would be so extensive as to make unlikely any concerted rescue operation, even if it could be mounted. Most people would be concerned with their own survival and the "illusion of centrality" which is held by disaster victims would for many be more of a reality than an illusion.

1.1 The classification of disasters as analogies for the nuclear case

Fortunately there are as yet no references to how people have reacted to a major nuclear war. Therefore, in order to provide some illustrative guidance, data about other catastrophes have had to be used as analogies for the nuclear case.

Disaster agents

A descriptive system first put forward by Hewitt and Burton (1971), and later adapted by Leivesley (1979) can be used to divide disaster agents into five categories: atmospheric, hydrological, geological, biological and technological. Disasters can also be categorized by the extent of energy release, frequency of occurrence, and period of duration. In general the disasters which cause most casualties, earthquakes, floods and cyclones, occur with lowest frequencies. This means that such terrible events tend to be rare in most people's experience, and thus it is hard to learn how to predict them and protect people against their worst effects. The power of these natural events may also make it seem futile to take many protective steps. In a more general sense, there are a wide variety of hazards which may lead to disaster. The perception of these hazards has an important impact on whether precautionary steps are taken. Hazards can be classified into: natural, such as earthquakes and floods, quasi-natural, such as air and water pollution, social, such as epidemics and riots, and man-made, such as building collapse, fire, and car accident. People's perceptions of hazard have been studied by factor analytical methods (Kates, 1976), and it has been found that they can be organized into two factors. The first factor, which accounts for most of the variation in perceptions is "orderly, relaxed, peaceful" versus "chaotic, tense, ferocious". The second factor is "natural, uncontrollable, fair" versus "artificial, controllable, unfair". From this it will be evident that wars are seen as chaotic, tense, ferocious and also artificial, controllable and unfair.

Turning now from the disasters themselves to the impact they have on human beings, differences exist between the levels at which the response of victims to the disaster can be studied. Individuals can be studied, or the level of analysis could be raised to that of the family, the community and society as a whole.

1.2 Appropriateness of analogies

The problem with the approach by analogy is that no single disaster approximates to all the features of a nuclear war. Although Hiroshima and Nagasaki represent the only examples of nuclear bombing, the weapons used there are very much smaller in their explosive power than those that are available today. The bombings occurred without any warning, the construction of housing was very different from that of modern European cities, and the population had no knowledge of nuclear explosions or radiation effects. In terms of psychological reactions Japanese culture was very different from that of present day Europe, there being a high degree of group identification and respect for authority. The relatively small size of the weapons meant that the effects of prompt radiation were proportionately larger than would be the case with most modern weapons (save, of course, radiation-enhanced "neutron" bombs). Most of all, the surrounding areas were not under nuclear attack, and were able and willing to give some assistance. Communications were maintained at a national level, so that radio and telegraph, roads and railways in the surrounding countryside were all functioning. Despite this, the basic effect of blast is the same.

A modern nuclear war could involve large numbers of far more powerful weapons falling, with or without any warning, over large sections of the Northern Hemisphere. Such a nuclear war might last hours, weeks or months, and electromagnetic pulse could disable most electronic communications.

In terms of sheer physical destruction, earthquakes give an indication of the effects of massive blast damage, but not even these physical effects are really comparable. Depending on the intensity and waveform of the quake, different types and degrees of damage occur, but they are different in form from blast damage. In some cases the tremors preceding the major event serve as a warning, particularly in areas where earthquakes have already been experienced by the population. Although earthquake damage can be widespread, radio communications are generally still possible and there is no fear of immediate contamination, as would be the case with radioactivity.

Massive fires replicate the effects of post-nuclear firestorms, but once again present data is based on there being an undamaged outside world to come to the assistance of those in the fire zone. Hurricanes and tornadoes replicate many features of blast damage, but they generally come with some warning, and do not leave immediately contaminated ground. Floods cause widespread damage, generally come with some warning, often lead to fears of health risks. Major epidemics leave the physical world undamaged, but replicate the immense depletion of population which would follow a major nuclear war, and come closest to revealing attitudes to radioactive contamination.

Table 1 summarizes the major features of disasters as analogies for a major nuclear war, and gives very rough, and highly debatable, estimates of impact for illustrative purposes only. It serves not so much to tie down each disaster into a rigid system of measurement, but simply to summarize some of their major features so as to make comparisons possible.

In the case of nuclear war, it is particularly difficult to make estimates within the same scale. Features are frequency, suddenness of impact, destructive power, geographical extent of damage, degree of contamination of environment, and extent to which communications are disrupted.

TABLE 1. CATEGORIZATION OF DISASTERS BY NATURE OF THEIR IMPACT

(Estimates are given on a 10-point scale)

Example	Frequency	Suddenness	Power	Extent	Contamination	Communication disruption
Hurricane	3	9	8	4	1	4
Fires	3	8	4	4	2	4
Floods	3	6	5	4	3	4
Earthquake	3	10	10	5	3	7
Conventional war	2	4	2	5	3	4
Nuclear war	<1	10	10	9	9	9

2. The analysis of human reactions to disasters

Although past disasters are imperfect guides to the future they must be studied if likely future reactions are to be understood. Leivesley (1979) in a study on disasters and welfare planning gives over 400 references, Kinston and Rosser (1974) give 117, Quarantelli (1980) has worked extensively in this area, underlining the need to clarify the social definition of disasters, and the generic factors which determine their impact (Quarantelli, 1985) and Churcher et al. (1981) and Thompson (1986a) have reviewed the literature with reference to nuclear war.

Kinston and Rosser (1974) reviewed the psychological effects of disasters, which they define as situations of massive collective stress, attempting to draw some conclusions from the extensive but unsystematized literature on human reactions to catastrophes. They note that there has often been a reluctance to fully investigate these reactions, as if researchers were averting their eyes from what they found. It was 17 years before any attempt was made to study the psychological consequences of the bombings of Hiroshima and Nagasaki. Even civil defence exercises set up to deal with simulated disasters fail to meet the pressing psychological needs of the supposed victims, and reveal an apparent unwillingness to confront the misery of personal tragedy.

Even when prompt and effective treatment is available, as in the burns victims described by Cobb and Lindemann (1944), and despite excellent planning and precautions to minimize psychological stress, 43% of the survivors showed evidence of psychiatric illness. This indicates the pressing need to investigate as fully as possible how people react to disasters, and to be aware of the psychological impairment which usually results. Despite a measure of reluctance to investigate the consequences of catastrophes, some features have been identified. Kinston and Rosser use a classification system based on the work of Tyhurst (1951) and Glass (1959), who categorize the phases of disaster as: threat, warning, impact, recoil and post-impact. Although these categories merely represent points along a continuum, and describe average reactions which may not occur in all people, they help us understand the course of events.

2.1 Threat

All life is subject to potential hazards, but some are more evident and dangerous than others. Earthquake belts, volcanic slopes, war zones and flood plains all carry particular risks. In terms of the risk of nuclear war, countries which themselves deploy nuclear weapons are especially at risk, and within those countries missile bases and possibly urban centres are likely targets. The evaluation of risk is a problematic subject, involving subjective estimates and attempts at calculated probabilities.

Slovic and Fischoff (1980) have looked at public perceptions of a variety of hazards, and have shown that perceived risks are often at variance with actual risks. These differences may be partly accounted for by the prominence which the media give to dramatic events, thus increasing their salience over less newsworthy occurrences. But Slovic, Fischoff and Lichtenstein (1982) have shown that when both experts and members of the public are asked to rate hazards by other perceived characteristics such as whether the risk is voluntary and what the extent of catastrophic potential, then much of the difference between the two groups disappears.

Threat is the condition under which we live at present. It is evident that a pressing danger exists, but the perceived salience of the threat will vary from person to person and time to time. Adults show a general perception that they are at risk because of nuclear weapons, though this is rarely stated as the most pressing worry people face. In 1982 a Gallup poll found that 72% of an adult sample were worried about nuclear war and 38% thought that nuclear war would occur. In general there is no consistent relationship between such anxieties and attitudes to nuclear weapons policies.

2.1.1 The impact of the threat of nuclear war on adults

Understanding the impact of the threat of nuclear war on our society is a compelling and complex issue. It involves having a clear understanding of people's feelings about the future, and the way in which all major forces affect their lives. There are two main aproaches to trying to gain this understanding. The first is to ask adults what they think and feel about the nuclear issue and how it influences them. The second is to study indicators of mass behaviour, to look for effects which might be caused by nuclear anxiety. The first approach has been the subject of much recent inquiry, but there is a shortage of appropriate research in the second category.

As has been made clear by Beardslee (1986), "understanding the impact of the nuclear threat is complicated by the fact that the issue is only one of several complex, rapidly changing forces operating in our modern industrial society". Since the atomic age began with the destruction of Hiroshima and Nagasaki, the industrialized world has changed considerably. In material terms, people are very much richer than they were before, and through the medium of television have a wider understanding of what goes on in the world. People are able to travel more, and to sample the ideas and the products of a global economy. The growth of technology, changing patterns of family structure, disillusionment with political systems, and growing economic troubles are other factors which account for changes in public attitudes. Schwebel (1986) has pointed out that the effects of the threat of nuclear war are difficult to distinguish from other sources of social distress. However, nuclear weapons have now entered the public consciousness. This is most obviously manifest in the mushroom cloud image, universally understood throughout the electronic village of our world. That image, seen from a safe distance, with its awesome power, and a certain detached beauty, is an emblem of the inventive capacity of modern man. Seen closer at hand on the ground, it reveals the vulnerable nature of our civilization, and the extent to which all our achievements can be vandalized in a moment's anger. Now, more than ever before, people are at the mercy of others, and their health and survival lie in distant hands. In Arnold Toynbee's words: "Mankind was safer when we were defenceless against tigers than we are today, when we have become defenceless against ourselves".

The question which must be asked is whether the present problems of our society, with terrorism, drug-taking, alcoholism and crime are in part due to anxiety about nuclear war, or whether our civilization can live with the threat of imminent destruction without showing any ill effects?

Fiske (1986) has given a very full and well organized account of American adult attitudes to the nuclear issue. Because of the clarity of her exposition, and the fact that is is grounded in the social psychology of attitudes, her descriptive framework will be adopted here. Fiske distinguishes between beliefs, feelings and actions, which must be in broad congruence if people are to maintain psychological equilibrium. In a review of over 50 studies from 1945 to the present she finds that this congruence is not maintained on the topic of nuclear war, since although beliefs and feelings concur, typically no action results.

Beliefs about nuclear war

The most common beliefs about nuclear war are that it is somewhat unlikely but that if it happens there will be complete material destruction with the people themselves definitely not surviving. Attitudes towards nuclear weapons have ebbed and flowed in the four decades since the bombing of Hiroshima and Nagasaki. Since the 1980s, however, concern about these issues has reached unprecedented levels. Despite this, the content of people's beliefs has changed remarkably little over the four decades. American respondents' beliefs differ surprisingly little across demographic characteristics and political ideology. Most importantly, people view nuclear war as not very probable. It is seen as fairly unlikely within the next 10 years, though it is estimated at a one-third chance of occurring within the average lifetime. In previous years this figure had been as high as 50%. If this somewhat unlikely nuclear war were to occur then people expect it to be horrific. Two features of the descriptions people give about nuclear war stand out. First, people describe the destruction of things far more often than they describe the destruction of people, and secondly the abstract content outweighs the concrete content. This emphasis on material things and abstract content is in complete contrast to the descriptions given by the Hiroshima survivors who focus almost entirely on the human misery. American respondents tend to report general impressions rather than specific personal impact. The average person also does not expect to survive a nuclear war. This is a change from earlier beliefs, up from about 40% in the 1950s to about 70% at the present time. Whereas before people used to comment about the quality of life in a post-nuclear world, now they do not expect to see it. A recent British study confirms many of these findings. Loizos and Marsh (1986) report on a survey carried out on 1005 Londoners aged 18 upwards. Respondents were asked what they thought was the likelihood of a nuclear attack on Britain in the next five years or in the next 20 years. Given the 20-year perspective, 25% are sure it will not happen and an additional 47% rate it evens or less than evens. When a five-year perspective was taken then 50% are certain it will not occur, and an additional 38% rate it evens or less. An overwhelming 67% of these respondents think it would be very unlikely that they themselves would live through the attack and 70% would hope not to survive such an attack.

Feelings about nuclear war

People seldom worry but they overwhelmingly favour a mutual nuclear freeze. Most people do not frequently think about nuclear war. The typical American adult apparently worries seldom or relatively little about the possibility. When they do think about it, then the typical person reports fear, terror and worry. Women sometimes report more anxiety than men, and children also report higher levels of concern than do adults. It is not clear how much of this difference is due to reporting biases as opposed to actual levels of worry. Given that people consider they have a one in three chance of experiencing nuclear war and think it is very likely that they will die in such a war, it is at first glance surprising that they do not worry about it more often. An American's level of nuclear anxiety seems to be related to non-conforming attitudes, felt vulnerability, drug use, low self-esteem and perceived lack of social support. A typical American response is to support a mutual freeze on nuclear arms although not a unilateral freeze. This support, which is as high as 77% of the population, has held firm over the decades since 1945. Small differences do occur regarding the use of nuclear force, with men and older generations being more supportive of this. There is about a 5-10% gender gap on this issue as on other foreign policy issues with women taking a more peaceful line. Loizos and Marsh (1986) found that about three-quarters of the population thinks or talks about nuclear war no more than once or twice a year, with about 50% saying they almost never or never talk about it. When they do think about it, then the majority of these respondents say they are either not very anxious or not at all anxious. This differs from the American findings, and shows a more phlegmatic or accepting attitude. Another approach has been to get people to estimate the likelihood of a whole list of hazards to health. Thompson (1986b) studying 245 polytechnic students, average age 20 years, found that nuclear war was the third highest rated risk after car accident and heart disease, but all three were rated below the mid-point of 4 on a 7-point scale. Also, respondents expected to live until about 74 years of age, so their nuclear fears had not really been fully taken in and applied to their own lives. The two strongest correlations with the nuclear warfare estimate were militarism and vulnerability. The measure of militarism used was a subscale of the Wilson-Patterson Attitude Inventory, and vulnerability was taken as the total score of all estimates across all the health risks mentioned in the survey. Nuclear war worry was not strongly correlated with the limited measure of general anxiety used in the survey.

