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Provisional agenda item 30   *Nuclear warfare*

EFFECTS OF NUCLEAR WAR ON HEALTH AND HEALTH SERVICES

Report of the WHO Management Group on follow-up of resolution WHA36.28[1]

In resolution WHA34.38 the World Health Assembly requested the Director-General of WHO to create a committee to study the contribution WHO could make to implementation of the United Nations resolutions on strengthening peace, détente, and disarmament and preventing thermonuclear conflict. In response to that resolution the Director-General set up an international committee of experts in medical sciences and public health, which met in 1982 and 1983 and submitted a report on the effects of nuclear war on health and health services[2] that was presented to the World Health Assembly in 1983. The Health Assembly endorsed the committee's conclusions in resolution WHA36.28, and recommended that WHO should continue to collect, analyse, and regularly publish accounts of activities and further studies of the effects of nuclear war on health and the health services, and keep the Health Assembly periodically informed. The Director-General set up a management group to carry out that recommendation. Members of the Group have participated in many of the numerous studies that have been carried out throughout the world since the 1983 report, notably by the Scientific Committee on Problems of the Environment of the International Council of Scientific Unions, the Institute of Medicine of the United States National Academy of Sciences, the Greater London Area War Risk Study Commission, and the United States-Japan Joint Workshop for Reassessment of Atomic Bomb Radiation Dosimetry.

Rather than present fragmentary information on the new studies that have been carried out, the Group considered it preferable to submit a revised version of the 1983 report, incorporating the results of the new studies carried out since that date. The new studies, which are described in the annexes, reflect the great interest in the subject and bring to bear a wide variety of scientific disciplines and modern analytical techniques on the assessment of the effects of nuclear war not only on human beings but also on the environment - effects, for example, on climate and agriculture that would profoundly influence human health and welfare. Those studies have produced more detailed information which does not alter the general picture of the devastation that would be caused by a nuclear war or the catastrophic effects it would have on health, but which, in the opinion of the Group, justifies the preparation of this revised report.

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[1] "The role of physicians and other health workers in the preservation and promotion of peace as the most significant factor for the attainment of health for all".

[2] Effects of nuclear war on health and health services. Geneva, World Health Organization, 1984.

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SUMMARY

1.   Nuclear weapons have now been amassed throughout the world to an estimated total of some 15 000 megatons and the quantity continues to increase. The destructive power of these bombs is such that if only 1% of them were utilized on urban areas, more people could be killed in a few hours than during the whole of the Second World War.

2.   In addition to the immediate effects of blast and heat, the radiation and fallout of nuclear explosions have devastating effects in both the short and long term.

3.   The many individual fires caused by the heat wave would conflagrate in superfires that could spread widely. In such a conflagration no one would survive, even in underground shelters. The number of fatalities caused by such a superfire could be 3-4 times greater than that caused by the blast wave.

4.   The dust clouds of smoke from these fires, together with millions of tons of particulate matter from bomb craters, would lead to a sudden temperature decrease. Even though the extent and duration of this decrease cannot be exactly predicted, a fall of a few degrees in temperature could seriously affect the growth of crops and create other environmental disturbances over large areas of the globe. These effects would not be limited only to the countries directly involved in the conflict, but would also influence people in other parts of the world and affect their health.

5.   After a major nuclear war famine and diseases would be widespread and social, communication and economic systems around the world would be disrupted.

6.   It is obvious that the health services in the world could not alleviate the situation in any significant way.

7.   Therefore the only approach to the treatment of health effects of nuclear warfare is primary prevention, that is, the prevention of nuclear war.

8.   It is not for the committee to outline the political steps by which this threat can be removed or the preventive therapy to be implemented.

9.   However, WHO can make important contributions to this process by systematically distributing information on the health consequences of nuclear warfare and by expanding and intensifying international cooperation in the field of health.

I. INTRODUCTION

1.   A nuclear war may break out by accident, by escalation from a conventional war, or as an act of deliberate policy. Such a war would be totally unlike any previous form of warfare waged by humankind in its immeasurably greater destructive power. Quantitatively, nuclear weapons are vastly more powerful than conventional weapons. Atom bombs of the type used at Hiroshima and Nagasaki represented an increase from tons of trinitrotoluene (TNT) to the equivalent weight of thousands of tons (kilotons, kt). Hydrogen bombs, developed about a decade later, represented an increase from thousands of tons to millions of tons (megatons, Mt). Nuclear weapons have now been amassed throughout the world to an estimated total of some 15 000 megatons and carry an explosive power 25-50 times as much as in the 1960s. The destructive power of these bombs is such that a single bomb may have an explosive power equal to that of all the conventional explosives used in all wars since gunpowder was invented. As Fig. 1 shows, the explosive power of all the nuclear arsenals of the world is now about 5000 times greater than that of all the explosives used in the Second World War.

2.   Qualitatively, the difference between nuclear and conventional weapons is of even greater significance than the quantitative difference. In conventional weapons the two most lethal agents are blast and heat. Blast and heat both cause injury and death when nuclear weapons are used, but to an extent thousands of times greater. Nuclear weapons, however, also produce additional lethal effects by radiation. Apart from the direct effects of radiation, the radioactive materials from a nuclear bomb can be transported to a great distance from the site of the explosion, as has recently been demonstrated on a very much smaller scale by the accident at the nuclear power plant at Chernobyl. Moreover, radiation from the fallout may be an obstacle to rescue operations and effective care of injured survivors and have harmful or lethal effects long after the explosion. Its deleterious effects may indeed continue to be felt in future generations, long after hostilities would have ended.

3.   Less quantifiable effects of nuclear war include atmospheric changes detrimental to agriculture and the economy not only in the countries where the war takes place but also in others not engaged in hostilities. Moreover, since the world has never experienced a large-scale nuclear war, other unpredictable direct and indirect effects cannot be excluded. Any assessment of the effects of a nuclear war must therefore be attended by a high degree of uncertainty. However, on the basis of the information derived from the explosions at Hiroshima and Nagasaki, the tests of nuclear weapons and accidents at nuclear power plants, research in radiation physics and biology, and earthquakes, fires, floods, volcanic eruptions, and other natural disasters, it is possible to predict with reasonable accuracy the main effects on people and their environment. Those effects would not be limited to the people of the area where the bombs fell; some of them would be felt by people throughout most of the world.

II. PHYSICAL CHARACTERISTICS OF NUCLEAR EXPLOSIONS AND THEIR EFFECTS (Annexes 1-4)

Phenomena occurring when nuclear weapons are exploded

4.   The detonation of nuclear weapons gives rise to the following phenomena:

- blast wave
- thermal wave
- massive fires
- initial radiation (neutrons and gamma-rays)
- radioactive fallout
- electromagnetic pulse
- climatic changes
- other environmental disturbances.

5.   Some of those phenomena became known only as a result of the use or testing of bombs and are not yet fully understood, but the recent introduction of more sophisticated computer modelling is making it possible to achieve a clearer idea of what may occur. The phenomena produce physical and biological effects that are directly or indirectly detrimental to human health and inflict severe damage on the environment.

FIG. 1.   NUCLEAR ARSENALS.   IF THE SMALL CIRCLE (RADIUS 1.4 mm)
REPRESENTED ALL THE EXPLOSIVES USED IN THE SECOND WORLD WAR,
THE LARGE CIRCLE (RADIUS 100 mm) WOULD REPRESENT THE
SIZE OF PRESENT-DAY NUCLEAR ARSENALS
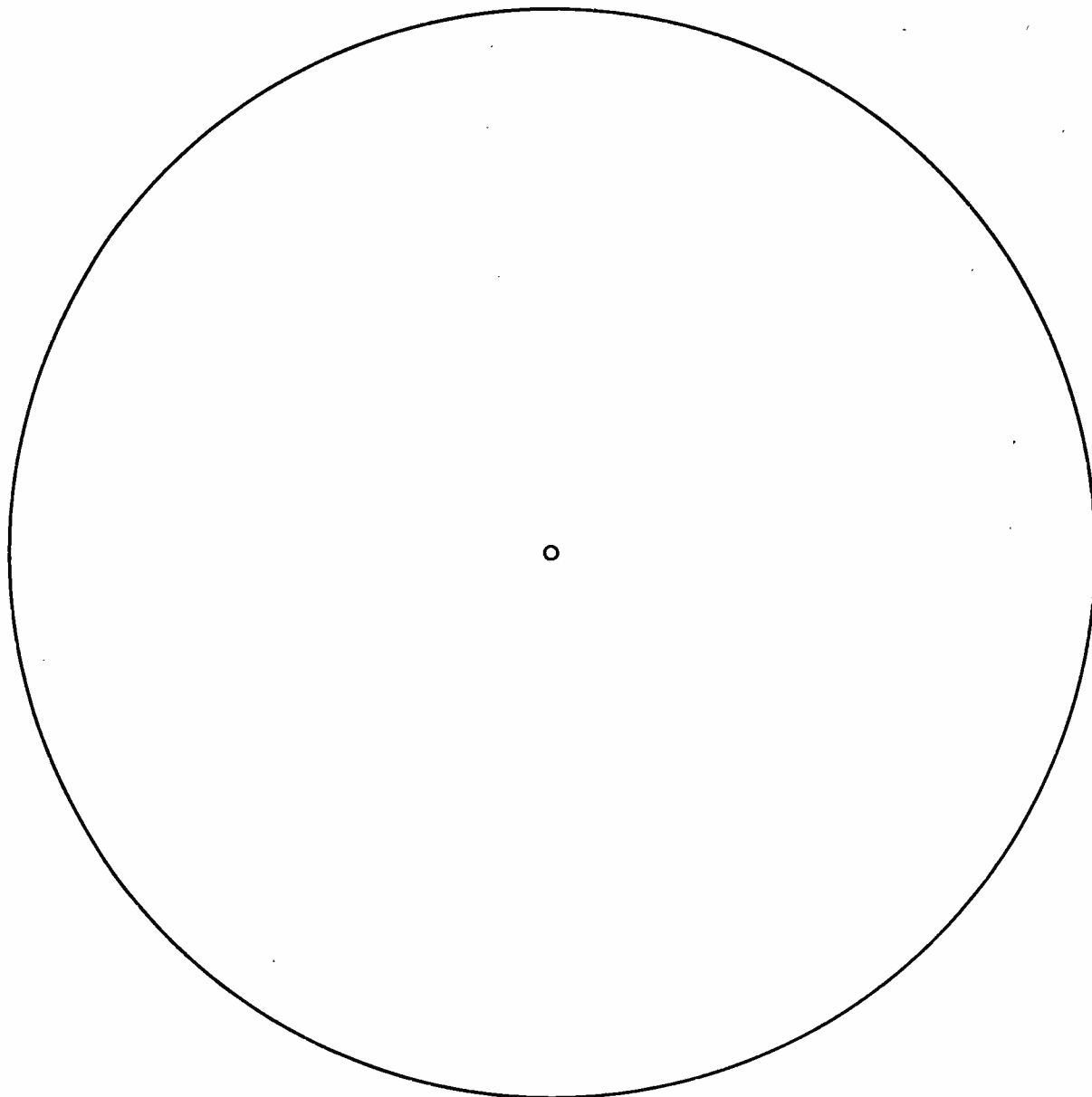
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Enlarged 1.75 times.