Actions concerning nuclear war

Most people do nothing. A typical American person does not act in any way that goes beyond voicing support for the policy of a nuclear freeze. Most people do not voice their concern through letters or communications with their elected representatives. They do not join and financially support the relevant organizations and they do not even sign petitions. Loizos and Marsh (1986) present data for United Kingdom Londoners. These show that actions vary according to political orientation, yet even among those whose party is committed to a change on nuclear policy, 61% have done nothing. More predictably, this rises to 92% in the case of those whose party supports nuclear weapons. If one looks at a minimal and apolitical action, which is simply whether respondents have discussed with friends or relatives outside London whether they could go there in the case of nuclear war being threatened, then 96% of them have never had such a discussion.

Given that most people do nothing, brief reference should be made to the psychological characteristics of those who carry out even minimal actions. McGraw and Tyler (1986) had shown that activists feel more efficacious, both personally and politically, than members of the public, and believe that nuclear war is preventable but not survivable. They worry quite a bit about the issue, more than any other group, but it has relatively low impact on their future plans and they tend to be moderately pessimistic. Locatelli and Holt (1986) suggest, on the basis of questioning volunteer college students, that lack of action is probably caused by habituation to the threat, and not by denial or psychic numbing. This is in line with the work of Vaillant (1976), who looked at the types of defence used by mentally healthy compared with less well adjusted adults. On the basis of his intensive interviews which reviewed various crises in their recent lives and how they had coped with them, Vaillant was able to verify which defences were more pathogenic and which were more adaptive. Projection, that is blaming other people for one's difficulties, and neurotic denial were the most strongly correlated with objectively diagnosed mental illness and most negatively correlated with good adult adjustment. Others, such as repression, were not significantly related to either criteria. The adaptive defence most highly correlated with good adjustment and strongly negatively correlated with diagnosed mental illness was suppression; deliberately putting out of one's mind what cannot be helped at the moment so that we can get on with life's business. Suppression is easily confused with the superficially but far more pathological defence, denial. For example, to stay sane, people transmute much of their fear into anger and action, or they deny it and go about their business. Locatelli and Holt believe that their data are consistent with Vaillant's and that there is therefore no reason to believe that people ought, for the sake of their mental health, to be fairly constantly thinking of the danger of a new holocaust and feeling the appropriate dreadful emotions. In summary, despite evidence of anxiety in many people, the most consistent reaction appears to be habituation to the threat. Some people avoid the subject totally. Other reactions are resignation, helplessness (Seligman, 1975), fatalism and unquestioning trust. The myth of personal invulnerability, that necessary fiction of everyday life, holds strong, and allows people to continue the necessary tasks of living. All authority tends to be displaced onto leaders and authorities, and people tend to feel helpless and unable to influence events through their actions. Therefore, "remaining relatively unworried and inactive, despite the horrific possibility of nuclear war, is not irrational if people are correct in judging that their activism would have no consequences" (Fiske, p. 461). If prevention of nuclear war is seen as a health issue, then it is particularly important to pair fear-arousing communications with possible action solutions, which must be perceived to be politically effective and something the ordinary citizen is capable of doing.

In conclusion, there is substantial evidence that the threat of nuclear war causes considerable anxiety to many people, but there is a lack of studies to show whether this anxiety translates into ill health.

2.1.2 The impact of the threat of nuclear war on children

The literature on children's perceptions of nuclear war, which first began over 20 years ago (Escalona, 1963, 1965) has more recently been extensively supplemented by further work (Bachman, 1984; Chivian et al., 1985; Solantaus, 1985, 1986). Tizard (1984) has reviewed the field and an unpublished WHO report provides a further review on which these following points are based.

Children above the age of 10 (there is no sufficient data on younger groups) have an acute awareness of the existence of nuclear weapons and of the possibility of nuclear war. They find out about these matters from television and the mass media. They are better informed about the effects of the weapons than about the politics that surround them.

About a third to a half of children in the countries studied are worried about the threat of war in general and nuclear in particular. This concern is not confined to any socioeconomic, ethnic or racial group.

Younger children worry more than older ones, and girls worry more than boys. Many children, especially boys, can have frequent thoughts about nuclear war and not be worried, though in general thoughts and worry go together.

A significant proportion of young people believe that a nuclear war will occur in their lifetime, that they and their family will be killed, and that their countries will be destroyed.

Most children do not discuss their concerns with their parents, nor do they know what their parents think about these issues. However, some studies suggest that some parents can transmit their nuclear anxieties to their children.

Those children who discussed the issue with their parents were more likely to feel confident that they could do something to prevent nuclear war than those who did not.

Equally, those most anxious about the possibility of nuclear war were more confident about prevention, both by their own efforts and those of others. These children were also likely to be doing well at school, and have a better personal adjustment.

The degree of nuclear anxiety does not seem to be associated with neurotic or psychosomatic symptoms, or with alcohol or drug abuse or any specific psychopathology.

Although it is hard to judge this, with so many other things influencing youngsters, there is little evidence that the threat of nuclear war is impairing their behaviour, personality development or future planning. On the contrary, realistic anxiety about nuclear war appears to be a positive reaction which could be seen as an expression of a developing sense of social responsibility.

2.2 Warnings

In order to understand the way people respond to warnings of impending catastrophes it is necessary to review the accounts that have been given of those disasters in which warnings were possible.

A few points must be considered about the relationship between warnings, stress and behaviour. For a warning to be effective it must have a reliable association with the threat, and there must be a credible action to take in response to it. However, human beings have considerable shortcomings as estimators of the probabilities of future hazards (Slovic et al., 1974; Kahneman, Slovic and Tversky, 1982). Even when a hazard is acknowledged, people may perceive it in many different ways, seeing it as improbable or on the other hand so inevitable as to vitiate any human actions.

Research on responses to stressors indicates that appraisal of threat is a psychological process, and knowledge about a stressor threat tends to improve coping responses in any situation where coping responses are possible. In addition, such knowledge may also facilitate the appraisal of one's own coping resources, a process termed secondary appraisal (Lazarus, 1966). Knowledge about the onset and duration of the stressful stimulus appears to facilitate adaptation to it as illustrated by the work of Glass and Singer (1972) on noxious noise. In general, having something to do which reduces the threat, or even simply appears to do so, reduces the impact of stressors.

In studies of experimental stress on animals, the least affected groups are those which receive warnings of impending shocks and can reduce the probability of receiving them by carrying out avoidance behaviours, however onerous. The groups which suffer most stress, as measured by the rate of stomach ulceration, are those which suffer an equal number of shocks without benefit of warning, and cannot reduce their frequency by any instrumental means (Weiss, 1973). Without a warning these animals can never relax, since they have no safety signal, and could experience a shock at any time. A reliable warning, on the other hand, does cause temporary high levels of anxiety, but once the danger is over, safety can be assumed by the absence of danger warnings. Such helpless animals suffer considerably, and their helpless behaviour has many similarities to human depression (Seligman, 1975), characterized by a failure to initiate responses even when these might lead to avoiding further stresses.

The safety signal hypothesis should explain why the conventional bombing attacks on London appeared to cause less psychological stress than that of the V-bombs later in the war. In the first case the air raid sirens and the eventual all clear provided reasonably reliable signals of safety, but with the rockets no such indication was possible.

2.3 Studies of disaster warnings

Simply because a warning has been given it does not mean that it will be heeded. Denial can continue in some individuals up to the moment of impact itself. During the Hawaiian tidal wave of May 1960 evacuation was minimal (Lachman, Tatsuoka and Bank, 1961), and on the banks of the Rio Grande festive crowds watched and cheered the rising floodwaters (Wolfenstein, 1957). These active denials of danger have their place in everyday life, but when they are carried over in the face of a real threat they constitute a danger in themselves, since they obstruct preventative action. The myth of personal invulnerability still holds. A measure of this delusion may be gauged by the finding that the majority of people believe they are more likely than average to live past 80 years of age (Britten, 1983).

Once the danger has been admitted then, in those who are trusting, an over-reliance on official pronouncements may result, with susceptibility to rumour being the case for those who lack faith in parental establishment figures. Precautionary activity depends on the adequacy of information as to what needs to be done, and a group effect as people begin to take the warning seriously. Conflicting advice is usual (Churcher et al., 1981), and many people may be unable to decide upon a consistent response.

2.3.1 Short warning times

Drabek and Stephenson (1971) have given a detailed account of the behaviour of 278 families randomly selected from approximately 3700 families who had been evacuated from their homes prior to a flood in Denver. After a tornado earlier in the day, a wall of water was seen sweeping down one of the tributaries of the South Platte River which flows through Denver. The local Sherrif raised the alarm at 3 p.m., and this was received with some incredulity, since a major flood had not occurred on the river for 100 years. By 4 p.m. police began evacuating those closest to the river, and by 5 p.m. broadened the area of evacuation. Throughout the warning period radio and television responded in a sporadic fashion. Some stations carried on with normal programmes, while others gradually shifted to increased flood coverage. This made many people switch from one station to another in an attempt to confirm conflicting stories which seemed impossible to believe. The wide area of television coverage meant that people in safe areas converged on the danger zone to contact friends and relatives or, in the largest number of cases, simply because of curiosity. From the viewpoint of the families in the danger area, their many attempts to confirm the warnings frequently yielded contradictory information, and of those who evacuated immediately as many as one-third returned home, often infiltrating through police lines which had been set up to prevent looting. At 8.15 p.m. the floodwaters arrived, causing considerable damage but no loss of life because of the evacuation.

Drabek and Stephenson argue that five analytical characteristics are especially important. In contrast to more typical slowly-developing floods this one was:

(1) sudden

(2) unexpected

(3) unfamiliar to the populace

(4) highly localized in its danger area and

(5) warnings were received in very varied social contexts.

Response to warnings suggests that individual responses will be affected greatly by group memberships, most importantly the family unit. Most people responded to the flood as family members, not as isolated individuals, and of those families that were together at the time of warning 92% evacuated together. When family members were separated at the time of the initial warnings, which happened for 41% of the total sample, their immediate concerns were making contact with each other.

Although 52% received their warnings from mass media, as opposed to 28% from peers and relatives and 19% directly from the authorities, these people were far more likely to ignore the message or spend time attempting to confirm it than those who got more direct warnings. For example:

Message content	Continued routine activity	Attempted confirmation	Evacuated
Some areas flooding or evacuating	36	38	26
River rising	38	33	29
Flood water coming down River Platte	29	25	46
Evacuate	22	18	60

(adapted from Table 2, Drabek and Stephenson, 1971)

Although mass media sources often urged evacuation of very specific areas, these warnings tended to be viewed as background information, while a direct request from the authorities was far more likely to get people moving. Mass media seemed to generate the behaviour of further information seeking - people stayed "glued" to their sets rather than leave as advised. Mass media and peer's recommendations to evacuate were received with scepticism by 60% of respondents, but when the authorities were the source, such scepticism occurred in only 22% of cases.

The overwhelming bias was to interpret the warnings as non-threatening and then search for other cues with which to discount or confirm them. Rather than being sterile receptacles of news, people actively worked on what they had been told, and even when they came to accept that a flood was imminent, they still maintained a feeling of personal invulnerability and thought that their own house would not be hit.

Another study of short warning times, in this case of about one and a half hours, was conducted by Hodler (1982), who surveyed residents in the path of a tornado which had passed through Kalamazoo in Michigan, killing five people, injuring 79, and leaving 1200 homeless. The storm had first been spotted and tracked at 2.30 p.m., and was routinely handled by the mass media, who at 3.45 p.m. issued a severe thunderstorm warning. A tornado was seen 15 miles to the west of the city, and the civil defence sirens sounded at 3.56 p.m., with mass media now making near-continuous emergency broadcasts. By 4.10 p.m. the tornado struck.

A random sample led to 263 personal half-hour interviews. Two-thirds of the subjects had heard the warning sirens, but 17% of those did not know what they meant. Safety was sought by 48%, the warnings were disregarded by 18%, and 22% tried to confirm the warning by looking outside or turning on their radios and televisions. This means that 40% did nothing or even tried to see the tornado. Michigan had experienced 306 tornadoes between 1953 and 1975, so this lethargic response was not based on ignorance.

2.3.2 Longer warning times

Perry, Lindell and Greene (1982) investigated the level of perceived risk, the warnings received and the extent to which these were believed by residents near the Mt. St. Helens volcano about 16 days after moderate earthquakes indicated that it had come to the end of a 123-year dormant period. At the time when the telephone survey started on a sample of 173 respondents a state of emergency had been declared for the surrounding area, and when it was completed two days later the news media reported that the immediate crisis was over. The study thus affords a quick look at a crucial phase in the disaster warning process. Residents monitored news media avidly, a majority of 55% even hearing four or more volcano reports per day, while only 10% heard only one per day. Television was the most common source of news at 98%, with newspaper at 91% and radio at 87% following close behind. Interpersonal contact was a somewhat less frequent source, though 70% received hazard information from friends and relatives and 21% had direct contact with officials. A majority of 52% were very confident that they had all the information they needed, 32% were moderately certain and only 16% remained very uncertain. Confidence was not related to how near respondents were to the volcano, nor to the source of the information nor to the frequency with which news reports were heard. Although the authors do not comment on this, the question could be conceived of as a measure of anxiety. Despite the high level of news monitoring, only two respondents had evacuated from their homes at the time of the survey.