Effect of size of bomb and height of explosion

6.   The extent of the damage caused by a nuclear bomb depends not only on the type and size of the bomb but also on the height at which it is detonated, the atmospheric conditions, the time of the detonation, and other variable factors. For a bomb of given size, for example, there is a definite height at which the area affected by the blast wave is greater and the number of deaths and injuries resulting from it larger than for any other height.

7.   The height of the detonation is the main factor determining whether there will be local radioactive fallout or not. If the fireball, the size of which depends on the explosive yield of the bomb, touches the ground, it sucks up huge quantities of earth and debris along with the radioactive products of the bomb. These, forming part of the characteristic mushroom cloud, are carried aloft with the wind. When the fireball cools, the radioactivity condenses on the particles of the material sucked up. Some of the particles are large and descend by force of gravity, the heaviest first; the others are deposited downwind from the site of the explosion.

8.   If the explosion is at such a height that the fireball does not touch the ground there is no local fallout except in certain circumstances. The mushroom cloud may encounter a rain cloud, in which case some radioactive particles may come down with the rain. Or the rain-out, as it is called, may be induced by the explosion itself.

9.   Local fallout would be produced by a 1-Mt bomb at any height up to about 860 m. For the blast wave the maximum effect is achieved at about 3200 m. Thus the conditions producing the maximum number of casualties from blast and from local radioactive fallout are quite different. The actual extent of the local fallout depends on local atmospheric conditions such as wind velocity.

10.   In terms of the amount of damage and the number of casualties caused by the blast wave, nuclear weapons at the lower end of their range of explosive power overlap with such conventional weapons as the blockbusters of the Second World War, which contained about 10 tons of TNT. There is no upper limit to the explosive power of nuclear weapons. However, for the same total explosive yield more blast damage is caused when the yield is distributed over several bombs. Thus, five 1-Mt bombs produce a larger blast effect than a single 10-Mt bomb.

11.   On the other hand, the local radioactive fallout is directly proportional to the explosive yield of the bomb, other conditions being the same. Thus, the area over which a 10-Mt bomb produces a given intensity of fallout is approximately 10 times larger than the area affected by a 1-Mt bomb. The situation is more complicated in relation to intermediate and global fallout. Large bombs lift the radioactive particles into the stratosphere, from which the descent is slow, allowing the radioactivity to decay before it is deposited on the ground. Smaller bombs deposit them in the troposphere, from which the descent is much more rapid, so that more radioactivity is deposited in the short term.

Electromagnetic pulse (EMP)

12.   The electromagnetic pulse is an extremely intense radiowave acting for a very short time. In most, if not all, countries there are vast numbers of collectors of electromagnetic energy, including not only antennas but also electric power cables, telephone lines, railways, and even aircraft with aluminium bodies. The energy picked up is transmitted to computers or other devices employing transistors and integrated circuits controlling systems of vital importance such as telecommunications and electricity and water supplies. All are extremely sensitive to the electromagnetic pulse, and it is highly probable that enough of their components would be damaged to render the systems useless.

13.   The effect of the electromagnetic pulse depends on the height of the burst. At low altitudes the range of action of the pulse is limited to a few tens of kilometres, whereas at high altitudes the range could be thousands of kilometres. Thus, detonation of a bomb at a height of 100 km would produce a pulse covering a circular area on the earth's surface with a radius of 1100 km. A single explosion at a height of 350 km would cover practically the whole of Europe, or of the United States as well as parts of Canada and Mexico.

14.   The electromagnetic pulse would present no direct hazard to healthy human beings, but it might interfere with the action of pacemakers and other electronic medical devices, thus

putting lives at risk. Moreover, it would disrupt communications and place enormous difficulties in the way of rescue operations by severing the links between rescuers and those in need of help. Disruption of the military command, control, communication, and intelligence system at a moment when vital decisions may have to be taken about the use of nuclear weapons could lead to panic use of those weapons and to an escalation of nuclear conflict, since communication could be lost between different governments, between a government and those obeying its orders or between strategic military commands.

15. Disruption of civilian networks could deprive people of electricity, gas, and water and stop telephone and radio communication and many other essential services, including medical and surgical services, that depend on electronic equipment.

Climatic effects

16. The climatic effects of a nuclear war have been the focus of much recent attention. Millions of tons of particulate matter would be injected into the atmosphere from the bomb craters of surface explosions and from the fires that would break out in cities, forests, and fuel stores. A substantial fraction of sunlight would be absorbed in the atmosphere instead of at the earth's surface, the dense clouds formed causing a fall in temperature and reducing photosynthesis in plants. The extent of the fall in temperature that would take place in a large-scale nuclear war is a matter of much debate, but a fall of even a few degrees could affect the growth of crops and create other environmental disturbances that, even if they did not create a so-called nuclear winter, would be far more serious than would have been thought a few years ago and would include a reduction in photosynthesis and in rainfall in the interior of continents, as a result of the absorption of much of the incident solar energy in the upper atmosphere. It is estimated that the burning of about a quarter of the combustible materials in NATO and Warsaw Pact countries alone could inject so much black smoke into the atmosphere that the temperature could fall by more than $10°C$ over a large part of the northern hemisphere. The disturbances could also extend to the southern hemisphere, though there the fall in temperature would be less. The cold could extend southwards from the middle latitudes of the northern hemisphere, where most of the nuclear weapons are likely to be used, to areas that would not have been involved in the conflict. The present estimates suggest that smoke carried high into the atmosphere could remain there for a year or more and cause long-term cooling throughout the world, reducing the temperature of the oceans and having ecological effects that would prolong and aggravate the atmospheric disturbances.

17. Other climatic effects could be caused by the release into the atmosphere of the chemical compounds produced by the explosions. Injection of nitrogen oxides into the troposphere would enhance the photochemical production of free radicals and ozone in the troposphere. If the oxides entered the stratosphere as a result of large thermonuclear bombs, they would deplete the ozone layer there to an extent that would depend on the number of high-yield bombs employed, and recovery could take several years. If the atmosphere was greatly disturbed by the smoke and gaseous products of the fires, long-term changes in the ozone layer could take place. Decrease in the ozone would permit harmful ultraviolet radiation to reach the earth's surface. The injection of other toxic chemicals into the atmosphere - carbon monoxide, hydrocarbons, sulfur oxides, hydrochloric acid, heavy metals - could, before they were removed or deposited, inflict great damage on many forms of life as well as human beings.

Effects of nuclear detonations

Blast wave

18. About half of the total energy released in nuclear explosions is in the form of a blast wave, the colossal build-up of pressure in the vaporized material of the bomb giving rise to a wave travelling through the air at supersonic speed. As the blast wave spreads, its intensity gradually diminishes until it is effectively dissipated, at distances that, if the bomb is in the megaton range, may be tens of kilometres or more. The typical structural damage to buildings caused by a 1-Mt bomb is shown below.

19. The human body can withstand pressures up to about twice the atmospheric pressure (which is about 100 kPa), but most deaths would be caused indirectly, from buildings or debris falling on people or from their being blown against walls or other solid objects. Thus an overpressure of 35 kPa would not crush them, but the accompanying wind blowing at 260 km/h could hurl them against nearby objects, with fatal consequences.

Damage to buildings from the blast wave of a
1-Mt air burst at a height of 2400 m

Distance (km)	Peak overpressures (atm.)	(kPa)	Wind velocity[a] (km/h)	Typical blast effects
1.3	1.4	142	750	Reinforced concrete structures levelled
4.8	0.70	77	460	Most factories and commercial buildings destroyed; small houses reduced to debris
7.0	0.35	35	260	Lightly constructed buildings destroyed; heavily constructed buildings damaged
9.5	0.21	21	150	Walls of steel-frame buildings blown away; houses damaged; winds sufficient to kill people in the open
18.6	0.07	7	60	Damage to structures; flying glass and debris

[a] According to the Beaufort scale, a wind of over 120 km/h is of hurricane force.

20. An indirect result of the blast wave would be fires. The wave would damage furnaces and stoves, smash fuel storage tanks and cars, spilling out volatile or explosive fuels, and cause short-circuits; and fires would inevitably result. The wave could also breach dams or flood barriers and cause catastrophic flooding. Or it could damage chemical plants and nuclear reactors as well as their storage facilities, releasing toxic substances into the environment.

Thermal wave

21. The thermal wave, or heat flash, contains about a third of the total energy released by a nuclear bomb. It results from the extremely high temperature generated by the bomb at the moment of the explosion and is of short duration, about a second for low-yield bombs and about 10 seconds for bombs in the megaton range. The thermal wave starts practically instantaneously, well ahead of the blast wave, and travels at the speed of light. The effect of the high temperature is to vaporize everything within a certain distance of the explosion, melt solid materials at greater distances, and still further away start fires.

22. An effect that would have catastrophic results would be the starting of a firestorm or superfire, of the kind that raged in Hiroshima and ravaged Hamburg, Dresden, and Tokyo during the Second World War. Within the area of the firestorm the temperature could rise to such heights that even in heavily protected shelters people would die from the heat, from lack of oxygen or from inhalation of carbon monoxide or carbon dioxide.

23. There can be no doubt that a multitude of fires would be started by the thermal wave directly and by the blast wave indirectly. The many individual fires started by the heat wave would in all likelihood coalesce to form gigantic superfires that could spread to distances greater than 10 km from the site of explosion of a 1-Mt bomb. The column of hot gases rising from the fire would bring an influx of air from the periphery, creating winds of hurricane force that would fan the flames into a fierce and all-consuming conflagration. In such a conflagration no one would survive in the ravaged area, not even in underground shelters.

24. Recent recognition of the very likely occurrence of a superfire after the explosion of a modern nuclear weapon has led to a revision of the estimated number of casualties resulting from the blast and thermal waves. For the overpressure or blast model, as it has variously been called, the lethal area (that is, the circular area in which the number of persons surviving is equal to the number killed outside the area) attributable to the overpressure

wave from a 1-Mt bomb detonated at a height of 1.5 km would be about 100 km^2. For the conflagration model involving a superfire, it would be about 350 km^2. The number of fatalities caused by the superfire could be 3-4 times that caused by the blast wave.

25. At distances beyond the lethal area many people would suffer injuries from burns. Many of the burns would be in people directly exposed to the thermal wave and their severity would depend on the distance from the site of the explosion and the duration of exposure. Other superficial, intermediate, or deep burn injuries would result from the fires that would break out.

Initial radiation

26. A small proportion of the energy released by the explosion of most nuclear weapons appears in the form of neutrons and gamma-rays emitted in the first minute. An exception is the enhanced-radiation warhead commonly known as the neutron bomb. The proportion of the energy carried by the neutrons in such a bomb could in theory be as high as 80%.

27. The initial radiation would not contribute much to the overall toll of casualties from bombs larger than 100 kt, as the lethal area from blast and heat is much larger than that from radiation. With smaller bombs, and especially with neutron bombs, the lethal area from neutrons and gamma-rays would be considerably greater than that from blast or heat.

Local radioactive fallout

28. When the fireball touches the ground the radioactive products of the bomb, to an extent depending on its size, are deposited downwind and expose people within certain areas to lethal doses of radiation. The material deposited within the first 24 hours constitutes local fallout. Such local fallout constitutes about half of the total radioactivity produced by the explosion. The other half, containing finer particles, rises with the mushroom cloud into the atmosphere. After a surface burst of a 1-Mt bomb, people remaining in the open may receive lethal doses of radiation within an area of nearly 2000 km^2 (Fig. 2). Injurious doses may be received over an area of some 10 000 km^2.

FIG. 2. COMPARISON OF THE EFFECTS OF BOMBS
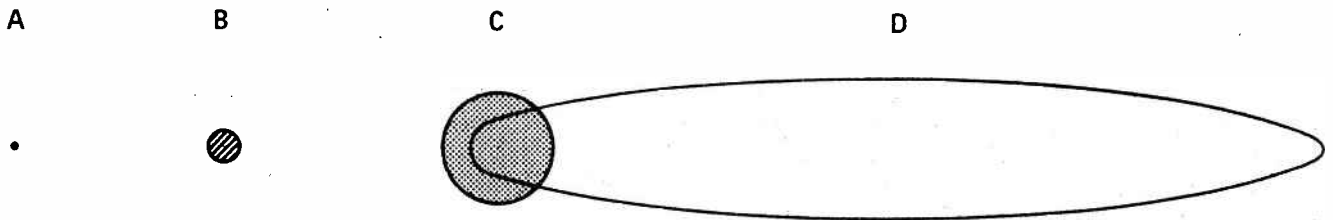
A — Lethal area from the blast wave of the blockbusters used in Second World War
B — Lethal area from the blast wave of the Hiroshima bomb
C — Lethal area from the blast wave of a 1-Mt bomb
D — Lethal area for fall-out radiation from a 1-Mt bomb

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Global and intermediate fallout

29.   It was the view until recently that the radioactivity from bombs not producing local fallout enters the stratosphere, where it spreads all over the world before slowly descending over a period of months or years to the ground as global fallout. During that period, it was held, the radioactivity becomes so weak that the external hazard from gamma-rays becomes insignificant, the danger to human beings then arising predominantly from the ingestion or inhalation of long-lived radionuclides such as strontium-90 and caesium-137.

30.   That in fact is true only for large bombs in the megaton range. The radioactivity from bombs of lower yield is largely deposited in the much more turbulent troposphere. The percentage of radioactivity deposited there increases as the bomb yield diminishes; thus, 80% of the radioactivity of a 100-kt bomb exploded in the higher latitudes of the northern hemisphere is deposited in the troposphere. When deposited in the troposphere the radioactive particles encircle the globe rapidly several times in a latitude band around that of the detonation and are then deposited on the ground during a few weeks. Because of the shortness of this period the radioactivity is much stronger than in global fallout and is termed intermediate fallout.

31.   Intermediate fallout is significant because the tendency in recent years has been to reduce the yield of nuclear warheads (although an opposite tendency is also emerging as a response to the measures being taken to protect the silos housing intercontinental ballistic missiles). It is also significant because it shows that the radiation dose from fallout would be greater than has hitherto been estimated. Intermediate fallout would, however, not produce acute effects except where meteorological conditions created the local concentrations of radioactivity known as hot spots. The long-term effect would be an increased incidence of cancer and genetic defects.

32.   The characteristics of the various types of fallout are shown in the following table.

Characteristics of types of fallout

Type	Time of deposition	Place of deposition	Main form of exposure
Local	24 hours	within hundreds of kilometres downwind	external (gamma-rays)
Intermediate	a few weeks	around the globe in a wide band in the latitude of the detonation	external (gamma-rays)
Global	months to years	whole globe	internal

Nuclear power stations

33.   If a nuclear bomb struck a nuclear reactor or a nuclear facility its radioactive contents would be carried up in the mushroom cloud along with the fission products of the bomb and add to the fallout hazard. Their contribution to the radioactivity received by the population would be initially small in comparison with the amount of radionuclides of short life that are generated by a bomb. As the short-lived radionuclides decayed, however, the contribution of the reactors would gradually become preponderant, because of the long-lived radionuclides present in reactors and storage tanks. Thus, an attack on reactors in a major nuclear war could result in a significant increase in the long-term radiation dose.

Effects of radiation on the body

34.   Radiation injuries can arise from two sources: the immediate burst of gamma and neutron radiations created in the explosion, or the radiation from fallout. The major hazard is from gamma-rays in the radioactive fallout, but beta-rays and even alpha-particles can contribute to the radiation exposure when the radioactive material is deposited on the body, ingested or inhaled.

35. Within minutes to several hours following exposure to radiation a person may begin to exhibit acute gastrointestinal and neuromuscular symptoms. These constitute the prodromal syndrome of radiation sickness. The gastrointestinal symptoms include anorexia, nausea, salivation, vomiting, abdominal cramps, diarrhoea, and dehydration. The neuromuscular symptoms are fatigue, apathy or listlessness, sweating, fever, headache, and hypotension followed by hypotensive shock. With high doses of radiation the complete constellation of symptoms may occur, whereas with low doses only some of the symptoms may make their appearance during the ensuing 48 hours.

36. The severity of symptoms and their occurrence following whole-body irradiation depend on the total radiation dose and the dose rate. Three clinical syndromes of radiation toxicity are recognized. (a) A central nervous system syndrome occurs with acute doses of over 20 Gy. 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. (b) A gastrointestinal syndrome occurs with acute exposure to doses of 5-20 Gy. Nausea, vomiting, and bloody diarrhoea with severe dehydration and high fever dominate the clinical picture. Death occurs in one to two weeks from enteritis, sepsis, toxaemia, and disturbances of body fluids. (c) A haemopoietic syndrome occurs at lower doses of 2-5 Gy. An initial 24 hour period of nausea and vomiting may occur promptly after radiation exposure followed by a latent period of apparent normality for the next week. Then general malaise and fever commence associated with a marked reduction in the circulating white blood cells. Petechiae in the skin and bleeding gums soon follow as the platelet count drops. Anaemia develops from bone marrow suppression and bleeding. Depending on the dose received and the extent of damage to the bone marrow, recovery may take place in weeks to several months or death occur from immunosuppression and sepsis or from haemorrhage. In the range of 1-6 Gy (100-600 rad) survival depends largely on the therapeutic measures that are taken. Older persons are more vulnerable to radiation injury than younger adults.