Perry, Lindell and Greene conclude from their survey that the situation around Mt. St. Helens was sufficiently threatening to make people attend to the danger, but there appeared to be enough time to evaluate the options for action without any pressing need for immediate evacuation. The intensive dissemination of hazard information during a short period of imminent threat of disaster sensitized people to the impending event.

2.3.3 Effects of warnings, and features which lead to them being heeded

Hansson, Noulles and Bellovich (1982) distributed questionnaires to 300 residents of a large floodplain in Oklahoma, getting a response rate of 59% to series of questions about knowledge about floods and flood warnings and a wide range of stress indicators. The respondents were people who had lived in their homes for eight years on average, and 40% of them had been flooded, on average two-and-a-half years before. Only 10% of respondents had ever rehearsed a family plan of action, and only a third had taken any action whatsoever to protect their homes from flooding. Knowledge of the variables affecting urban flooding was associated with reports of actions during the last flood reflecting greater calm and perceived control. Warning was associated with intensified trauma, as measured by most of the stress indicators. The nature of the four-hour flood warnings tended to generate anxiety rather than effective defensive activities. Those with personal experience of flooding paid greater attention to the reality and immediacy of the threat, and with increased dread. The more often they had been flooded, the higher their scores on measures of depression and family health stress.

Miller (1981) conducted a telephone survey of 248 heads of household living within 10 miles of Three Mile Island to find out which factors determined whether people evacuated during the accident at the nuclear plant. Measures of coping style showed little effect, but situational variables such as proximity to the plant, disruption of telephone service and specific directives to evacuate were significantly related to the decision to leave. Jackson (1981) surveyed 302 residents of earthquake zones on the American west coast and found that there was a preference for crisis response. Even though 80% had experienced an earthquake, and 96% expected earthquakes to occur in the future, few believed that they themselves would sustain damage. Only 7.5% had taken out insurance or made structural improvements to their home. When asked to list the disadvantages of their city only 1.7% mentioned earthquakes, as opposed to the 18.2% who mentioned air pollution, suggesting that more immediate social and environmental concerns take precedence over earthquake hazard for the majority of respondents.

When people's views about the likelihood of future earthquakes were sought, it was found that 23.2% denied that they would experience an earthquake, 8.9% expected that they would, and 67.9% were uncertain. An interesting relationship was found with the extent of the loss which had been experienced in previous earthquakes. Those who had suffered the most damage showed the least uncertainty, and polarized into those who denied that there would be any further earthquakes and those who expected further damage. The reasons for this finding may lie in the notion of a just world, in which those who have been punished will be spared further castigation.

2.4 Summary

A full explanation for people's failure to respond to well-founded threats and warnings is required. The theory of bounded rationality is a possible explanation. As described by Slovic et al. (1974) a very narrow range of adjustments is perceived and adopted. Most people do nothing, or very little. People show a preference for crisis response, saying that they will respond when disaster strikes, forgoing precautions in the absence of personal experience, and making changes only in the aftermath of the disaster. People tend to misperceive risks and deny the uncertainty inherent in nature, or show an unshakeable faith in protective devices such as flood control dams or earthquake building codes. They may sometimes flatly deny that a recurrence of a disaster is possible, or misperceive such events as coming in cycles.

The heavy casualties in the Bangladesh cyclone of 1985 were ascribed to an unwillingness to heed warnings which had proved unreliable in the past. The Bradford football fire occurred in a stadium which was known to be a fire hazard four years previously, but no action was taken to clear the stand of inflammable material. The Bhopal chemical gassing tragedy was similar in conceptual terms to the accident at Three Mile Island, in that back up safety systems designed to cope with an even which the planners could not really believe would ever happen, were unable to properly cope with the rare event when it occurred. The conceptual failures which cause major technological accidents have been well described by Perrow (1983), and do not bode well for a tightly-coupled and time-sensitive system like the global nuclear weapons machine.

3. Post-disaster behaviour: impact, recoil and post-impact

3.1 Impact

When disasters are sudden and severe, most people feel that they are at the very centre of the catastrophe. This illusion of centrality, though understandable, may prevent optimum responses since most people will concern themselves with their own local problems. In a tornado people may believe that only their house has been hit. The myth of personal invulnerability, which is so strong in the threat phase, is now called into question. Faced with the reality of death, usual assumptions disintegrate, and mood and beliefs oscillate wildly. As the full extent of the destruction becomes apparent, and help fails to materialize, there is the second shock effect of dismay at abandonment. Intense emotions are felt, and these fluctuate, making later recall of events problematical. Feelings fluctuate between terror and elation, invulnerability and helplessness, catastrophic abandonment and miraculous escape. All survivors must attempt to make sense of the fact that they could have died, and nearly died, but managed to come through alive. They show the exhilaration of massive anxiety relief, but also the vulnerability to disappointment which is the longer-term effect of the massive fear they have experienced. Joy at having survived may be mixed with colossal optimism that the worst is over. Life itself seems sufficient reward, and in particular joining up with loved ones, who were feared lost, brings intense happiness. The quite random fact of survival may be rationalized by a feeling of personal invulnerability and mission. Those who have had a brush with death are left in a heightened state of emotional turmoil.

This effect is short lived, and soon gives way to the "disaster syndrome". Victims appear dazed, stunned and bewildered (Wallace, 1956). Contrary to popular belief, their reactions are not the ones associated with panic. Quarantelli (1954) describes panic as an acute fear reaction, developing as a result of a feeling of entrapment, powerlessness and isolation, leading to nonsensical and irrational flight behaviour. Such frenzied activity is only found when people are trapped, and when escape is thought possible only for a limited period of time. Then contagious panic can indeed occur, but it is not the norm in disasters.

After a disaster victims are apathetic, docile, indecisive, unemotional, and they behave mechanically. They are still in a state of high autonomic arousal, but appear to be paying for their period of terror by emotional and behavioural exhaustion. Various explanations have been put forward for this passive response. It may be a protective reaction, cutting people off from further stimuli which would only cause them anxiety and pain. In an account of the Tokyo earthquake of 1894 Balz noted that he observed the terrible event "with the same cold attention with which one follows an absorbing physical experiment ... all the higher affective life was extinguished" (cited in Anderson, 1942). Again, it could be a form of wishful fantasy - "if I don't react then nothing has happened". Or it could be that people feel helpless in the face of the massive damage and the impossibility of repairing their shattered world. Whatever the reason, the survivor is left in a diminished condition, and is highly vulnerable. Guilt feelings are common, since the catastrophe will have released unacceptable egotistical feelings, including excitement at the deaths of others. Fear will have prevented people from helping others, leaving survivors with only the fantasy of the heroism they would have liked to have shown in the emergency. Even within families, some will have put their own safety above those of other family members.

Popovic and Petrovic (1964) arrived on the scene of the Skopje earthquake 22 hours after the event, and in the following five days, together with a team of local psychiatrists, toured the evacuation camps. They found that much of the population was in a mild stupor, depressed, congregating in small unstable groups and prone to rumours of doom. Prompt outside help, responsible and informative reporting by the press, and the speedy evacuation of the more disturbed victims all contributed to an eventual return to apparent psychological normality. By way of comparison with nuclear war, it should be noted that only one in 200 of the people died, and three in 200 were injured, far less than would be expected in nuclear explosion.

In any disaster, according to Kinston and Rosser's (1974) estimates, although roughly three-quarters of the population are likely to show the disaster syndrome, anywhere from 12 to 25% will be tense and excited, but able to cope by concentrating on appropriate preparatory activities. They will be capable of making themselves too busy to worry, though their activities may often be of only marginal relevance to the threat they face. At times of stress overlearned familiar routines can serve as a solace. Equally, 12 to 25% will fare far worse, and will show grossly inappropriate behaviour, with anxiety symptoms predominating. There will be an immediate increase in psychological distress, as those already vulnerable are triggered into breakdown. Such effects are more likely for reactive disorders than those which are psychotic in origin. Those whose behaviour is contained only by social pressure are likely to behave in psychopathic ways. The crisis will provide an opportunity which some will be willing to exploit.

3.2 Recoil

If the cause of the disaster is seen to pass, and some sort of "all clear" can be announced, then there will be an opportunity for a return to something approximating a normal psychological state. About 90% of subjects show a return of awareness and recall. They are highly dependent, talkative, childlike, seeking safety and forming unstable social groups. In this state they remain highly vulnerable and emotionally labile. Some respond with totally psychopathic behaviour, and looting, rape and heavy drinking may occur. People show a return of energy with a commensurate return of reason. They behave hyperactively and often irrationally. They become obsessed with communicating their experiences to others, and need to work through the events in order to give them some meaning. The need for explanation is part of dependency, and leads to rumour and absurd gullibility. People will be anxious to obtain reliable news, and will expect their own experiences to be news. Monitoring the news serves as an attempt to reconstruct a comprehensible set of explanations, and to reduce the uncertainty brought about by uncontrollability. For example, following the murder of President Kennedy the average United States adult spent eight hours per day for the next four days listening to the radio or watching television, behaviour which Janis (1971) interpreted as an attempt to work through the cultural damage. In this dependent and vulnerable state, chance factors can have a disproportionate effect on the interpretation of the event and the view as to what has to be done in the future. Scapegoats may need to be found, and chance may provide them. Scientists, militarists and politicians may escape initial attention while those involved in bringing relief may be the target of frustration and feelings of betrayal (Lacey, 1972).

Once the immediate danger is past, some survivors will begin to take steps to cope with the consequences. Even as the warning of danger is announced people will find themselves in a conflict of roles. They will have to decide whether they should continue with their jobs, take up civic and emergency duties or return to look after their families. Killian (1952) found that conflicting group loyalties and contradictory roles were significant factors affecting individual behaviour in critical situations. Typically, it is the person without family ties who leads rescue work, while the others generally run to their homes to discover if their families are in danger. Even so, Killian reported that some who were searching for their families, after a tornado had struck, were capable of helping others they found on the way. Those whose occupational roles bore little relationship to the needs created by the disaster, such as shopkeepers, disregarded their jobs more easily and came to the assistance of the community.

Faced with an overwhelming catastrophe family bonds are likely to predominate over civic duties, because everyday tasks and responsibilities will be seen as irrelevant and futile by most people. It should be noted that natural disasters generally come without warning, and rarely require emergency workers to leave their families unprotected while moving themselves to places of relative safety, as would apparently be required of them in the event of nuclear war.

3.3 Post-impact

Gradually, individual reactions become coordinated into an organized social response. The form this will take depends very much on cultural norms. Many of the victims will be coping with the consequences of loss and bereavement. This will diminish their capacity to interact socially in a productive manner. Victims need some form of acknowledgement of their suffering, but social norms may deny them the right to express their grief and hopelessness. Fear and apprehension persist, and many may feel that the catastrophe will recur. Aftershocks of an earthquake commonly cause more fear than the initial shock itself. People develop a conditioned fear response, and their capacity to maintain control of their emotions is diminished. Disaster persists as a tormenting memory, and is relived again and again.

4. Conventional bombing

Although conventional bombing campaigns involved far less explosive power and far longer time courses than would be likely to be the case in a nuclear war, they should be given some attention for two main reasons. First, the mass raids on cities in some instances approach the extent of destruction caused by small nuclear weapons. Second, facts and fictions about the Blitz influence both popular and official perceptions of the way Londoners would react to a future bombing campaign.

Many accounts have been given of World War 2 bombing raids (Titmus, 1950; Ilke, 1958; Janis, 1951; Harrison, 1978), and in this instance it would be most informative to collate data from many different sources so as to highlight the common features which have emerged.

4.1 Preparations

These raids were preceded by a long period of international tension which gave the public and the authorities time to make practical and psychological preparations. The previous data on urban bombing were sparse, and the predictions were that there would be massive casualties, considerable panic, and that if deep shelters were provided this would lead to a "shelter mentality" in which people would refuse to come out to work. As a projection of the reports from Guernica this was an understandable view, as was the overriding fear of a gas attack.

The very long conditioning period of the "phoney war" served to give the population time to develop coping responses. Duties were allocated which served to give key community members an important role in air raid preparations, thus providing them with something to do, and setting a coping example for others to follow.

4.2 Effects

When the bombing began, however, social cohesion and morale broke down very quickly in the worst affected areas, though censorship ensured that this was not widely known at the time. Badly damaged zones had to be cordoned off by the police, and emergency services were unable to cope. All this occurred despite the fact that there was warning of attack, pauses between attacks, and that there had been the evacuation of one-and-a-half million women and children.

The fact that the bombing could not be maintained without pause gave the population time to make some adjustments, and the fortuitous fact that a bomb fell near Buckingham Palace while the East End was receiving the brunt of the attack defused an explosive social divide, and made Londoners feel that "they were all in it together".

The shelter policy resulted in fewer casualties than had been calculated, but the extent of damage to housing and infrastructure had been severely underestimated, as had been the problems of dealing with large numbers of displaced homeless people. Nearly a quarter of a million homes were damaged beyond repair, while 3.5 million suffered repairable damage, though these losses could not be made good during the war period. Emergency services adapted to the new demands, but in many areas of London fires raged uncontrollably.

The authorities had prepared for massive casualties and panic. Instead they had a dazed but functioning population which required food, clean water, shelter and new forms of social organization. Titmus (1950) observed: "The authorities knew little about the homeless who in turn knew less about the authorities".

The speed with which the large number of people in a dazed and bewildered condition could be organized and rehabilitated determined the rate at which the damage could be repaired, production returned to full capacity, and further demoralization in surrounding areas avoided. What was needed, the observers of that time agreed, was a "much more powerful and imaginative organization" to deal with "the purely psychological and social effects of violent air attack" (Mass Observation 1940, cited in Harrison, 1978). This organization should bring a wave of social help, hot tea and sympathy, to snatch people out of their introversion and to link them up again with the outside world. The impact of World War 2 bombing on the United Kingdom population was twofold. First there were the direct casualties (about 60 000, but second and more numerous were those who suffered disruption and loss because of damage to the structure of society itself. Children and old people suffered disproportionately through neglect, such that their wartime mortality figures were elevated, and accounted for another 6000 deaths through indirect effects. The raid on Coventry on the night of 14-15 November, 1940 caused such damage to the infrastructure of that city that in the aftermath there was close to being a breakdown of social organization. Food had to be brought in from Birmingham and Stoke-on-Trent, and entry to the damaged areas prevented by armed troops.