37. Inhalation of radioactive dust from the fallout can result in internal radioactive contamination affecting the lungs. 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 that can occur from much lower exposures.

38. Estimates of the radiation casualties in a nuclear war depend on assumptions about the LD_{50} value, i.e. the dose that would result in a 50% mortality within 60 days after exposure. Recent studies indicate that the effective LD_{50} under wartime conditions may be considerably lower than the heretofore assumed values of 4.5-6 Gy, which are based on animal studies and peacetime therapeutic or accidental radiation exposure of humans. The new lower estimates of the LD_{50} derive from new surveys of radiation exposures from the Hiroshima experience. These new estimates of the LD_{50} indicate that the number of fatalities from radiation in a nuclear war would be considerably larger than was previously considered.

39. The deposition of beta-emitting radioactive fallout on the skin produces erythema, oedema, blistering, and ulceration of the skin. Usually the injuries are localized and transient, but they may lead to infection and gangrene, healing being protracted.

40. The most radiosensitive tissues of the body are those with a rapid turnover of cells – the bone marrow, the gastrointestinal tract, and the reproductive organs. Irradiation of the reproductive organs may cause temporary or permanent sterility. Severe mental retardation in the child is likely from exposure of the fetus to radiation from the eighth to the fifteenth week of pregnancy.

41. The radioactive products of the bomb may be inhaled with contaminated air or ingested with contaminated food or water. Iodine-131, for example, is preferentially taken up by the thyroid gland, and its radiation can damage thyroid tissue and cause hypothyroidism and cancer of the thyroid. The transport of iodine-131 from its source to cow's milk can be surprisingly rapid. Strontium-90 is preferentially taken up by bone, close to the highly radiosensitive bone marrow; and caesium-137 accumulates in cells, close to the genetic material deoxyribonucleic acid (DNA). Once absorbed, these radionuclides cannot easily be eliminated from the body.

42. Another effect of exposure to sublethal doses of radiation is impairment of the immune response of the body. Because of suppression of the immune response, people who could have been expected to recover may die. Not only ionizing radiation but also physical trauma, burns, infection, malnutrition, and stress all act to impair the immune response, and several acting together may greatly enhance the effect. Under the conditions of nuclear warfare epidemics of disease may spread on an unprecedented scale as a result of impairment of the immune response.

43. Staying indoors or in specially designed shelters could to a considerable degree reduce the radiation dose received, depending on the type of building, the thickness of the walls and ceilings, the floor level in a multistorey building, proximity to other buildings, etc. The protection afforded by such screening is expressed by the protection factor, which is the ratio of the dose that would have been received by a person in the open to that received inside a building or shelter in the same location. A good shelter could reduce the dose by a factor of 1000 or more, but most countries have no shelter programme and people would be unlikely to remain in shelters for any length of time.

Nuclear war scenarios

44. The only occasion on which nuclear weapons were used in wartime was in 1945, in Hiroshima and Nagasaki. The devastation caused by those first crude nuclear weapons, which would now be classified as mere tactical weapons, gives an idea, if perhaps only a slight one, of the catastrophic consequences of a nuclear war waged with the weapons now existing in the nuclear arsenals of the world. But the experience gained from Hiroshima and Nagasaki does not provide a sufficient basis for a quantitative prediction of the consequences of a nuclear war. It was assumed, for instance, that the probability of death and injury was associated with the blast overpressure because that assumption fitted in well with the distribution of casualties in those cities. But recent work has shown that the conflagration model (paragraph 24), which takes into account the high probability of superfires ignited by nuclear weapons, provides a better estimate of casualties from the direct effects of blast and heat than the overpressure model. Other work has shown that in a population under stress in a nuclear war, radiation would cause deaths at much lower doses of ionizing radiation than was previously assumed.

45. Detailed predictions about the number of casualties in a nuclear war cannot be made with any claim to accuracy. It would depend on the number and type of nuclear weapons used, the height at which the bombs were detonated, the time of the explosions, the season, and the atmospheric conditions. It would also depend on the density of the populations attacked, their reactions, and the civil measures taken. Despite these large uncertainties it is still informative to make estimates of casualties under postulated specific initial conditions. A number of such scenarios using computer modelling have been published in recent years; they range from limited nuclear attacks on specified targets to all-out nuclear war.

46. Once nuclear weapons are used in combat it cannot be excluded that there would be a rapid escalation to a full-scale war in which most of the weapons in the nuclear arsenals would be put to use. However, even a scenario in which only military installations are assumed to be targeted gives a vivid idea of the terrifying slaughter that a counterforce nuclear war would cause. Several such scenarios are considered below, based on recent studies carried out in London, Princeton, and Milan.

Scenario 1. A city under attack

47. A recent report of the Greater London Area War Risk Study Commission assessed the effects of a nuclear war that would affect Greater London, which has a population of about 7 million. A number of scales of attack on the United Kingdom were studied, varying in intensity from an attack with bombs of 8 Mt total yield targeted on nuclear capabilities outside the London area to a 90 Mt attack on military, industrial, and urban targets, of which 10.35 Mt fell on London. Computer estimates were made of the number of deaths and of casualties (deaths plus injuries) caused by the three direct effects of nuclear explosions: flash burns, blast, and local fallout. The figures in the table below give the casualties as a percentage of the population of London. They do not include those killed or injured in fires or those who would die later from starvation, disease, or climatic effects.

Casualties from attack on London

Total bombs on London (megatons)	1.35*	5.35	10.35
Percentage killed	11.5	67.6	90.4
Percentage total casualties	23.0	84.9	97.0

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* These bombs were dropped on the periphery of London.

Scenario 2. A counterforce attack

48. A Princeton group studied the consequences of a Soviet counterforce attack on the United States (i.e., an attack in which the targets were the strategic nuclear forces), and of a similar United States attack on Soviet strategic nuclear forces.

49. In the attack on the United States it was assumed that there would be 1215 targets, the great majority being missile silos. Each missile silo was attacked with two 500-kt bombs, one a ground burst, the other an air burst. Altogether 2839 nuclear warheads were assumed, with a total yield of 1342 megatons, a mere fraction of Soviet nuclear capacity. In the attack on the USSR 1740 targets were assumed, again mainly missile silos, but with weapons of lower yield – between 100 and 350 kt, plus a small number of 1.2-Mt warheads. The total number of warheads was 4108, the aggregate yield 844 megatons; that too a mere fraction of United States nuclear capacity. The table below summarizes the results of the study. The numbers of casualties from blast and heat represent the range of possibilities from the overpressure and conflagration models. The range of values for radiation casualties covers four different wind conditions and three LD$_{50}$ values, 2.5, 3.5, and 4.5 Gy. Protection from fallout by staying indoors or in shelters was allowed for by assuming a protection factor of 3 for half the population and of 10 for the other half.

Casualties from a counterforce attack (millions)

	Attack on the USA	Attack on the USSR
Deaths		
blast and fire	7-15	5-11
radiation	4-14	9-24
Total deaths and injuries	23-45	25-54

Scenario 3. A limited nuclear war in Europe

50. In a Milan study of the effects of a limited nuclear war in Europe, the scenario assumed that 470 military targets were attacked: 362 in Western Europe and 108 in Eastern Europe (excluding the Soviet Union); and that 652 bombs, each of 150 kt, were used, 80% of them in ground bursts. The total yield was 98 megatons. As in the Princeton study four different wind conditions were considered but only two LD$_{50}$ values, 2.5 and 3.5 Gy. Ranges of protection factors were assumed with average values of about 2 and 5.

51. The results of the computer analysis are given in the table below. The large number of radiation casualties reflects the assumption that the explosions would be mainly ground bursts and that the protection factors would be lower than those used in the Princeton study, in addition to the higher population density in Europe.

Casualties from attacks on military targets in Europe (millions)

Deaths	
blast and fire	7.4
radiation	42-79
Total deaths and injuries	72-112

Scenario 4.   A limited attack on urban areas

52.   The Princeton group also estimated the casualties from attacks on urban areas using about 1% of the nuclear weapons in the United States and Soviet arsenals. In one of these scenarios the 100 most populated regions within the United States and Soviet Union were each targeted with a 1-Mt bomb exploded at a height of 2 km. On the same assumptions as in scenario 2, such attacks would result in up to 66 million dead and 71 million total casualties in the United States and up to 77 million deaths 93 million total casualties in the Soviet Union. This study also showed that an attack on the centres of 100 cities in the United States alone would kill or injure 51 million people.

53.   The use of only 1% of the nuclear weapons in the arsenals of the two superpowers could therefore kill or injure a large proportion of the population of those countries. As their combined population is about a tenth of the world population it is clear that, in theory at least, 10% of weapons similarly used on other urban centres of the world could bring devastation to the rest of the world from the immediate effects. In other words 1% of the present nuclear weapons could kill more people in a few hours than were killed during the whole of the Second World War.

III.   THE THREAT OF NUCLEAR WAR AS IT IS PERCEIVED (Annex 5)

54.   Studies of how people in industrialized countries perceive the threat of nuclear war show that the commonest view is that it is unlikely in the immediate future but that, if it happens, it will cause complete material destruction and people will not survive. Most consider that nuclear war is not likely within the next 10 years but that there is a one-in-three possibility of its occurring within the average lifetime.

55.   In spite of those views about the likelihood of a nuclear war, most people do not think about it much, other subjects such as unemployment, accidents, the environment, or disease claiming more of their attention. When they do think about it they worry and are afraid, women and children more so than men. On the whole, however, concern about a nuclear war is not strongly correlated with a generalized feeling of anxiety. Nor do most people take action in support of their views about nuclear war. The most consistent reaction therefore seems to be habituation to the threat, which is met with fatalism or a feeling of helplessness.