In the Southampton raids large sectors of the population ignored official instruction and began "trecking", moving out into the country and sleeping in hedges during the night, and then some of them trecking in to work the next day. The stresses of long periods of deprivation and uncertainty caused deep rifts in society which was also noted in Japan and Germany during the air war.

Towards the end of the war the V-bomb campaign imposed new stresses on London's population, and this was particularly the case for the V2 rocket, which fell without warning. Stress levels were very high, and a new evacuation began again. No "all clear" was ever possible until the launch bases themselves were destroyed.

The raids on Hamburg in 1943 caused heavy casualties and mass evacuation. Only because of the evacuation were there sufficient undamaged houses (only about 50% of the housing stock remained) for the very much smaller population which returned to the city to live there in cramped quarters.

4.3 Summary

The findings from conventional bombing offer only a very partial view of reactions to nuclear war. The power of nuclear weapons is so great that massive destruction can be caused virtually without warning on a society which is now even more inter-dependent and tightly-coupled as an industrial system. It is thus more fragile and will have to absorb more damage without time to recover. The aftermath of a major nuclear war will be like Nagasaki asking Hiroshima for help.

5. Nuclear bombing: Hiroshima and Nagasaki

The bombings of Hiroshima and Nagasaki offer a partial view of the effects of a potential future nuclear war. The weapons were very small by present day standards, the culture and the age were different, and there was neither warning nor any knowledge of radiation. The Hiroshima bomb, at the equivalent of about 15 000 tons of TNT, would now be regarded as a small battlefield weapon or merely as the detonator of a 1 megaton strategic bomb. However, these bombings are still the closest examples of what would occur in a contemporary nuclear war, with larger explosions on a potential 18 500 strategic targets (SIPRI, 1984).

Considering the importance for our age of these events, the bombings of Hiroshima and Nagasaki have been underreported. Some accounts have been often repeated, but much of the film material collected at the time has only recently been released, and the work done with the survivors was incomplete and often exaggeratedly technical, avoiding personal accounts and bypassing a mass readership. The account here is taken from Thompson (1985). Lifton (1967) picked 33 survivors at random from lists kept by local Hiroshima research institutes, plus 42 who were particularly articulate or prominent in the A-bomb problem. A structured interview explored the individual's recollection of the original experience and its meaning in the present as well as residual concerns and fears, and the meaning of his or her identity as a survivor.

No account can hope to capture what the survivors experienced. They were submitted without warning to an explosion so vast that it seemed that the world itself was coming to an end. At 8.15 a.m. on 6 August 1945 most people in Hiroshima were in a relaxed state, since the all-clear had just sounded. Few people could recall their initial perceptions, some seeing the "pika", a flash of light, or feeling a wave of heat, and some hearing the "don", the thunder of the explosion, depending on where they were at the moment of impact. Everyone assumed that a bomb had fallen out of a clear sky directly on them, and they were suddenly and absolutely shifted from normal existence to an overwhelming encounter with death, a theme which stayed with each survivor indefinitely (Lifton, 1963). Those far from the city were shocked to see that Hiroshima had ceased to exist. A young university professor, 2500 metres from the hypocentre at the time summed up those feelings of weird, awesome unreality in a frequently expressed image of hell:

> "Everything I saw made a deep impression - a park nearby covered with dead bodies waiting to be cremated ... very badly injured people evacuated in my direction ... Perhaps the most impressive thing I saw were girls, very young girls, not only with their clothes torn off but their skin peeled off as well ... My immediate thought was that this was like the hell I had always read about ... I had never seen anything which resembled it before, but I thought that should there be a hell, this was it."

In Nagasaki a young doctor (Akizuki, 1981) was preparing to treat a patient when the atom bomb exploded. After pulling himself from the debris of his Urakami hospital consulting room, he was eventually able to look out of where the window had been to the world outside.

> "The sky was dark as pitch, covered with dense clouds of smoke; under that blackness, over the earth, hung a yellow-brown fog. Gradually the veiled ground became visible, and the view beyond rooted me to the spot with horror. All the buildings I could see were on fire ... Electricity poles were wrapped in flame like so many pieces of kindling. Trees on the nearby hills were smoking, as were the leaves of sweet potatoes in the fields. To say that everything burned is not enough. The sky was dark, the ground was scarlet, and in between hung clouds of yellowish smoke. Three kinds of colour - black, yellow and scarlet - loomed ominously over the people, who ran about like so many ants seeking to escape. What had happened? Urakami hospital had not been bombed - I understood that much. But that ocean of fire, that sky of smoke! It seemed like the end of the world (Akizuki, 1981)."

After encountering so much horror, survivors found that they were incapable of emotion. They behaved mechanically, felt emotionally numb, and at the same time knew they were partly trying to pretend to be unaffected in a vain attempt to protect themselves from the trauma of what they were witnessing.

> "I went to look for my family. Somehow I became a pitiless person, because if I had pity I would not have been able to walk through the city, to walk over those dead bodies. The most impressive thing was the expression in people's eyes - bodies badly injured which had turned black - their eyes looking for someone to come and help them. They looked at me and knew I was stronger than they ... I was looking for my family and looking carefully at everyone I met to see if he or she was a family member - but the eyes - the emptiness - the helpless expression - were something I will never forget (Lifton, 1963)."

A business man who had hastily semi-repaired his son's shoe before he went to work in the city centre was overcome with guilt that this same shoe had prevented his child from fleeing the fire. The man fruitlessly searched for his child's body, and was left in a state of perpetual self-accusation.

Most survivors focused on one ultimate horror which had left them with a profound sense of pity, guilt or shame. A baby still half-alive on his dead mother's breast, loved ones abandoned in the fire, pathetic requests for help which had to be ignored - each survivor carried a burning memory.

In Nagasaki, Akizuki was swamped by burnt survivors clamouring for water and medical attention.

> "Half naked or stark naked, they walked with strange, slow steps, groaning from deep inside themselves as if they had travelled from the depths of hell. They looked whitish; their faces were like masks. I felt as if I were dreaming, watching pallid ghosts processing slowly in one direction - as in a dream I had once dreamt in my childhood."

Severely injured people cried out for help. Parents refused to leave dead children, still requesting that they be attended by the doctor. Passing planes caused panic, and victims tried to hide until they had passed. Most survivors had witnessed terrible scenes, piles of dead bodies heaped up in streams, mothers and children locked in each other's arms, a mother and her fetus still connected by its umbilical cord, all dead (Akizuki, 1981). These survivors were so profoundly affected by what they had experienced that all aspects of their subsequent lives were marked by it, and they felt that they had come into contact with death but remained alive. Survivors attempt to make sense of the fact that they have survived whilst others have perished. Unable to accept that this was a chance occurrence survivors are convinced that their survival was made possible by the deaths of others, and this conviction causes them terrible guilt. Guilt and shame developed very quickly in Hiroshima survivors, as it did in those who escaped concentration camps, and in both cases it has been intense and persistent. Lifton set out the train of thought of Hiroshima survivors thus:

> "I was almost dead ... I should have died ... I did die or at least am not alive ... or if I am alive it is impure of me to be so ... anything which I do which affirms life is also impure and an insult to the dead who alone are pure ... and by living as if dead, I take the place of the dead and give them life."

This is the painful accommodation which the holocaust survivor makes to the joyless fact of having survived. It is grief made the more keen by there being no bodies to be buried and mourned, nor any familiar landmarks to show that life continues, and thus aid adjustment to loss. Person, body, house, street, city and even nature itself have been consumed.

Although proper follow-up studies of psychological effects do not appear to have been done, psychotic disorder is uncommon, but depression and anxiety about cancer, fears of death and dying, and generalized complaints of fatigue, dizziness, irritability and difficulty in coping are usual. This pattern is similar to that found after major disasters and could be conceptualized as an understandable concentration of the attention on possible danger signals to the exclusion of long-term plans. The absence of proper follow-up studies is itself a psychological phenomenon worthy of note, since it suggests that the scientific community itself averted its eyes from the long-term consequences of the disaster.

x x x

The experience of the atomic bombings differed from other disasters in that it plunged the survivors into an interminable and unresolvable encounter with death. The immediate horrifying carnage was followed by long-term delayed effects, thus breaking the myth of personal invulnerability in a permanent way. In experiential terms, every victim saw their secure sunlit world destroyed in an instant. It felt like the end of the world, not just the end of one city. It is not hard to understand why they should distrust the apparent "all-clear".

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ANNEX 6

HEALTH PROBLEMS IN THE SHORT TERM: CASUALTY MANAGEMENT

by

A. Leaf

Introduction

The short term is taken to include the first two to four months following a thermonuclear attack. It will encompass the direct destructive effects of the explosions, including the local fallout, and social chaos.

Any description of the effects of nuclear war on health must be fraught with considerable uncertainty, for actual experience is fortunately limited. Despite the devastating experiences of Hiroshima and Nagasaki, examined in detail, it has become evident only recently that for 40 years even the basis for calculating potential casualties has been deficient. Virtually all estimates of acute casualties were based on the effects of blast. Now it is appreciated that deaths from superfires in urban areas are likely to occur in considerable excess over those from blast effects (1,2). Also under some circumstances casualties from radioactive fallout may equal those from blast or fires (3). These recent estimates have served only to worsen the potential health problems that would result from a nuclear war, whatever its magnitude might be.

Description of injuries

The direct effects on the individual may be divided into the immediate effects of the explosion - from blast, heat, initial radiation, and from local radioactive fallout - and the later effects of local and global radioactivity and of changes in the ecosystem that are hostile to human health and survival. This section will deal only with the immediate effects.

Fires

It is now recognized that fires ignited by the enormous thermal energy released by thermonuclear explosions will be the major cause of casualties rather than blast (4). Burns will result from both the direct thermal pulse, so-called "flash burns", and indirectly from the fires caused by the explosions. The thermal wave would cause immediate charring of exposed parts of the body that were in the direct line of the thermal rays. The severity of burns would depend upon the yield of the bomb, the distance from the hypocentre, and the degree of shielding. Depending on its intensity, the heat would cause erythema of the epidermis (superficial partial thickness injury, e.g. first-degree burn), or deeper burns with coagulation and carbonization or even vaporization. The burns are sharply outlined and limited to exposed or lightly clothed body surfaces. Such flash burns would occur within fractions of a second following the explosion and reach their maximum within a few seconds. In Hiroshima and Nagasaki the temperature reached 3000-4000°C near ground zero; it exceeded 570°C even at a distance of 1100-1600 m (5).

Indirect burns from fires started by the initial thermal pulse and from the blast would result in many more casualties, and is now recognized as the major cause of early death and disability following a nuclear explosion (1,4). A single one-megaton air burst may ignite combustible material in an area with a radius of 5-15 km depending on the clarity of the atmosphere (4). With usual weather conditions yielding a 12 km radius, simultaneous fires would be promptly ignited coalescing into a superfire over an area of some 450 km^2. Urban and suburban districts are estimated to contain sufficient combustible materials to sustain superfires. Only those in the outer penumbra of approximately 2 km will have a chance to escape the fire zone and, even in this zone, 50% of individuals will die, one-third will be injured and only one-sixth will be unharmed (4) - see Annex 4 for further details. Air temperatures within the fire zone will exceed that of boiling water (1), sufficient to roast anyone who could not very promptly escape. Lung burns and toxicity from noxious chemicals would take a heavy toll. In Hiroshima where a superfire burst forth 20 minutes following the explosion, few fractures were reported, presumably because blast victims with fractures who were unable to move were burnt to death in the ensuing fire.

Blast

Some 50% of the enormous energy released by a thermonuclear explosion is dissipated as blast. Although the human body can tolerate considerable pressure, the shock waves created by the explosions will result in many injuries. Collapsing buildings, flying debris, and individuals hurled through the air at immovable objects will cause many head injuries, fractures, crush injuries, and penetrating wounds of the abdomen and thorax. A one-megaton air burst is capable of killing nearly everyone within a radius of some 7 km from the hypocentre (over-pressure of 35 kPa or greater) and this had until recently been the accepted means of calculating the immediate deaths following an air burst.

Many individuals may be expected to suffer from combined blast and burn injuries. In Hiroshima, of the injured, 70% suffered blast and 65% suffered burns, yielding a 35% overlap with combined injuries (5).

Radiation

Radiation injuries can arise from two sources: the immediate burst of gamma and neutron radiations created in the explosion, or the radiation from fallout of radioactive particles from the bomb (and radioactivity induced in matter by the initial neutron radiations). The latter will also be largely gamma-rays but beta-rays and even alpha-particles can contribute to the radiation exposure when the radioactive material is deposited on the body or is ingested or inhaled. With the large bombs that comprise the strategic nuclear arsenals of the superpowers, direct radiation from the bomb burst itself does not cause casualties - the lethal range of blast and fires exceeds that of radiation. With small bombs of the size used in Hiroshima and Nagasaki or those intended for tactical use today, the initial radioactive emissions will cause injuries and death.

Whole body irradiation

Within minutes to several hours following exposure to radiation a person may begin to exhibit symptoms of acute gastrointestinal and neuromuscular effects. These constitute the prodromal syndrome popularly called radiation sickness. The gastrointestinal symptoms include: anorexia, nausea, vomiting, salivation, intestinal cramps, diarrhoea, and dehydration. The neuromuscular symptoms that may occur are: fatigue, apathy or listlessness, sweating, fever, headache, and hypotension followed by hypotensive shock. The complete constellation of symptoms may occur with high doses of radiation whereas with low doses only some of the symptoms may make their appearance during the ensuing 48 hours. Thus a dose in the range of 0.2 to 0.6 Gy is likely to produce anorexia in 10% of the exposed population, while a dose of 1.7 to 4.4 Gy will produce the symptom in 90% of the population (6).

The severity of symptoms and their occurrence following whole-body irradiation depend on the total radiation dose and the dose rate. There are three clinical syndromes of radiation toxicity recognized:

1. With acute doses of over 20 Gy a central nervous system syndrome results. Headache occurs in minutes to an hour, followed rapidly by drowsiness, severe apathy and lethargy, generalized muscle tremor, loss of muscular coordination, coma, convulsions and shock. Death occurs within a few hours to a couple of days. There is no treatment and the condition is invariably fatal.

2. A gastrointestinal syndrome occurs with acute exposure to doses of 5 to 20 Gy. Nausea, vomiting and bloody diarrhoea with severe dehydration and high fever dominate the clinical picture. Death occurs from enteritis, sepsis, toxaemia and disturbances of body fluids in one or two weeks.

3. At lower doses between 2 and 5 Gy, the haematopoietic syndrome occurs. An initial 24-hour period of nausea and vomiting may promptly follow radiation exposure with a latent period of apparent normalcy for the next week. Then general malaise and fever commence

associated with a marked reduction in circulating white blood cells. Petechiae in the skin and bleeding gums soon follow as platelet counts drop. Anaemia develops from the bone marrow suppression and bleeding. According to the dose received and the extent of damage to the bone marrow, recovery may take place in weeks to several months or death occurs from immunosuppression and sepsis or from haemorrhage.

During peacetime conditions and with optimal medical care providing a sterile environment, antibiotics, parenteral fluids, and platelet, white blood cell or whole blood transfusions, as necessary, the haematopoietic syndrome should be survivable but with 8 to 12 weeks of hospitalization. Following a nuclear war such optimal conditions of medical care will not be available.

Even for doses of radiation below which there are few or no symptoms some immunosuppression and a late increase in cancers, particularly leukaemias, will occur.

Among survivors epilation, especially of the scalp, is a specific sign of radiation injury. In Japan hair loss was observed 1 to 4 weeks after the explosions, the peak loss occurring during the second and third weeks (7). It correlated roughly with the estimated exposure dose. Purpura was another common symptom, occurring as early as the third day and reaching a climax after 3 to 4 weeks. Oropharyngeal ulcerations were common.

Partial-body irradiation

Several organs are particularly radiosensitive: the reproductive organs (with resulting transient or permanent sterility by loss of ova and spermatozoa), the gastrointestinal tract, bone (especially growing bone), the lung, the eye (with the risk of cataract starting at low doses of about 2 Gy), and, of course, the bone marrow.

Surface irradiation

Skin is vulnerable to radiation and may be heavily exposed without much exposure to other parts of the body, i.e. in radiation limited to an extremity. The first stage of skin reaction is erythema, with a threshold around 3 Gy for a single dose delivered over a short time. Acute exudative radiodermatitis appears after localized doses of around 12 to 20 Gy and often results in chronic radiodermatitis, which may proceed to ulceration, necrosis, atrophy and scarring. Keloid formation was a common late development among the Japanese exposed to radiation.

The deposition of beta-emitting radioactive fallout on the skin produces so-called beta burns, characterized by erythema and oedema of the skin, blistering, and ulceration. The injuries are localized and transient, but may lead to infection and gangrene, with protracted healing.

Inhalation

Internal radioactive contamination may also result from inhalation of radioactive dust from the fallout. If the dose is high enough, acute local effects, even leading to death, may occur, quite apart from the long-term effects, such as fibrosis and cancer, which can occur from much lower exposures. Radiation can affect the permeability of the membranes of the alveoli (air sacs) allowing fluid to leak into them. Symptoms of coughing, shortness of breath, and feelings of drowning may occur. Sputum may become bloody, alveoli collapse and lungs consolidate. With the associated loss of immunological function infection may intervene with pneumonia developing. The cause of death will be hypoxia, pneumonia and sepsis. The lethal dose to the lung is about 10 to 20 Gy and death may be as late as some months following inhalation (6). Usually the combined exposure of other organs to radiation will worsen the prognosis and may make even smaller doses to the lungs fatal.

Ingestion

Among the many radionuclides present in the local fallout, iodine-131 presents a special risk owing to its accumulation by the thyroid after ingestion. This may lead later to hypofunction of the thyroid and still later to the development of cancer. The effects of ingested radioactive strontium and cesium will also become apparent only later.

Magnitude of the problem

"Limited" nuclear war

There has been considerable doubt whether a limited nuclear war is even an option to the superpowers. Once passions are raised to the point of unleashing nuclear weapons and in the ensuing stress and confusion, it is unlikely that moderation - if such a term can be applied to the use of any nuclear weapons - can prevail. Much more probable would be the firing of all one's arsenal to minimize retaliation and to assure use of one's weapons before they could be destroyed. Nevertheless, there have been several reports to estimate the numbers of casualties to be anticipated were a limited use of nuclear weapons used on strategic targets (7,8). The most recent and comprehensive study by Daugherty, Levi and von Hippel (4) will be cited.

They considered four hypothetical attacks, each involving 1-Mt air bursts over approximately 100 targets: the city centres of 100 of the largest US urban areas; A "worst-case" set of 100 ground zeros deliberately chosen so as to maximize the number of civilian deaths; 101 final assembly factories, selected by a Department of Defence contractor as the highest priority targets for an attack on US military-industrial capability; and 99 key strategic nuclear targets. Further details of these scenarios and effects can be found in Annex 4.

It is apparent from these estimates (16 to 71 million total casualties of which 11 to 66 million were killed according to the "conflagration model") that the casualties incurred even in a so-called "limited" nuclear exchange would be truly overwhelming. Earlier studies drew the same conclusions. The extent of casualties likely from even a very small fraction of today's nuclear arsenals emphasizes the futility of any health system to provide significant medical care.

"Massive" nuclear war

A massive nuclear attack would, of course, create many more casualties. The scenario adopted by the US Federal Emergency Management Agency (CRP-2B) has been used by Abrams (9) to calculate the types of numbers of casualties. In this hypothetical attack on the US with 6559 Mt of nuclear bombs, there would be an estimated 142 million killed (out of a population of some 235 million). Of the 93 million survivors 32 million will have been injured: 23 million of these will have radiation sickness of varying degrees of severity; 14 million will have suffered trauma or burns. With 35% having combined injuries, there would be 9.1 million burn and 9.8 million blast injuries. Among the blast injuries probably 6 million will have open wounds. Although all of the 5.3 million severely burned would warrant hospitalization in peacetime, for the 40%, or 2.12 million, with critical burns, hospitalization would be mandatory. These estimates give the dimensions of the medical problems, as best as we can know them. A major feature of the situation, which differentiates this from all other human disasters in history, is that the total numbers of casualties would likely to be incurred in a brief period of minutes to a few hours at most.

The medical response

Historically medicine has played an important part in military campaigns. This has been particularly the case in recent wars in which the effectiveness of a prompt medical response did much to maintain morale among combat troops. Following a nuclear war, however, all the evidence indicates that medicine will have nothing to offer the injured survivors; the number of casualties will be too great and the remaining medical resources grossly insufficient.

Experience from natural disasters and conventional wars has defined an ideal management of disaster victims. There should be a rapid and effective triage at the site of the disaster, a sorting and classification of casualties according to the severity of injury and the urgency of treatment. Those whose injuries are slight and not incapacitating are shunted aside and ministered to later locally and returned to duty. Those more seriously injured may receive first-aid measures and be moved back promptly behind the lines of combat to receive more intensive therapy before being returned to combat. The most seriously injured may be evacuated from the combat zone for long intensive hospital care. Medical corps men with the combat troops do the initial triage and treatment of minor injuries. Mobile medical field units near the troops provide the second echelon of care with more sophisticated facilities backing them. Evacuation from the combat zone to tertiary hospitals completes the system. Such an organization of medical care with adequate, trained staff, good communication, ample medical supplies, good transportation facilities - and not too many casualties - can function effectively. But even this ideal management has proved inadequate in recent wars with shelling and bombing of civilian population centres with conventional weapons.

There are, however, major quantitative and qualitative differences between a nuclear and a conventional war. The destructive capacity of a thermonuclear bomb is several orders of magnitude greater than that of a conventional bomb. A large number of the casualties surviving the explosion would be affected by radiation damage, about which there is little experience and no specific treatment. Case management would, therefore, be faced with special problems resulting from the enormous numbers of victims, the specific difficulties of triage and treatment, social disorganization, and the inadequacy of resources.

Following a nuclear war the actual possible management of casualties will differ greatly from the ideal. This statement may be tested by an examination of the consequences of any of the scenarios, briefly stated above, whether of a "limited" nature or of a massive nuclear war between the superpowers. Even an attack on all major US strategic nuclear facilities alone, involving 1342 Mt of explosives, would kill some 24 million and injure another 11 million even though most strategic missiles are placed in sparsely populated areas (4).

Since the explosions in each of the scenarios mentioned would occur virtually simultaneously, the problem of trying to provide aid to the injured survivors would be overwhelming even were many urban centres with their medical facilities spared from destruction. Finding the injured among the debris, providing first aid, and then transporting them out of the area of destruction to adequate medical facilities would be very difficult even were such efforts not hampered by radioactive fallout, raging fires, and streets cluttered and obstructed by debris of fallen buildings. No attempt has been made to partition the injured in the scenarios depicting the limited attacks according to their major disorder, but severe burns, trauma, and radiation sickness would, either singly or often in combination, be present. These are conditions which place maximum demand on medical facilities for blood, plasma, other parenteral fluids, surgery, antibiotics, nursing, physician's attention, sterile facilities, and all the other sophisticated resources of modern medicine. Furthermore, these are injuries which each require days of intensive care and weeks to months of hospital care. There simply do not exist the resources to cope with such a burden of casualties.

Abrams (9) has provided a detailed analysis of the medical needs of the injured and compared them to the resources that would be available following a major nuclear exchange between the superpowers. To explore this issue, he used a scenario (CRP-2B) in which the United States was assumed to be exposed to 6559 Mt of nuclear explosives. The targets were military bases and equipment, industrial centres, and population concentrations of 50 000 or more. A worst case situation was considered - that is the kind of conditions that prevailed in Japan in 1945. With 73% of the population living in or near cities with greater than 50 000 inhabitants and approximately 80% of the country's medical resources (hospital beds, personnel, drugs, and medical supplies) also located in these vulnerable areas, it is clear that great damage to populations and to medical resources would result.

Using data provided by governmental agencies, the Hiroshima and Nagasaki experience and certain peacetime accidents, Abrams estimated casualty figures, as mentioned above. Based on these sources there would appear to be 93 million survivors in the United States of whom some 32 million would have been injured: 23 million would have radiation sickness of varying degrees of severity, while 14 million would have suffered trauma and/or burns. On the basis of the Japanese experience 35% combined blast and burn injuries were assumed. Thus a total of 9.1 million burn and 9.8 million blast injuries of whom 4.9 million would have combined trauma and burns. Among the 9.8 million blast victims probably 6 million would have open wounds with hundreds of thousands of head, thorax, abdominal and extremity injuries, he estimates.

The kinds of injuries cited are just those that are most demanding of medical resources. Burns of second or third degree involving 20% of the body surface are generally regarded to be fatal unless given intensive therapy with massive fluid replacement, sterile management, antibiotics, surgical care, and general nursing, dietary and supportive care for periods of weeks in the hospital followed by lengthy rehabilitation. Even with today's sophisticated medical care there will be considerable mortality, especially among the elderly.

The numbers and severity of the burns will not be limited to those unfortunates who are exposed directly to the initial thermal pulse but to the many more who will be casualty victims of the mass fires, as described earlier. Abrams estimated (9) that some 2.12 million of the burn casualties would fall into the critical category requiring intensive prompt medical care in order to survive. In the US there are some 135 burn centres with a total of 1400 beds for the proper management of these burn casualties even were none destroyed; it is evident that the great majority would not receive adequate care and would succumb painfully in time from their injuries.

Trauma will pose a problem of similar dimensions. The estimated 6 million with open wounds would not be able to receive the prompt care that is necessary to stop bleeding, administer fluids, clean and close wounds, prevent and treat infections. Even were all the hospitals with their medical supplies and staffs intact, any meaningful treatment of such numbers of casualties created over such a short time would be impossible.

The concentration of physicians, nurses, and allied health workers in urban areas will result in a disproportionate loss of trained personnel. The same situation applies to hospitals and medical supplies. To illustrate the formidable medical problems that even a single megaton air explosion over a metropolitan area could create, estimates have been made for an attack on Boston, USA. With a population of 2 844 000, the US Arms Control and Disarmament Agency estimated there would result 695 000 direct fatalities and 735 000 surviving injured. At the time of these estimates (1979) there were 5186 physicians in Boston. If physician casualties occurred in the same proportion as in the general population, then 50% of physicians (2593) would be potentially available to treat the injured. This would result in some 284 injured persons for each available physician. (Actually the Commissioner of Public Health estimated that 80% of physicians and 70% of nurses would be casualties making the ratio of injured persons to surviving health workers even worse.)

The situation with hospital beds would be as bad. Boston has 12 816 hospital beds, but they are mostly in the urban target area, so that of the 48 acute care hospitals, 38 would be destroyed or badly damaged. Thus 83% of the beds would be destroyed leaving some 2135 beds for the care of 735 000 seriously injured survivors. Of course, if only one city were destroyed, help could come from the outside. Clearly the numbers needing medical care, however, even with one city attacked, would overwhelm the medical facilities and resources of the entire country. In the event of actual hostilities the attack would not be limited to a single city.