56.   Studies have also been carried out on how the young in the industrialized countries view the threat of nuclear war. They show that children over the age of 10 years have an acute awareness of the possibility of a nuclear war, an awareness derived from television and other mass media. About a third to a half of the children in the countries studied are concerned about the threat of nuclear war. This concern is not confined to any socioeconomic or ethnic group. Younger children appear to worry more than older children, girls more than boys. A significant proportion believe that a nuclear war will occur in their lifetime, that they and their family will be killed, and that their country will be destroyed. Most children do not discuss their concern with their parents, nor do they know what their parents think about the issue of nuclear war. A number of studies, however, suggest that parents can transmit their anxieties on the subject to their children. Many children can think about nuclear war frequently and not be worried, though in general thinking and worrying about it go together. Children who had discussed the issue with their parents were more likely than those who had not to feel confident that they could do something to prevent nuclear war. The degree of anxiety about a nuclear war does not seem to be associated with neurotic or psychosomatic symptoms, with alcohol or drug abuse, or with any specific psychopathological condition.

57.   Although, with so many other influences on the young, it is difficult to be definitive, it has not been proved that the threat of nuclear war is at present affecting the behaviour, personality development, or attitude of the young in their plans for the future. Those most anxious about the threat of nuclear war - who were most likely to be doing well at school and to be well adjusted personally - were also more confident about preventing it by their own and others' efforts. Realistic anxiety about nuclear war appears indeed to be a positive reaction that could be seen as an expression of a developing sense of social responsibility.

IV. MANAGEMENT OF CASUALTIES IN A NUCLEAR WAR (Annex 6)

58. In any scenario of even a limited nuclear war the number of dead and injured would be
enormous. After the explosion of a 1-Mt bomb no survival would be possible over an area of
some 100 km^2. Beyond that area the number of casualties would depend on many factors such
as the time of the attack, the behaviour of people at the time of the attack and after, and
the kind of shelter they were in, if any. A large number of people would suffer from several
types of injury, and their chance of survival would be correspondingly diminished.

59. When needs far exceed the resources available, the aim of medical care is to save the
maximum number of lives and therefore to utilize what resources are available and carry out
treatment as effectively as conditions permit. The experience of warfare and of natural and
man-made disasters has enabled a number of basic principles to be established for disaster
care. They are: triage, evacuation, and appropriate emergency care.

60. In triage people are sorted out into three groups: those who have a poor or no chance
of survival; those who have a reasonable chance of survival if treated; and those for whom
treatment can be postponed. Rapid assessment is generally required, since delay would mean
that more victims would shift from the category "survival possible" to the category "survival
improbable or impossible".

61. Triage for victims of the blast wave would be mainly confined to those suffering from
indirect blast injuries, since a large number of those affected directly by the blast wave
would have been killed immediately. The victims of the thermal wave would be more numerous
because of the greater area ravaged by fire. Most survivors outside the lethal area would
have both blast and burn injuries; in Hiroshima, for instance, 70% of the casualties had
blast injuries and 65% burns, thus there was a 35% overlap. In the best of conditions people
with third-degree burns affecting less than 50% of the body surface can be saved. In the
conditions of nuclear warfare that threshold could decrease to 20%, especially if, as is
likely, the burns were accompanied by injuries from blast or radiation or both. Triage for
victims of radiation would be rendered more difficult by the similarity of the early signs
and symptoms in people exposed to lethal and sublethal doses.

62. The difficulties of triage are well illustrated by what happened in Hiroshima and
Nagasaki, where the explosive power of the bombs was a mere fraction of that of most
present-day strategic warheads. In Hiroshima all the hospitals within a kilometre of the
hypocentre were totally destroyed, and virtually everyone within them was killed or injured;
93% of the nurses and 91% of the medical staff were killed or injured. In Nagasaki the
university hospital, which contained over three-quarters of the hospital beds and medical
facilities of the city, was destroyed and 90% of its occupants killed or injured.

63. The concentration of hospitals, medical supplies, physicians, nurses, and other
essential health workers in urban areas would result in a disproportionate loss of medical
resources if cities were targeted. To illustrate the formidable medical problems that even a
1-Mt air burst over a metropolitan area could create, estimates have been made for an attack
on Boston. Out of its population of some 3 million, the United States Arms Control and
Disarmament Agency estimated that there would be 695 000 direct fatalities and 735 000
injured. At the time of the estimates (1979), there were 5186 physicians in Boston. If
physician casualties occurred in the same proportion as for the general population, then 50%
of physicians would be potentially available - certainly not all of them expert in emergency
medicine - to treat the injured. This would leave some 280 injured persons for each
physician available.

64. The situation with hospital beds would be just as bad. Boston has 12 816 hospital beds,
but they are mostly in the urban target area, so that 38 of the 48 acute care hospitals would
be destroyed, leaving some 2135 beds for the care of 735 000 seriously injured survivors. If
only one city were destroyed help could come from the outside, but clearly the numbers
needing medical care even in a single city would overwhelm the medical facilities and
resources of the entire country.

65. A recent study of the effects of a major nuclear attack on Greater London confirms the
inadequacy of what medical facilities survived to care for the needs of the injured. Greater
London has 270 hospitals with a bed capacity of 57 620. After a major nuclear attack, it is
estimated, only 1 out of 7 hospitals would remain. There might therefore remain 7500 beds to
cope with the needs of over a million casualties, or some 150 candidates for each bed.

66. If the injured could find a doctor or a nurse, which in the immediate aftermath of an attack would be next to impossible, the doctor or nurse would be besieged by people clamouring for attention and could give them only cursory attention. The whole infrastructure required for dealing with serious injuries – operating rooms, surgical equipment, blood and other fluids, antibiotics and other drugs, water supplies, telephones, heating, transport services, etc. – would be in complete disarray or totally destroyed.

67. In any management of casualties the essential is to act quickly and appropriately. A prerequisite of appropriate treatment is effective rescue and transport facilities to convey the injured to hospitals and treatment centres. Another is sufficient staff, equipment, and supplies in those hospitals and centres to provide the appropriate treatment. In the conditions of a large-scale nuclear war as described the ability of the surviving medical and other health personnel to provide appropriate treatment, or even enough first aid to keep the remaining injured alive, would be non-existent or next to non-existent. Moreover, entering the radioactive fallout areas would present great hazards. Rescue teams would have to be monitored and, if possible, decontaminated, and personnel would have to be rotated to prevent them from being subjected to too much radiation. In the chaos prevailing after the explosion of a bomb it is hard to believe that such measures could be taken. Furthermore, the proportion of casualties among health care personnel would probably be greater than that of the general population, because their work would be in the urban areas and expose them more to radiation, infection, and the other hazards of the period following on the explosion.

68. In the radioactive fallout areas a large percentage of the patients would probably consist of those presumed to be suffering from radiation sickness. For the treatment of such patients highly specialized facilities are required in normal conditions. Thus, in France in 1978 four persons who had been accidentally exposed to very high doses of radiation were treated in sterile conditions, each receiving 50-100 transfusions of blood cells and heavy doses of antimycotics and antibiotics. Without such treatment they would inevitably have died. In the Chernobyl accident intensive hospital care was given to about 200 injured and proper medical attention was given to 135 000 evacuees mobilizing health service personnel and supplies from the whole country. Even the limited nuclear war scenarios using 1% of the present nuclear arsenals would result in millions of serious casualties. Obviously the health services of the world could in no way cope with such a situation. In sum, in the event of a nuclear war triage would at best be insignificant, rescue work scarcely other than makeshift. Casualties, if treated, would have to be treated on a first-come first-served basis, which means that those most needing treatment might well not be seen at all. The great majority of casualties would be left without medical attention of any kind.

V.   HEALTH EFFECTS OF A NUCLEAR WAR (Annexes 5-7)

Short-term effects

69. In the immediate aftermath of a nuclear attack many health problems would emerge, not only for the injured survivors, for whom the outlook would be bleak, but also for the uninjured survivors, as a consequence of the collapse of the whole administrative structure, the destruction of sources of energy, the breakdown of communications, and social disturbances. Since the supplies of water would be interrupted, the lack of water would be of crucial importance, and it would in most cases be contaminated by radioactivity and harmful microorganisms. Rain might concentrate the local radioactive fallout in places, producing high levels of radioactivity. Fresh water would therefore be unsafe for drinking. Fresh food would also be contaminated, the only safe food being canned or so stored as to prevent contamination. Internal radiation from the inhalation or ingestion, or both, of radioactive isotopes would add to the danger of external irradiation.

70. In ordinary circumstances minimal standards of sanitation are difficult to achieve in populations living in conditions of hardship and overcrowding, as in refugee camps and shanty-towns. Sanitary problems would be enormously greater for the survivors of a nuclear war lodged in shelters. They would have to stay in the shelters for a considerable time before they could safely risk venturing out into the open air. Within the shelters there would probably be too many people, some injured, some dying; and the problems of overcrowding, sanitation, care of the injured, disposal of excreta and dead bodies, and coping with the psychological stresses that would inevitably arise would drive many people to leave the shelters prematurely in spite of the radiation, even if food and water supplies were sufficient.

71. Infection would emerge as a major problem. It is a leading cause of death in victims of burns as well as of radiation. The epidemiological pattern of disease would be altered drastically in the aftermath of a nuclear war, by impairment of the immune response of the body, by malnutrition, by the lack of sanitation, by the proliferation of insects and microorganisms, which are much more resistant to radiation than human beings, and by the collapse of epidemiological surveillance and disease control. Outbreaks of diarrhoeal and respiratory disease would be likely to occur in the surviving population and be intensified by the overcrowding and insanitary conditions of the shelters in which people would have taken refuge.