The most extensive and detailed study of the health effects of a nuclear attack on a major urban centre has been recently made of London (10). Five scenarios of nuclear attacks were considered:

Scenario 1 - A nuclear attack limited to nuclear targets in the United Kingdom with 8.0 Mt (38 weapons) exploded. London could escape damage.

Scenario 2 - As above plus military command and control centres with 13 Mt (56 weapons) exploded on the United Kingdom, including 2 Mt (7 weapons) on London.

Scenario 3 - As above plus United Kingdom naval and air power with 31 Mt (207 weapons) exploded on the United Kingdom, including 1.35 Mt (9 weapons) on London.

Scenario 4 - As above plus military, industrial, and urban targets with 65 Mt (241 weapons) exploded on the United Kingdom, including 5.35 Mt (13 weapons) on London.

Scenario 5 - As above but with 90 Mt (266 weapons) exploded on the United Kingdom, including 10.35 Mt (18 weapons) on London.

Greater London has 270 hospitals with 57 620 beds. Table 1 shows the percentage damage to hospitals and hospital beds that were estimated would occur with each of the attack scenarios.

TABLE 1. PERCENTAGE DAMAGE TO HOSPITAL BEDS IN LONDON

Scenarios	2	3	4	5
Damage	Beds	Beds	Beds	Beds
Severe to moderate	3	9	67	81
Light	3	12	15	13
Undamaged	94	79	18	6

From (10), p. 166

Table 2 shows the remaining uninjured medical and auxiliary staff estimated following the same nuclear attack scenarios.

TABLE 2. SURVIVORS AMONG MEDICAL AND AUXILIARY STAFF IN LONDON

Type of personnel	Pre-war numbers	Numbers left uninjured in scenarios			
		2	3	4	5
Hospital doctors	9 400	7 940	7 240	1 420	280
General practitioners	4 054	3 430	3 120	610	120
Dental practitioners	2 790	2 360	2 150	420	80
Nurses	67 330	56 900	51 800	10 200	2 000
Ambulance personnel	3 525	3 000	2 710	530	100

From (10), p. 167

The report (10) indicates that most previous studies had assumed attacks of about 200 Mt or more to strike the United Kingdom rather than the maximum of 90 Mt considered in scenario 5. Yet the latter scenario would suffice to kill or injure half the population of the United Kingdom, and 97% of Londoners.

Not only hospitals, physicians, nurses, all other health professionals and technicians would be in short supply, but antibiotics, parenteral fluids, bandages, surgical equipment and all the sophisticated medical technology would be similarly lacking. The problems facing surviving medical workers would be overwhelming. They would not only lack nearly all essential facilities for care of the injured, but would need to find the injured among the debris of collapsed buildings and houses, transport them through streets clogged with fallen structures, raging fires, and contaminated with radioactivity, probably with little if any transportation available and without electricity or fuel, while having major worries about the fate of their own loved ones and themselves.

Disruption of communications, locally and nationally, would contribute to the general chaos following a nuclear attack. Even without the deliberate creation of an electromagnetic pulse, EMP, to destroy electronic equipment and disrupt communications (see Annex 1 for details), the local destruction of telephone wires, electric power supply, and radio facilities would leave survivors uninformed of happenings. Lack of news and communication would add to the other real anxieties of survivors, increase rumours, and lead to counterproductive individual and group behaviour. It would make impossible any semblance of coordinated social effort to provide help to the millions of immediately injured survivors.

Shelters

It is always rational to take measures to protect oneself from potential injury if one cannot prevent or avoid the injurious event. Thus it is not surprising that much effort has gone into seeking means to find shelter from the effects of thermonuclear explosions. The problems of creating shelters from blast, fire and radiation differ. Short of very deep, very hardened subterranean shelters there can be no shelter from blast effects in targeted areas. The expense of providing such shelters for any significant portion of the population is prohibitive. Since the majority of the populations of the USSR, USA, and Europe live in or near to cities, most persons reside within potential target areas. In the USA, for example, 73% of the population lived in or near cities with more than 50 000 population in 1981 (9).

Underground shelters which may provide some modicum of protection from the effects of blast may prove, however, death traps from the ravishes of fires. This was the case apparently in Hamburg and Dresden where only those who escaped from the bomb shelters within the fire zone survived. Those who remained were asphyxiated by carbon monoxide, carbon dioxide, and other toxic pyrogens, or roasted in their shelters. It is now appreciated that superfires will engulf most urban targets so that conventional bomb shelters of World War II vintage would be worse than useless in protecting against fires.

It is only as protection against radiation from local fallout in areas outside of the blast and fire zones that shelters would seem to have value. There are three different factors that interact to determine the health risks to humans from radiation exposure: the cumulative exposure, the biological repair rate, and the intensity of exposure per unit of time (the dose rate). Unless the cumulative radiation dose has reached the lethal level, it is continuously being reduced, although not totally erased, by the intrinsic biological repair mechanisms. The repair processes may correct a major portion of the damage to the DNA over time leaving some residuum which is irreparable. Shelters can significantly reduce the cumulative dose based on the fact that the intensity of radioactivity decays with time and is reduced by shielding. The protection factor (PF) is the ratio of the radiation level outside the shelter to that inside and reflects the mass (density and thickness) of the shielding material. For the same material the PF will differ depending on the kind of radiation involved. Neutrons and initial gamma radiation are more penetrating than are the gamma rays from fallout so PFs will be lower for these radiations. Indoors in a single family frame house the effective PF from fallout gamma rays might be 3 above ground and 10 in a fully-below-ground basement (5). Much larger reductions in exposure due to shielding are discussed in the civil defense literature (13) but, for PFs greater than 10, the radiation dose of the population will be determined primarily by the amount of time people are forced to spend outside. Alpha-particles, from plutonium or other actinides, have a very short range, and unless they are within a few centimetres of the skin, they will not produce any external dose. Beta-particles, emitted from most fission products, have a longer range, about 1 m in air, but a thickness of a few millimetres of most materials will stop them. Ordinary clothing is sufficient to protect the body from alpha- or beta-particles, so they are hazardous chiefly if ingested or inhaled.

The health problems encountered by survivors in fallout shelters are not, however, trivial. If the site of the shelter is exposed to high levels of fallout radiation, individuals may have to remain two to three weeks within the shelter before attenuation of the radioactivity in the surroundings makes it safe to emerge from the shelter even for short intervals. During that time sanitation can become a serious problem with crowding, disposal of excreta, vomitus, and corpses. Care of burn and blast injuries and of the communicable respiratory and enteric illnesses, which will almost invariably spread among the crowded inmates, will cause serious logistic and psychological problems. Food supplies may become scarce unless great care had been given in stocking the shelter for whatever number of persons might actually crowd into it. Similar problems might well affect the water supplies. Unless the shelter had its own independent air and water supplies, it is likely that, within a relatively short time, most of the population in shelters would be drinking water and breathing air contaminated with radioactivity.

The psychological problems of the survivors in shelters could be overwhelming - see Annex 7. The crowded, cramped quarters, the sights and odours from excreta and from injured and dying individuals would alone create strong revulsion. Worries about family and loved ones, from whom they have been separated, anxieties and hostilities regarding present and future conditions may make the incarceration intolerable so that individuals will be leaving the shelters prematurely, thus increasing their cumulative radiation dose. If the days must be spent in the dark because of power failures, mental health will undoubtedly deteriorate rapidly.

All these potential health problems related to the use of shelters have reduced the enthusiasm of most individuals for fallout shelters. As an alternative, planners have introduced the possibility of crisis relocation, i.e., the evacuation of populations from urban areas that are thought to be likely targets in the event of a nuclear attack but before hostilities actually commence. How accurately this prodromal period can be recognized in time to complete evacuation prior to an attack, the effect of the obvious movements of populations on an enemy's timing of an attack, the ability to move large urban populations without intractable traffic jams occurring, the ability of the countryside to absorb large numbers of city dwellers, the possible retargeting of nuclear missiles and many other logistic and psychological potential problems make crisis relocation of populations of dubious merit realistically despite its theoretical potential. The British Medical Association has concluded that both shelters and evacuation strategies are likely to be futile (11,12).

All civil defense proposals distract from the one overridding issue, namely, that the human health effects of nuclear war will invariably be so overwhelmingly disastrous that only prevention of nuclear war must be sought, not futile and illusory means to try to minimize the resulting casualties.

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ANNEX 7

INTERMEDIATE AND LONG-TERM HEALTH EFFECTS

by

A. Leaf

Fallout and radiation effects

Fallout occurring more than 24 hours following an explosion is called delayed fallout. After 24 hours the radioactivity will have decayed so that only 20% of the initial total dose remains. Considerable exposure could still result from nuclides with long half-lives for distances of thousands of kilometres downwind from the explosion sites and still contribute significantly to the total accumulated radiation dose.

The greatest potential hazard comes from iodine-131, which has a half-life of about eight days so that about four weeks are required for its activity to decrease tenfold. Iodine-131 enters the body primarily by ingestion of milk from cows. The route from bomb, to atmosphere, to grass, to cow, to milk, to man is surprisingly rapid and milk with high concentrations of iodine-131 has been detected thousands of kilometres from test explosion sites.[1] In fact it was the major stimulus for the cessation of atmospheric testing by the USA and the USSR. The radioactive iodine is concentrated in the thyroid gland where its radiation can destroy thyroid tissue producing hypothyroidism and late thyroid cancer. Prophylactic ingestion of iodine as potassium iodide or Lugol's solution before exposure to radioactive iodide can block significant accumulation of the latter in the thyroid. The radioactive iodine will then be excreted in the urine, minimizing the radiation exposure.

Radioactive material released by air bursts from large bombs may be lofted into the stratosphere from which the fine particulate matter may descend to earth slowly over months or years. This is the so-called "global" fallout, or late fallout. By the time the global fallout reaches the ground its radioactivity will have decayed to a small fraction of its initial levels. Nevertheless, its long-lived radioactive isotopes can constitute a considerable hazard to man. The height to which the radioactivity is raised depends on the yield of the explosive. With the smaller bombs being made today, the radioactivity is likely to be confined to the troposphere and fall to earth earlier with a larger load of radioactivity, the so-called intermediate fallout. Within the upper stratosphere (above 21 km) there is fairly rapid transfer of radioactive material between the hemispheres, making the fallout truly global.[1] Radioactivity below this height is confined largely to the hemisphere of its origin as exchange between the hemispheres is very slow (half residence time about five years).

The major effect of the long delayed descent of global fallout is that the short-lived nuclides will have decayed and the radioactivity that does reach the ground is so weakened that the external hazard from gamma-rays no longer predominates over the internal hazard from beta-rays.[1] The main internal hazard then arises from the ingestion of radioactive material which enters the food chain after being deposited on the ground.

Strontium-90 and caesium-137 are the nuclides of greatest concern. Their long half-lives (some 29 and 30 years, respectively) make the long delay in their deposition reduce their activities only very little. Their fission yields are high and since they are products of gaseous nuclides, a greater proportion of them is present in the delayed fallout than would be expected from the fission yield.[1] Strontium mimics calcium in the body and is deposited in bone and teeth. This places its radiations close to the highly radiosensitive bone marrow. Caesium in the body is distributed as is potassium and, therefore, accumulates within all cells bringing it in close juxtaposition to nuclear DNA. The beta- and gamma-rays emitted from both nuclides can deliver considerable internal doses.

Because of their cationic nature they are trapped in the superficial layers of the soil from which they are taken up by plants which are then eaten by animals. Man then consumes the radioactive nuclides with vegetables and meats. Strontium-90 reaches man mainly through milk and meat, whereas caesium-137 enters through fish, vegetables and other plants. Both elements probably contribute later to the increased incidence of cancers. Once internalized there is no rapid or efficient means of ridding the body of this radioactive burden. Increasing the rate of turnover of calcium and potassium in the body through increased intake of these elements, with or without diuretics, can hasten their excretion modestly. But the pools of calcium and potassium in the body, with which the nuclides mix, are so large and closely regulated that attempts to hasten their excretion from the body would require long and persistent efforts which would be most unlikely to occur with the other stresses and distractions of the post-attack period.

Immune suppression

It is well appreciated today that the immune system protects us from infectious organisms, foreign substances, and tumour cells. It recognizes self from non-self and attacks and eliminates the latter from our bodies. Both humoral and cellular immunity are involved in these protective activities. Human lymphocytes serve both the humoral and cellular activities through differentiation into B-lymphocytes and T-lymphocytes. B-lymphocytes are responsible for humoral immunity as they are the precursors of antibody-secreting plasma cells. T-lymphocytes control cellular immune responses against certain bacterial infections and many viral and fungal infections, as well as resist malignant tumour cells.

T-lymphocytes are subclassified into: (1) effector T-lymphocytes which respond to specific antigens in cell-mediated immune activity, such as elimination of malignant tumour cells and viral infected cells; (2) helper T-lymphocytes which regulate the activation of effector T-lymphocytes and the conversion of B-lymphocytes into mature antibody-secreting plasma cells; (3) suppressor T-lymphocytes which prevent the interaction of helper T-lymphocytes with B-lymphocytes, and inhibit B-lymphocytes from differentiating into mature antibody-secreting plasma cells. It is largely through interfering with the normal interactions of these T-lymphocyte subclasses that effects of thermonuclear explosions directly or indirectly suppress the immune response.

Greer and Rifkind[2] reviewed the potential effects of a nuclear war to impair the normal immune response. They indicated that there are several features of nuclear warfare that adversely affect the immune response: (a) ionizing radiation, (b) hard ultraviolet radiations (UV-B), (c) burns and trauma, (d) psychological factors, and (e) malnutrition.

(a) Ionizing radiation

The effect of ionizing radiation to impair function of the immune system is well substantiated from animal studies and from clinical observations on the use of radiation therapy in humans. Virtually all elements of the immune system are affected by irradiation, but not equally. At high radiation doses all elements of the immune system are impaired, resulting in the development of sepsis from endogenous enteric organisms, which in the immunocompromised state become invasive and rapidly lethal.[46] At lower radiation doses differences in radiosensitivity of cell populations and subpopulations of the immune system become apparent. Experiments on mice demonstrate the following decreasing gradation of sensitivities of immunocompetent cells: immunocompetent cell precursors, B-lymphocytes, and T-lymphocytes.[47] For all cell types, the minimal damaging dose of radiation is less than 1.0 Gy.

Some studies suggest a possible temporary enhancement of antibody synthesis in response to antigenic challenge after exposure to rather low doses of 0.2-0.5 Gy.[48] This apparent stimulation appears to result from radiation damage to suppressor T-lymphocytes.[47]

The recovery of immunocompetent cells from radiation injury occurs at different rates, the slowest being that for T-cells, with a higher rate for B-cells which produce immunoglobulins.[49] Therefore, during the development of acute radiation sickness and after clinical recovery, there is an imbalance of the immunocompetent cells, while normal antibody synthesis and cellular immunity require them to function in a strict proportion.[47]

The antibacterial and antiviral effect of antibodies is closely associated with complement and phagocytosis. Of importance for the bactericidal action of serum are lysozyme and properdin, the latter being an activator of the alternative complement pathway. Serum bactericidal activity is reduced after exposure to doses below 1.0 Gy. Lysozyme and properdin syntheses exhibit the greatest radiosensitivity; the concentration in the blood serum may begin to alter even following exposure to 1.0 Gy. By contrast, during the first days post-exposure, an increased complement content is observed.[50] Because, however, of a reduced properdin level at that time, normal biological utilization of the complement and its protective function are disturbed.

A high radiosensitivity of phagocyte migration and phagocytosis has been observed, with initial changes caused by doses of about 0.1-1.0 Gy.[47] The endocytotic function of phagocytes is more radiation-resistant, but microorganisms captured by them may not be killed and have the possibility of intracellular existence. The same is true for the reticulo-endothelial cells of the bone marrow, spleen, and lymph nodes.

Animal experiments thus show that acute exposure even to sublethal radiation doses results in damage to B- and T-lymphocyte immune systems and in a reduced function of the organism's nonspecific resistance. As a consequence, the number of microorganisms in the intestines, oral cavity, on the skin, and elsewhere increases.[51,52] Infectious diseases in an irradiated individual are characterized by an accumulation and invasion by microorganisms of the blood stream and internal organs causing necrosis of tissues. These changes occur at doses of about 0.1-1.0 Gy causing a reduction of resistance, so that previously harmless infectious challenges become fatal.

In humans a similar reduction in immunity occurs with radiation. An increased incidence of viral infections (herpes zoster and varicella) is seen in patients with Hodgkin's disease who are subjected to extensive radiotherapy.[3] The antibody response to pneumococcal vaccine is markedly impaired by total lymphatic radiation, and the ability to respond to immunization may not return for several years.[4] Impaired T-cell function has been noted in some Japanese atom bomb survivors 30 years after exposure.[5]

The mechanism of the immune suppression from ionizing radiation appears to be by a reduction in T-lymphocyte function, specifically a reduced ratio of helper to suppressor T-cells.

(b) Hard ultraviolet radiation

It is only recently that the immunosuppressive effect of ultraviolet light has been recognized. Studies in animals show that exposure to ultraviolet radiation, particularly to UV-B (wavelengths ranging from 290 to 320 nm), results in a T-cell mediated immunosuppression characterized by a predominance of suppressor T-cells.[6] The energy in UV electromagnetic waves is non-ionizing in contrast to the much higher energy X- and gamma-rays. Nevertheless, like X-rays, UV will reduce helper T-cells[7] and increase suppressor T-cell activity to impair defence against tumours.[8,9]

Several studies[10-13] have indicated that the large amount of oxides of nitrogen that would be lofted up to the stratosphere following megatonnage range thermonuclear explosions would destroy the ozone layer in the lower stratosphere which normally absorbs the incident hard UV and prevents it from reaching the surface of the earth. The reduction in the protective ozone is dependent upon the amounts of nitrogen oxides formed, which are determined by the total megatons exploded and the height to which the nitrogen oxides are lofted. In general, maximum ozone depletions are found to range up to perhaps 50% for scenarios of some 5000 Mt including high-yield weapons; the peak depletion is reached in six to 12 months, and a sustained depletion of 10% or more can persist for three to six years. On the other hand, with only low-yield weapons, the peak ozone depletion may never reach even 10%. The increases in ultraviolet radiation at the ground arising from reductions in total ozone depend on latitude and season as well as on any absorption and scattering by intervening clouds of smoke, dust, and ice. Calculations indicate that the reduction in ozone following a 5000 to 10 000 Mt exchange would be sufficient to allow a fivefold or more increase in UV-B reaching the earth's surface.[12] This would be sufficient to impair the immune system, cause an increase in skin cancers, and damage eyes and plant life.

(c) Burns and trauma

Major burns and trauma can result in severe immunosuppression. Burns and wounds also serve as obvious portals for entry of infections. Serious infections are all too common accompaniments of burns and wounds, and gram-negative sepsis is the most common cause of death following these injuries after the initial shock phase is survived.

Reduced T-lymphocyte activity is thought to be largely responsible for the immunosuppression induced by burns.[14,15] The number of T-lymphocytes in the blood is reduced and may remain low for a month following the burn.[53,54] The functions of helper and effector T-cells are most depressed, and this in turn leads to a shift in the balance of helper and suppressor T-cell subpopulations. A low helper to suppressor T-cell ratio has been noted in patients soon after burn injuries of greater than 30% of body surface area. Sepsis is most likely to occur when suppressor T-cells are at a maximum, seven to 14 days after the injury,[16] and a reduced ratio of helper to suppressor T-cells in this setting predicts a low survival.[17]

The B-lymphocyte is considered to be more resistant to thermal radiation than is the T-lymphocyte. The number of circulating T-lymphocytes is reduced during the first 24 hours after the burn and then is rapidly restored.[54,55] The functional activity of the B-cells in burned patients, however, is disturbed.[56,57] This is indicated by a reduced immunization response, with lower concentrations of immunoglobulins G in serum and lower levels of immunoglobulins M and A.[54] Also with burns, the humoral factors of nonspecific resistance are lowered: the C_1, C_2, C_3, C_4 and C_5 components of complement,[58,59] properdin and lysozyme,[54] phagocytosis and the digestive activity of phagocytes.[54]

With trauma the pathology of the immune system is characterized by reduction of T- and B-lymphocytes during the first day following injury. On the third to fifth days the number of cells approaches the initial level or even exceeds it. The number of T-cells is the quickest to recover, while the B-cells return more slowly. Restoration of the numbers of immunocompetent cell types is not, however, accompanied by restoration of immunological function. There are, therefore, two stages of immunodeficiency with trauma; the first is characterized by a reduction in numbers of cells, the second by the suppression of their functional activity.[60] The duration of the first stage is several days, and of the second, about one month. The function of helper and effector T-cells is reduced during that period.[61] The concentration of immunoglobulin M is decreased in the blood serum; lesser variations in the concentrations of immunoglobulins A and G also occur.

The nonspecific immune factors are also functionally impaired after trauma as manifest by the lowering of serum bactericidal activity attributable to reductions in concentrations of properdin, complement, and all stages of phagocytosis.[62]

The development of immunodeficiency and suppression of the factors affording nonspecific resistance in burned and traumatized persons result in an increase in sensitivity to infections generally. Coliform bacilli, pseudomonas, and staphylococci are the most common causes of sepsis and death in these patients who survive the initial state of shock.[63,64]

(d) Psychological factors

Stress, depression and bereavement would be widespread among survivors of a nuclear war. Clinical studies suggest that psychological factors can influence susceptibility to infections and delay recovery from upper respiratory diseases, influenza, herpes simplex lesions, and tuberculosis.[18] Bereaved spouses and patients with primary depressive disorders have been shown to have reduced T-cell function.[19-21] Furthermore, clinically depressed patients have been shown to have an increased mortality rate, cancer incidence, and frequency of certain viral infections.[21,22] Once again T-cell disturbances appear to mediate the abnormal immunological state. The concentration of the components of complement in blood and of other factors of nonspecific resistance is also lowered under conditions of constant psychological stress in humans.[65,66]

(e) Malnutrition

As discussed by Scrimshaw,[23] Leaf,[45] and recently by Harwell & Hutchinson,[24] food shortages, malnutrition and starvation are highly probable outcomes of a major nuclear war. Animal studies have shown impaired immune functions associated with specific dietary deficiencies. Deficiencies of vitamins A, B_{12}, riboflavin, and iron all have been associated with reduced T-lymphocyte function or increased susceptibility to infections.[25,26] Abnormalities of T-cell function have also been noted in pyridoxine and zinc deficiencies.[27] Disturbances of antibody synthesis have been observed with deficiencies of folic acid, pantothenic acid, and pyridoxine.[67]

Nonspecific factors of resistance are also affected by dietary deficiencies.[68] Serum bactericidal activity is lowered in deficiencies of vitamins B_1, B_2, B_{12}, A and E. Of the bactericidal factors in serum, complement is the most sensitive to vitamin deficiency. Complement activity of serum is reduced in deficiencies of vitamins B_1, B_2, B_6, and with deficiency of folic acid and pantothenic acid.[68] Vitamin K deficiency lowers levels of properdin; vitamin A and B_{12} deficiencies reduce lysozyme levels in serum.[69] Phagocytic cell functions are also sensitive to vitamin C, B_1, B_2, A, E, folic acid and biotin deficiencies.[68]

It is well known that individuals with protein-calorie malnutrition have a high incidence of many infections, notably with mycobacteria, viruses, and fungi. They develop lymphopenia and reduced cutaneous hypersensitivity to antigenic challenges.[28] Among populations suffering protein-calorie malnutrition, there is a high mortality from infections that would cause only minor illness in well-nourished individuals.[29]

(f) Synergism of effects

Each of the factors discussed - ionizing radiation, increased UV radiation, burns and trauma, psychological factors, and malnutrition - would be prevalent after a major nuclear war. As Greer and Rifkind[2] indicated, each affects the immune system so as to increase the incidence and severity of infectious diseases.

It is probably through their effects on the immune system, furthermore, that combined injuries of radiation with burns or trauma are synergistic. The combination of even low-dose radiation and other injuries may yield synergistic and disastrous effects. This was shown experimentally in animals some years ago by Brooks[30] - see Fig. 1. He observed no mortality in dogs exposed to a whole-body radiation dose of 100 rads and only 12% mortality from a 20% body-surface, second-degree burn. When the two injuries were combined, however, the mortality rate increased to 73%. Death results from inability of the irradiated animal to fight sepsis because of the impaired immune response. After a nuclear war with a 5000 to 10 000 Mt exchange, there would be millions of people in the Northern Hemisphere subjected to sublethal radiation from fallout who would have increased susceptibility to many infectious diseases that are likely to be rampant at just that time, as well as the many suffering from associated burns and trauma.

Infectious diseases

The intermediate period following the attack will include the shelter period, when survivors attempt to sustain themselves in fallout shelters amid intensive radiation with fires still smouldering about them and probable deprivation of food, water and sanitation within the shelters. This intermediate period will blend into the late period characterized by efforts to survive in a chaotic primitive economy and to rebuild some semblance of social and economic order. During both the intermediate and late periods, infections are likely to be a major cause of morbidity and mortality. Abrams[31] has considered the problems of infection in the intermediate post-attack period. The problem of infection during the crowded, unsanitary stay in shelters has been discussed. Once radioactive decay has made it safe for people to leave shelters even for a few hours daily, conditions favouring spread of communicable diseases will continue. Sanitary water supplies, properly prepared and refrigerated food, sewage and waste disposal and treatment will be seriously compromised or totally lacking. Enteric diseases to which people are likely to be highly vulnerable will spread: infectious hepatitis, *E. coli* infections, salmonellosis, shigellosis, amoebic dysentery, typhoid, and even cholera are the enteric diseases that may be expected. These are the diseases that have marched in the wake of wars in the past and have plagued refugee camps recently, but conditions after a nuclear war would be more conducive to their occurrence than any prior known condition.[32]

There will be millions of human corpses left in the wake of a nuclear war; these will post a further threat to sanitation. With all the other survival problems to cope with, it is not likely that burial or cremation will quickly remove this source of infection and contamination. Rats and other scavenging animals are likely to be the major undertaker force.

Insects generally are much more resistant to radiation than are humans, animals, and birds. Thus few of their natural enemies will remain, but the lack of sanitation and undisposed corpses will feast them. An explosion of flies is anticipated as well as of other insects, and these will serve as transmitters of the enteric diseases, but also such diseases as typhus, malaria, dengue fever, and encephalitis will appear and increase.

Other infectious diseases that exist among us but are held in check by good sanitation, nutrition, housing, and medical treatment will increase under post-attack conditions: tuberculosis, hepatitis and all enteric diseases, pneumonias (both viral and bacterial), influenza, meningitis, whooping cough, diphtheria, streptococcal infections, poliomyelitis, tetanus and many others that still unfortunately occur in some parts of the world and that are fostered by poor sanitation, malnutrition, crowding, and lack of immunization and medical care. Other epidemic diseases, that have been essentially suppressed, will return, such as cholera, malaria, plague, yellow fever, and typhus. Infections will take a heavy toll on survivors, even as they had from antiquity until the present century, and in the absence of antibiotics and other medical treatments, and in the presence of widespread immune suppression, their lethal effects should be anticipated as devastating.[31,32]

Food supplies and starvation in the aftermath of a nuclear war

Hunger and starvation would plague the survivors of a nuclear war. Millions would starve to death in the first few years following an all-our nuclear war.[23,24,45]

World food reserves, as measured by total cereal stores at any given time, are frighteningly small should production fail. They have amounted in recent years to about two months' supply of cereals at present consumption rates.[33] The stores fluctuate seasonally, being largest immediately after harvest and gradually decline, reaching their nadir just prior to the next harvest. In the United States, food stores would feed the population for about a year.[34] Portions of the stores, however, would be destroyed by blast, fire, or contaminated by radioactivity. Crops in the field would be damaged to an unpredictable extent.