72. The psychological state of the survivors may be gauged to a certain extent from that of survivors of Hiroshima and Nagasaki, but there the attack consisted of a single bomb, the inhabitants had no prior knowledge of nuclear weapons, and help came from neighbouring untouched areas. In a major nuclear war little or no help could be expected and the widespread awareness of the effects of nuclear weapons, especially of the radiation they cause, would considerably affect the behaviour of the survivors, leading to a decrease in coordinated rescue and rehabilitation efforts.

73. The effects of the blast and thermal waves, radiation, carbon monoxide poisoning from the firestorms, and other factors would produce neurological and behavioural disturbances among the survivors. The survivors could be expected to be initially dazed, disoriented, and subject to fluctuations of mood, their field of consciousness and their span of attention constricted, their ability to comprehend stimuli reduced. Experience from natural disasters suggests that the majority of the survivors would suffer from such an acute stress reaction and that they would remain in a depressed, frightened, and highly vulnerable state until the cause of the disaster was seen to have passed. Any flight reaction would add to the difficulties of rescue operations.

Intermediate and long-term effects

74. There are inevitably major uncertainties in predicting the intermediate and long-term health effects of a large-scale nuclear war. Among the effects would be radiation injury from radioactive fallout, suppression of the immune response, infectious diseases, contaminated water supplies, social and economic disintegration, food shortages, increased ultraviolet radiation, climatic and ecological disturbances, and a higher incidence of cancer and genetic disorders.

75. Survivors of the acute effects of the thermonuclear explosions would still be confronted by intermediate and global radioactive fallout. Though the danger from high-dose external radiation would have abated, the longer-lived radioisotopes, particularly strontium-90 with its 29-year half-life and caesium-137 with its 30-year half-life, would remain a hazard over large areas.

76. Suppression of the immune system is now recognized as a highly probable consequence of nuclear war. It would make people increasingly vulnerable to infection and cancer. Ionizing radiation, hard ultraviolet radiation (UV-B), burns and trauma, psychological factors, and malnutrition can all impair the immune system, reducing the helper T-lymphocytes and increasing relatively the suppressor T-lymphocytes. Because of the combined effect of immunosuppression and injury, many people would succumb in the aftermath of a nuclear war to injuries or infections that would have been trivial in normal circumstances. An impaired immune system would contribute later to an increased incidence of cancer.

77. With the destruction of public health and sanitary facilities the way would be open for the spread of disease. Water supplies would be contaminated not only by radioactivity but also by pathogenic bacteria and viruses. Sewage treatment and waste disposal facilities would have disappeared. Lack of refrigeration would lead to spoilage of what food supplies remained. The survivors emerging from shelters would not find conditions outside much better than those inside. Millions of putrefying human and animal corpses and mounds of untreated waste and sewage would provide a perfect breeding-ground for flies and other insects that are more resistant to radiation than human beings. The uncontrolled growth of insect populations would favour an increase in the numbers of insect vectors of disease. Contaminated water and food would spread the enteric diseases. A number of diseases, such as salmonellosis, shigellosis, infectious hepatitis, amoebic dysentery, malaria, typhus, streptococcal and staphylococcal infections, respiratory infections, and tuberculosis would occur in epidemic form throughout the world. Moreover, many of the survivors would have been subjected to

sublethal doses of radiation and would suffer from varying degrees of immunodeficiency. This would make them more susceptible to and more seriously affected by the diseases mentioned above - more susceptible, indeed, to pathogens of all kinds. Nor would it be easy to restore the public health system after an all-out nuclear war since it depends on a stable social organization and a sophisticated manufacturing and distribution system.

78. The social and economic structure of the world would be disastrously affected by a large-scale nuclear war. Since industrial sites, sources of raw materials, and skilled workers would be among the direct casualties, there would probably be a temporary reversion of the present world economy to a more primitive stage. How long this would last would depend on a number of factors, such as the time it would take survivors to adapt themselves to such a postnuclear world, to re-establish water, food, energy supplies, transport, trade and monetary systems, or to build up public health and educational systems, etc.

79. Experience from Hiroshima and Nagasaki and from other disasters would suggest that after the early phase of stupor survivors might suffer from demoralization, anxiety, depression, and changes of mood, leading to impaired concentration, disturbed sleep, and reduced activity. In the face of the need to adapt themselves to an entirely new world, many would be overcome with a sense of helplessness and be unable to cope. The long-term effects of severe stress are modified by the social context in which people find themselves after a disaster or a catastrophic personal experience. This context is difficult to predict after a large-scale nuclear war, but the fabric of society would assuredly suffer severe damage. A feeling of helplessness and alienation could result, and might lead to lasting personality changes, with emotional blunting and acute bursts of panic or aggression. These effects might be carried over to the next generation. Among children there might in future be vulnerability to psychological disorders because of defective socialization by an adult generation suffering from the survivor syndrome.

80. The social effects are also hard to predict. The surviving population would probably break up into fragmented groups because of damage to communications and transport. Because of the scarcity of resources and the enormity of the destruction, such groups would have to struggle to secure whatever food stocks or other resources were to be found. It cannot be predicted how such groups would relate to each other, but it is likely that their outlook would be defensive and competitive. On the world scale there would be a scramble for scarce and uncontaminated resources, and the breakdown of international relations would bring competition and violence rather than cooperation.

81. A large study by the Scientific Committee on Problems of the Environment of the International Council of Scientific Unions confirmed earlier predictions of severe food shortages and starvation in the aftermath of a major nuclear war. In fact, the study indicates that people living at subsistence level would be precipitated into starvation and millions would die. The major factor leading to this prediction would be the destruction of transportation which would make it impossible to move food supplies from sites of harvest or storage to the hungry populations. In industrialized countries food is no longer supplied locally but is provided by a vast network of enterprises which involves not only farming, animal husbandry, and fishing, but also farm machinery, pesticides, fertilizers, petroleum products, and commercial seeds. It utilizes sophisticated techniques to handle the food that is produced which include grain elevators, slaughter-houses, cold-storage plants, flour mills, canning factories, and other packaging plants. It also includes 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 major nuclear war and would result in severe food shortages. But noncombatant countries are likely to suffer similar shortages because of cessation of imports of food and because of the cooling and drought affecting the interior of continents. Noncombatant countries are therefore likely to suffer as severely as those countries actually targeted in a nuclear war.

82. Fear of cancer and of genetic defects as a result of the radiation received was a notable feature among the survivors of Hiroshima and Nagasaki. It has been estimated that the risk of cancer in a large-scale nuclear war would be increased by about a fifth in populations exposed to radioactive fallout. This estimate needs to be reviewed in the light of the recent revision of the dosimetry system in Hiroshima and Nagasaki, which indicates that the cancer risk is greater. Outside the target area the increase would be smaller and related to the fallout pattern. Hereditary damage in the fallout area might be expected to be about double that of today. Although this increase may appear to be small, the absolute numbers of those affected would be considerable because large populations would be involved.

Moreover, the psychological impact of the threat of cancer and hereditary damage would be profound and difficult for survivors to cope with, especially when added to the stress, anxiety, depression, and bewilderment that would accompany their attempts to adjust to the hostile conditions of the post-nuclear world.

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83. It is a tragic irony that, whereas the initial warning time in a nuclear war has shrunk to hours and minutes, the detriment to health that it could cause would persist for years, decades, and generations.

84. When treatment is ineffective, the only solution available to the health professions is prevention. Prevention is obviously the only possibility in case of a nuclear war.

GLOSSARY[1]

(Explanations of some terms used in this report and in the annexes)

Activity	A measure of the intensity of a radioactive source; it is equal to the number of nuclides disintegrating per second.
Atom bomb (A-bomb; atomic bomb)	A nuclear weapon in which the explosive energy is derived from fission only.
Becquerel (Bq)	Unit of activity. One Bq is the amount of a radioactive substance in which one disintegration occurs per second. The old unit of activity, the curie, is equal to 37 thousand million becquerels.
Beta-particles (or beta-rays)	Fast-moving electrons emitted spontaneously from the majority of radioactive nuclides.
BMR	Basal metabolic rate: the minimal rate of energy production, generally expressed in calories or kilocalories of a resting person or animal. It is the energy requirement of the body in the absence of exercise.
Boundary layer	The layer of the atmosphere - several hundred metres to several kilometres in depth - that is affected by the nature and characteristics of the surface of the earth.
Chain reaction	A reaction that stimulates its own repetition. In a fission chain reaction a nuclide undergoing fission after the absorption of a neutron releases neutrons which can then cause further fission.
Coliform bacilli	Refers to the bacteria which normally inhabit the intestine, of which E. coli is the predominant bacterium.
Collateral damage	Unintended damage to property or harm to people occurring in the use of weapons.
Collective dose	A measure of the total dose to a population resulting from exposure to radiation. It is equal to the product of the mean dose and the number of persons exposed.
Complement - C_1 to C_5	A complex of proteins normally present in the serum that are destructive to certain bacteria and other cells that are sensitized by a specific complement-fixing antibody; thus, a part of the natural defence mechanisms of the body against invading bacteria and foreign cells.
Conflagration	The spreading of fires by the wind, following the start of individual fires by the blast wave or the thermal pulse from a nuclear explosion.
Counterforce attack	The employment of nuclear weapons to destroy the opponent's military potential (missile silos, air and naval bases, C^3I systems, etc.).
Countervalue attack	The employment of nuclear weapons to destroy the opponent's industrial and economic bases.
Critical mass	The smallest mass of fissile material that will support a self-sustaining chain reaction under stated conditions. For an explosion to occur a mass greater than the critical (supercritical) is required.

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[1] Based on Rotblat, J. Nuclear radiation in warfare. London, Taylor & Francis, 1981.

C^3I — Command, control, communications and intelligence system.

Dose — A general term denoting the quantity of ionizing radiation absorbed by the body.

DS86 — The system of dosimetry in Hiroshima and Nagasaki established in 1986 to replace the previous dosimetry (T65D).

Down's syndrome — A syndrome of mental retardation with a variable constellation of physical abnormalities. It is a genetic disorder associated with an abnormal chromosome 21 (trisomy 21).

Electromagnetic pulse — The intense and very brief pulse of electromagnetic radiation - mostly in the radio frequency range - emitted after a nuclear explosion (usually refers to a high-altitude explosion).

Electromagnetic spectrum — The electromagnetic radiations ranging (in order of increasing wavelengths) from gamma-rays, or X-rays, to ultraviolet, visible, infrared, radar and radio waves.

Electron — A negative charged elementary particle of a mass nearly 2000 times smaller than that of the proton. It is a constituent of all atoms.

Enzymopathy — A disturbance of enzyme function, including genetic deficiency of specific enzymes.

Extinction coefficient — A quantity defining the efficiency of a substance to deplete or reduce the flux of radiation passing through it (see optical depth).

Fireball — The luminous sphere of hot gases that is formed immediately after a nuclear explosion in air.

Firestorm — The merging of many small fires into a single convective column, creating very high temperatures.

Fission — The splitting of a heavy nucleus into two approximately equal parts, accompanied by the release of energy and several neutrons.

Fission bomb — See Atom bomb.

Fission-fusion-fission (F-F-F) bomb — A nuclear weapon in which energy is released in three stages: (1) fission - acting as a trigger; (2) fusion - occurring at the high temperature created in the first stage; and (3) fission - by the neutrons emitted at fusion, in a uranium tamper.

Fission products — The (mostly) radioactive fragments of fission plus the nuclides formed as the result of their radioactive decay.

Fluence — The intensity of radiation (number of particles, energy) falling on a unit of surface area.

Fratricide effect — The inhibiting effect on the detonation of a second nuclear weapon on a target by the effects (X-rays, thermal or blast waves) of the first weapon.

Fuel loading — The mass of combustible material per unit area.

Fusion — The formation of a heavier nucleus from lighter ones, with an attendant release of energy; usually refers to the interaction of hydrogen nuclei to form helium.

Fusion bomb — A nuclear weapon in which the explosive energy is derived from fusion (apart from the fission trigger).

Galactosemia	An inborn error of galactose metabolism due to autosomal inheritance of a deficiency of an enzyme with resulting toxic accumulation of partially metabolized products of the sugar, galactose.
Gamma-rays	Electromagnetic radiation of high energy and penetration accompanying many nuclear reactions, such as fission, and radioactive decay.
Genetic effects	The changes in the germ cells caused by ionizing radiation.
Global fallout	The deposition on the ground of the radioactivity from a nuclear weapon initially deposited in the stratosphere.
Gram-negative sepsis	A serious, often fatal, infection in the blood stream with gram-negative bacteria.
Gray (Gy)	The SI unit of absorbed dose; it corresponds to the absorption of energy of 1 joule per kg of tissue. See also Rad.
Ground zero	See Hypocentre.
GWe	(gigawatt electric) The power output of a nuclear reactor in the form of electricity ($1GW-10^9W$).
Half-life	The time in which half of the number of nuclides in a given radioactive substance disintegrate.
Hydrogen bomb (H-bomb)	See Fusion bomb.
Hypocentre	The point on the ground vertically beneath an air explosion of a nuclear weapon.
Immunodeficiency	A condition resulting from a defective immunological mechanism due to a defect in one or another component of the nonspecific immune mechanism or to a defect in either the B-lymphocyte or T-lymphocyte systems.
Immunoglobulins	A class of structurally related proteins which are the antibodies that bind to foreign proteins, microorganisms, or cells and serve as the humoral watch-dogs of the body.
Intermediate fallout	The deposition on the ground of the radioactivity from a nuclear weapon initially deposited in the troposphere.
Ionizing radiation	Beams of particles (e.g., neutrons, beta-rays) or electromagnetic waves (e.g., X-rays, gamma-rays) that produce ions when passing through matter.
Ions	Atoms that have acquired an electrical charge by the loss or acquisition of electrons.
Isotopes	Nuclides with the same atomic number and thus identical chemical properties.
Keloids	Overgrowths of connective tissue resulting from an overzealous repair process of the body in response to traumatic injury, surgery, burns or infections, which often produce unsightly nodules or knobs at the skin surface.
Kerma	(Acronym for kinetic energy released in matter). A measure of the intensity of the ionizing radiation field at a given location. It gives the dose (in grays) which a tissue would have received if it were in air at a given location.

LD$_{50}$ — The dose of radiation required to kill 50% of individuals in a population within a specified period.

Linear energy transfer (LET) — The average amount of energy lost by an ionizing particle per unit path length.

Local fallout — The deposition of the radioactivity from a nuclear weapon, in the downwind direction, during the first 24 hours after a ground burst.

Lugol's solution — An iodine-potassium iodide solution: it can saturate the system in the thyroid gland which takes iodine from the blood stream and thus, if administered prior to exposure to radioactive iodine, blocks further iodine uptake by the thyroid.

Lymphocyte, B- — A bone-marrow derived, small mononuclear white blood cell which is the precursor of the mature antibody producing plasma cell. It is responsible for the humoral immunologic defence of the body.

Lymphocyte, T- — A thymus derived small mononuclear white blood cell which is responsible for providing tissue immunity.

Lysozyme — An enzyme present in the tears and some other body fluids which is capable of hydrolysing certain complex sugars and thus destructive to the cell walls of certain bacteria.

Megatonnage equivalent (MTE) — A measure of the power of a nuclear weapon in terms of the mechanical effects it may produce. It is equal to the actual explosive yield (in megatons) raised to the power of two-thirds.

MIRV — (Acronym for "multiple independently targetable re-entry vehicles). The capability of one missile to carry a number of warheads each directed onto a different target.

Mushroom cloud — The characteristic shape of the cloud of hot gases, dust, and other particulate matter carried upwards after the detonation of a nuclear weapon.

Neutron — An uncharged elementary particle with a mass slightly greater than that of the proton. The neutron is a constituent of the nuclei of every atom heavier than hydrogen.

Nuclear radiation — Beams of particles or electromagnetic waves originating from the atomic nucleus (see ionizing radiation).

Nuclear winter — The term popularly used to describe the situation resulting from the reduced sunlight and lowered temperature following the extensive employment of nuclear weapons.

Nuclide — Species of atom characterized by the number of protons and the number of neutrons in its nucleus. A nuclide is usually specified by giving the symbol of the element (which defines the atomic number) and the mass number, for example ^{235}U (or uranium-235).

One-dimensioned climatic model — A method of studying atmospheric effects in which the vertical variations are analysed but not the horizontal variations (average values being assumed for the latter).

Overpressure — The transient pressure exceeding the ambient pressure in the blast wave from an explosion.

Ozone — A molecular form of oxygen consisting of 3 atoms. A layer of ozone normally resides in the lower stratosphere.

Phenylketonuria	A congenital deficiency of an enzyme which is necessary for conversion of phenylalanine into another important amino acid, tyrosine, with resulting accumulation of toxic metabolites of phenylalanine producing brain damage; the condition is characterized by the excretion of a phenylketone in the urine.
Photon	A quantum of energy of electromagnetic radiation. Its energy content is inversely proportional to its wavelength.
Pneumococcal vaccine	A vaccine to immunize individuals against infection by pneumococcus bacteria.
Polydactyly	A congenital disorder characterized by one or more extra fingers or toes.
Prodromal syndrome of radiation	The early stage of acute radiation effects, which are usually referred to as radiation sickness.
Properdin	A normal serum protein that participates, in conjunction with other factors, in an alternate pathway for the activation of components of the complement system; thus part of the normal immune system.
Proton	An elementary particle carrying a unit positive electrical charge. It is identical with the nucleus of hydrogen (of mass number 1), and is a constituent of the nuclei of all atoms.
Pseudomonas	Mobile flagellate gram-negative bacteria capable of producing serious infections in humans, especially in immuno-compromised persons.
Rad	Unit of absorbed dose. It is equal to one-hundredth of 1 gray, the SI unit which has replaced it.
Radioactivity	The spontaneous disintegration of some nuclei, accompanied by the emission of ionizing radiation.
Rain-out	The removal of radioactivity from the ascending mushroom cloud from a nuclear explosion, by an encounter with a rain cloud. In self-induced rain-out, the removal may occur by the convective cloud created by the heat from the explosion.
Reactor	A system containing a controlled fission chain reaction. It is used to generate electricity, to produce plutonium, or for research.
Residence time	The average period of time in which substances (smoke, radioactivity) remain in the atmosphere after being deposited there.
Roentgen	Unit of exposure to radiation; for X-rays or gamma-rays the roentgen is numerically nearly the same as the rad.
Scavenging	The removal from the atmosphere of particles or gases by precipitation or by clouds.
Shear	Difference in wind velocity at various altitudes.
Slant distance	The distance from a given location on the surface of the earth to the point where the explosion occurs.
Smoke yield	The mass of smoke produced per gram of material burned.
Somatic cells	All cells of the body other than germ cells.
Stratosphere	The layer of atmospheric air above the tropopause in which the temperature changes very little with altitude.