More importantly, the means to transport the food from sites of harvest or storage to the consumers would no longer exist. Transportation centres would be prime targets of an aggressor intent on destroying the industrial competence of an opponent to sustain a war. Roads, bridges, rail and port facilities are likely targets. Foods that appear in our markets are not grown locally. In Massachusetts, for example, more than three-quarters of the food arrives from out of state by truck or rail, and supplies on hand would last only a few days. In a nuclear attack, most of these supplies in urban areas would be destroyed.

In the developed countries food no longer is carried by farmers to nearby markets. The northeastern United States, for example, is particularly vulnerable to a breakdown in transportation of foods since some 80% of its food is imported, but other sections of the country would fare only little better. Eighty-five per cent. of US corn is grown in 11 midwestern states; one-sixth of the wheat is grown in Kansas alone, and most of the rest is grown from Texas north to Minnesota, North Dakota, and Montana, with some in Michigan, the Pacific Northwest, and New York, but only a negligible amount in the northeast; two-thirds of the soy beans are grown in the Great Lake States and the corn belt; rice is grown mainly in Arkansas, Louisiana, Texas, Mississippi, and California; fruit and vegetable production is nearly as regionally concentrated.[23] With key railway links and highways destroyed and gasoline and diesel fuels unavailable, what crops survived could not be moved to places where needed. Conditions in other industrialized countries are very similar.

Food is supplied today in the developed countries by a complex network of enterprises that involve not only farming, animal husbandry, and fishing, but also farm machinery, pesticides, fertilizers, petroleum products, and commercial seeds. It utilizes sophisticated techniques and technology to handle the food that is produced. These include grain elevators, slaughter houses, cold-storage plants, flour mills, canning factories, and other packaging plants. It also includes the transportation, storage, marketing, and distribution of foods through both wholesale and retail outlets. A breakdown in this vast agri-industry would be an inevitable consequence of a nuclear war. Without the means to harvest, process, and distribute what crops survived, there would be much spoilage.

So much of the social and economic structure of society as we know it would be destroyed that relationships which we take for granted would disappear. Money would have little or no value. Food and other necessities would be obtained, when available, by barter. More likely, as people became desperate with hunger, survival instincts would take over, and armed individuals or marauding bands would raid and pilfer what supplies and stores existed.

The early death of millions of humans and animals would not sufficiently compensate for the reduced available food supplies. Stocks of fuel, fertilizers, agricultural chemicals, and seed would soon be exhausted. Not only functioning tractors, but also beasts of burden, would be in short supply, and food production would become very labour-intensive - a throwback to the primitive, labour-intensive farming methods. The doubling of crop yields per hectare that has occurred over the past 30 years is partly the result of improved seeds, but also of the energy subsidies to agricultural production in the form of fossil fuel products. The amount of diesel fuel currently consumed in raising crops in developed countries is approximately 100 litres per hectare. In developing countries, this figure may be zero to 10 litres. Once local centres of supply became depleted in combatant countries, it would be difficult to obtain fuel for agricultural purposes. In non-combatant countries, supplies of fuel that were imported would not be forthcoming, and even fuel from sources within a country may fail to be delivered. In addition to the direct energy subsidies to operate and manufacture farm machinery, fertilizers are extremely important in determining high levels of crop productivity largely in the developed countries. For example, in 1983 in the US, nitrogen applications for maize had reached a level of 152 kg per hectare, typical for developed countries. Wheat and rice production also received relatively heavy applications of fertilizers.[24]

The resistance of insects to radiation and the lack of pesticides would further reduce the yield of crops. Fields downwind from targeted sites are likely to be made unusable by radioactive fallout for weeks to years.

There is likely to be a deterioration of the quality of the soil following a nuclear war. Death of plant and forest coverage due to fire, radiation, lack of fertilizers, and the probable primitive slash-and-burn agricultural practices of survivors will leave the soil vulnerable to erosion by wind and rain. Desertification and coarse grasses and shrubs would render agriculture and animal husbandry less productive.[35]

Water supplies may be seriously reduced. Dams and large irrigation projects may well be targeted, most certainly in a counter-value attack. Reduced rainfall, predicted in most models of the climatic effects of a nuclear war, would interfere with agricultural productivity. Radioactive fallout will contaminate reservoirs and surface waters with long-lived radioactive isotopes, primarily strontium-90 with a half-life of 29 years and caesium-137 with a half-life of 30 years. These elements in the ground water are soon taken up by plants entering our food chain. Eventually they will concentrate in humans: the strontium accumulating in bone and the caesium within cytoplasm where they contribute to the long-term burden of radioactivity in survivors.

Not only will food be scarce, but it is likely to be unsanitary as well. The destruction of sanitation, refrigeration, and food processing methods, especially in remaining urban areas or population centres, would result in contamination of food with bacteria, particularly with enteric pathogens. Spoiled meat, carion of domestic animals and even of human corpses, is likely to be eaten by starving persons, as has happened in major famines in the past.[23] Pathogens to which civilized humans have lost resistance would be acquired from foods and water contaminated by excreta and by flies, other insects, and rodents which are likely to proliferate in the aftermath of a nuclear war.

A reduction in average temperature by even a few degrees at the earth's surface, due to soot and dust in the atmosphere absorbing solar energy, would shorten the growing season in northern latitudes and markedly reduce or prevent maturation and ripening of grains that are the staple of our diets. But we have been hearing the debates not of whether some cooling would occur, but how many tens of degrees the temperature would be reduced and for how long. During most of the growing season a sharp decline in temperature for only a few days may be sufficient to destroy crops.[24]

Chronic reductions in average temperature during the growing season of slightly more than 2°C for spring wheat and 4°C for barley would result in total elimination of these crops from production in Western Canada, irrespective of any change in light or precipitation. Only slightly greater temperature reductions would eliminate these grains from any mid-latitude growing areas. The growing season decreases at a rate of about 10 days per degree C decrease in average temperature at the same time that the maturity requirements for wheat and barley are increased by four to six days. These two opposing factors lead to an insufficiently long growing season compared to what crops require, and total crop loss would result.[24]

Combinations of temperature and light reductions are synergistic, with the combined sensitivities being highly dependent on location and timing of the onset of a climatic perturbation.

Since most of the wheat and coarse grains are grown in the temperate regions of the Northern Hemisphere, which would be the zones most affected by climatic cooling, it is evident that a nuclear war, especially during the spring or summer, would have a devastating effect on crop production and food supplies for at least that year. The United States and Canada are literally the bread basket for the world; North American total cereal production in 1982 was 387 million metric tons, of which 123 million metric tons or nearly one third were exported.[33]

After the atmospheric soot and dust finally clear, the destruction of the stratospheric ozone would allow an increase in hard UV-B rays to reach the earth's surface. In addition to direct harmful effects to skin and eyes of humans and animals, these hard ultraviolet rays are damaging to plant life and would interfere with agricultural production. If the oxides of nitrogen increased in the troposphere, there might occur an actual increase of ozone at low levels of the atmosphere.[36] Such an increase in tropospheric ozone is anticipated as nuclear bombs become smaller; that is, decrease in size from megaton to tens to hundreds of kilotons. Ozone is directly toxic to plants.

If temperatures fell to freezing or near freezing as postulated in some scenarios, then the direct effects of cold could have serious consequences to human survival, especially if the low temperatures affected regions not accustomed to cold. When core body temperature begins to fall, the body responds by shivering which increases heat production. This and the increased activity resulting from attempts to keep warm will increase caloric requirements. Thermogenesis resulting from increased sympathetic nervous system activity on the human equivalent of the "brown fat" of lower animals also leads to increased caloric expenditure. The effect of cold, even if not directly so pronounced as to be lethal, can still increase caloric needs just at a time when food supplies are very constrained.

Hunger and starvation would not be limited to the combatant countries alone or even to just the Northern Hemisphere. It will be truly a global occurrence. Even without the possible climatic effects of a "Nuclear Winter" spreading to the Southern Hemisphere, millions will die in non-combatant countries of starvation. Today a large portion of food exports goes to parts of the world where, even with grain imports, millions of people are suffering undernutrition and hunger.[37]

The number of undernourished persons in developing countries is staggering, approaching one-quarter of all mankind.[23] On the basis of 1980 data, the World Bank estimated in 1980 that some 700 million persons in developing countries - from 65 to 71% of the population in the 40 countries reviewed - have deficient diets.[37] In addition, the World Health Organization identifies at least 450 million children suffering from varying degrees of protein-malnutrition.[51] A large number of these persons are dependent on the food supply and price structure made possible by the food exports of North America, so a disruption of these supplies would have grave consequences for most of the populations of developing countries.[23]

In the past decade an increasing interdependence of countries on their food supplies has occurred.[41-43] In 1982, as shown in Table 1, the major grain exporting countries, the United States, Canada, the European Economic Community, and Australia, exported 170 million metric tons of cereals.[33] The developing countries were the major recipients of these exports. Africa imported 24 million tons of cereals in 1982, equal to a third of its own total grain production for that year. In South America cereal imports equalled 11% of total cereal production; and in Asia, excluding China, this figure equalled 18% of total cereal production. By 1990 the situation in the food-deficit countries will worsen and the food shortages increase despite their efforts to increase production and contain populations.[39,44]

The SCOPE-ENUWAR report[24] summarized the likely effects of a major nuclear war on food supplies as follows:

(1) Most countries in the world would suffer severe food shortages and mass starvation if agricultural production were eliminated for a single growing season. Food exporting countries would normally have adequate food stores, but many of these countries could be targets of nuclear weapons. Climatic disturbances of sufficient magnitude to produce these effects might be possible over large areas of the Northern Hemisphere, and some regions of the Southern Hemisphere.

(2) If international food trade were eliminated following a nuclear war, those countries that import a large fraction of their food requirements would experience severe food shortages, even with no climatic disturbances.

(3) Agricultural production in most of the world would probably be impaired for a period of at least several years after a major nuclear war. Climatic disturbances and disruptions in world trade and production of fossil fuel, machinery, fertilizers and other agricultural subsidies could reduce the level of production maintained in the chronic phase.

It is evident from the above considerations that hunger and starvation will decimate survivors of a major nuclear war. Millions of deaths will result not only among survivors in combatant countries but throughout the world. The developing countries, in fact, may be the main victims of this famine, as their populations may not be as immediately reduced as will be the case in the combatant countries. It has been concluded that starvation will be essentially global - a consequence of a major nuclear war that at present seems likely to cause more deaths than all the direct effects of nuclear war combined.[24]

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TABLE 1. FOOD AND NUTRITION (FAO, 1982)

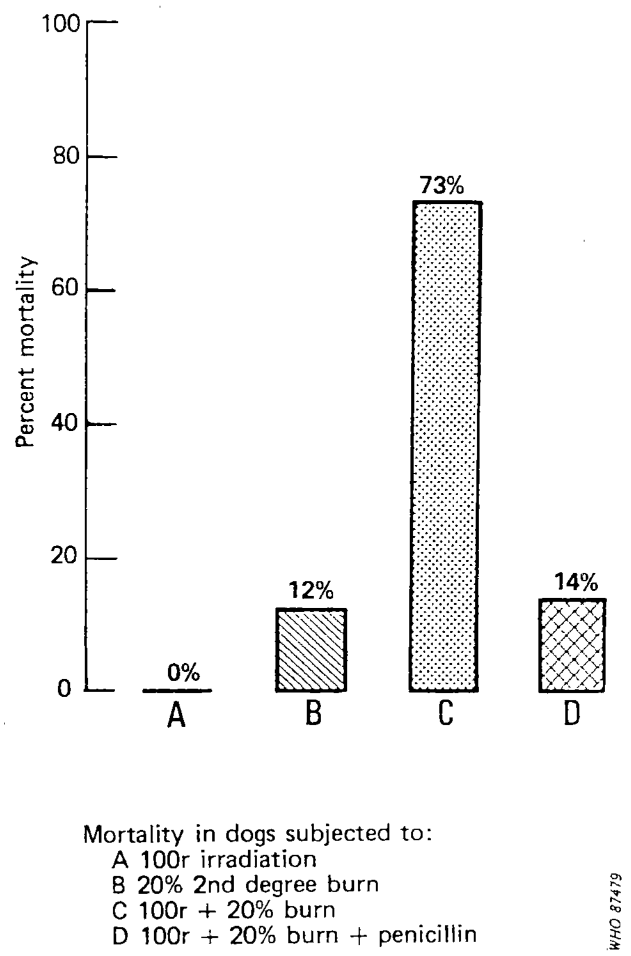
Total cereals* - exports and imports

		10^6 metric tons Exported	Produced	% of production
Exports:	USA**	95	333	29
	Canada	28	54	52
	EEC	18	133	14
	Argentina	18	34	53
	Australia	11	14	79
	Total	170	568	30
		Imported		
Imports:	Africa	24	74	32
	South America	11	80	14
	Asia (except China)	64	363	18
	Europe	31	271	11
	Total	130	788	16
	USA	2	333	0
	USSR	33	173	19

* Wheat, coarse grains and rice.

** USA, with 5% of the world's population, grows 20% of the world's cereals, and imports only 0.7% of the world's total cereal imports.

FIG. 1



Mortality in dogs subjected to:
A 100r irradiation
B 20% 2nd degree burn
C 100r + 20% burn
D 100r + 20% burn + penicillin

(Brooks, J.W., et al. Ann. of surgery 136:533–544,1952)

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