Superfires	The result of firestorms and conflagrations.
Synergism	The interaction of several effects such that the total effect is greater than the sum of the individual effects.
Tamper	A material used to reflect neutrons in a bomb assembly and to provide greater inertia thus increasing the yield of a weapon.
Thermonuclear bomb	A weapon in which part of the explosive energy is derived from fusion reactions.
Thermonuclear reaction	A fusion process brought about by very high temperatures.
Three-dimensional climatic model	A method of studying atmospheric effects in which both vertical and horizontal variations are analysed.
TNT	A chemical explosive, trinitrotoluene, used as a measure of the energy released in the detonation of nuclear weapons.
Triage	Initial routing of patients or casualties, assigning them to appropriate medical care facilities.
Tritium	A radioactive isotope of hydrogen of mass number 3.
Tropopause	The boundary between the tropopause and the stratosphere.
Troposphere	The region of the atmosphere immediately above the earth's surface in which the temperature falls with increasing altitude.
UV-B	The band of ultraviolet radiation with wavelengths in the range 290 to 320 nm.
X-rays	Electromagnetic radiation, identical with gamma-rays, but produced in processes outside the atomic nucleus.

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PHYSICAL EFFECTS OF NUCLEAR WAR

by

J. Rotblat

Introduction

This Annex describes the new information and knowledge about the physical effects of nuclear detonations that have become available since the WHO report of 1983.[1]

It is amazing that four decades after Hiroshima and Nagasaki, and the intensive research during that period, new phenomena are still being discovered and new facts come to the fore which affect our understanding even of the physical consequences of nuclear war and our estimates of likely casualties. One reason for this is the introduction of sophisticated techniques and computer models that have made it possible to tackle highly complex phenomena, such as the atmospheric and climatological changes after multiple nuclear explosions. These techniques also enable us to carry out retrospective studies of the events that accompanied the bombs dropped on the Japanese cities, and to draw more reliable conclusions.

Large-scale fires

In estimates of the number of casualties in a nuclear war, the blast wave was generally considered to make the largest contribution.[2] Although fires were the major cause of casualties in Hiroshima and Nagasaki, it was thought that this would not be the case in modern cities. For example, the Office of Technology Assessment[3] - a source very frequently cited - stated that at a distance from the hypocentre at which the blast overpressure was 35 kPa - often assumed to define the "lethal area" from blast effects - only 10% of buildings would sustain a serious fire. For this reason, only the direct casualties from the heat flash, that is the burns sustained by people who were either outdoors or in the direct line of the heat wave entering through windows, were included. The number of people in these categories was thought to be between 1% and 25% of the population living at distances that might be reached by the thermal pulse.

Recent studies,[4,5] however, have shown that not only individual fires, but fire storms and conflagrations - referred to as superfires - are very likely to occur in attacks on cities, and would produce the largest number of immediate casualties. In these studies, the characteristics of large-scale urban fires were analysed, mainly using the experience from the fires started during World War II in Dresden, Hamburg and Tokyo. In each of these cities the number of fatalities due to burns was of the same order of magnitude as that in Hiroshima, but whereas the air raids with bombers required the use of some hundreds of aircraft and sorties spread out in time, the Hiroshima fires were all lit by one bomb. The almost simultaneous start of a multitude of fires greatly increases the probability of their merging into one superfire. Moreover, the nuclear weapons in the modern strategic arsenals are between 10 and 100 times more powerful than the Hiroshima bomb; this again increases the probability of such superfires. For these reasons, a "conflagration model" has been introduced in the calculation of casualties (see Annex 4).

The explosion of a nuclear weapon can start fires either directly, by the thermal pulse, or indirectly, by the blast wave. Residential houses usually contain a great variety of substances, such as drapery, padded furniture, newspapers, which are easily ignited by thermal radiation with ignition thresholds of about $60\text{-}90 \times 10^4$ Jm^{-2}. The large window areas of modern buildings increase the chance of exposure of these materials to the radiation. Commercial buildings too often contain large amounts of synthetic and highly flammable materials. Blast-induced fires may develop from the spilling of volatile liquids, rupture of gas lines, overturned radiators, short circuits, sparks near volatile or explosive fuels.

Apart from the yield of the weapon and height of burst, the probability of an individual fire starting at a given distance from the explosion depends on a number of factors. For directly started fires these include: ignition threshold, visibility, cloud or snow coverage. For indirect fires they include the type of building, its contents, and proximity to other buildings. For each of these factors there is a range of values likely to occur. Table 1 lists nine specific factors used in the calculations. Assuming that these factors are independent of each other, and assigning to each an estimated standard deviation, the overall probability of a fire starting at a given distance can then be calculated for weapons of various yields.

Fig. 1 shows the result of such calculations[4] for a one-megaton bomb exploded at a height of 1.5 km. The solid curve presents the average probability of a fire starting at a given ground distance from the hypocentre. The two dashed curves give the 95% confidence limits, representing the range of variability. As is seen, there is a 100% probability of a fire starting up to a distance of 8.2 km, with a range of uncertainty between 4.5 and 16 km.

Even when the probability is only 50%, the individual fires are most likely to merge into one superfire engulfing the whole area. The mechanism for this is explained in Fig. 2.[5] In the vicinity of the individual fires a column of hot air is created which rises to considerable heights. The reduced air pressure at the bottom of the column brings an inflow of cooler air from the surroundings. The pressure gradient is sufficient to cause winds of hurricane force (120 km per hour). The supply of fresh oxygen fans the individual fires and causes them to burn more fiercely, creating more heat and generating new fires, so that the whole area becomes engulfed in one huge conflagration.

Within the area in which fires rage no one is likely to survive. Even the people in deep underground shelters would die from one or more of the secondary effects of the fires, namely: high temperature, reduced levels of oxygen, and elevated levels of carbon monoxide or dioxide. Table 2 lists the levels of these agents that would cause death within four hours, if acted singly. If two or more of these agents acted simultaneously – as is likely to be the case – lower values than those given in Table 2 would suffice to cause death.[5]

With the area engulfed by fires exceeding that damaged by the blast wave, and no time to escape, the number of immediate fatalities from a given attack is bound to be much greater than estimated previously, perhaps two to four times greater. For example, after the detonation of a one-megaton bomb at a height of 1.5 km, the "lethal area" (defined as the circular area in which the number of survivors is equal to the number of people killed outside the area) due to the blast[6] would be 104 km^2, corresponding to a radius of 5.8 km. With a conflagration, the average lethal area might be 353 km^2 (radius 10.6 km). If the population density were assumed to be uniform, the number of immediate fatalities would be 3.3 times greater than that caused by the blast wave. Under circumstances favouring the spread of fires the increase could be even greater.

As a specific instance, consider the effect of a single 250-kiloton bomb detonated at a height of 1 km above the NATO headquarters on the outskirts of Brussels. Such a warhead might be carried, for example, by a SS-20 missile.[7] On the map of Brussels, in Fig. 3, the inner circle represents the lethal area as predicted by the blast model; it includes about half of the city of Brussels, and the number of deaths would amount to about 200 000. The outer circle shows the lethal area from the fires. This time nearly the whole of the city plus about half of the Brussels Agglomeration is engulfed, with a total of about 700 000 deaths.

In the area between the two circles a very large number of people would have suffered injuries, mainly from the blast effect, and required medical attention. The lessening of the burden on medical services, resulting from the immediate deaths of these people, is only illusory. Outside the area completely engulfed by the fires there would still be many individual fires, and the number of people with burns, upwards of 100 000, would far exceed the facilities available in peacetime, let alone after a nuclear attack. The total number of hospital beds in special burn treatment centres is only 63 in the whole of Belgium.[8]

The magnitude of the problem is illustrated by the fire at the football ground in Bradford, England, in April 1985; the admission of 83 burn casualties to hospitals overwhelmed the medical facilities of the whole area.[9]

Apart from the immediate effects, the numerous fires started in urban areas after a large-scale nuclear attack may give rise to serious climatological effects (see Annex 2).

It has been suggested[10] that many fires could be started in urban areas by the new types of weapons in the defence systems envisaged in the Star Wars programme. These systems include kinetic energy projectiles, particle beams and various kinds of laser beams. Only some of the latter could possibly be used for incendiary purposes, namely lasers operating within certain wavelength bands enabling them to penetrate the atmosphere.[11] However, atmospheric conditions and other factors affecting the laser beams impose serious limitations on the efficacy of this method of starting fires.

Electromagnetic pulse (EMP)

Of all the physical phenomena that accompany nuclear explosions, the one not directly hazardous to healthy people is the EMP; yet huge efforts and a large outlay of expenditure are being made to protect against it. This is so because of the important bearing the EMP has on the management of international crises and the prevention of a nuclear confrontation, as well as of the indirect effects of the EMP on the consequences of a nuclear war.

Every nuclear explosion is associated with the instantaneous emission of gamma-rays. If the detonation is at a very high altitude, tens or hundreds of kilometres about ground, these rays can travel some distance before they encounter atoms of air in the upper atmosphere. The electrons emitted as a result of these collisions are forced by the earth's magnetic field into orbital motions which give rise to a coherent pulse of electromagnetic energy propagating towards the surface of the earth.[12]

The greater the altitude of the explosion, the further the gamma-rays can travel before colliding with atoms of the air, and therefore the larger the area on the ground reached by the EMP. A detonation at a height of 100 km produces a pulse that can cover a circular area on the earth's surface with a radius of 1100 km. A single explosion at a height of 350 km can cover practically the whole of the continental USA, as well as parts of Canada and Mexico.

Even low-altitude explosions can produce an electromagnetic pulse, by a somewhat different mechanism, but the distance at which damaging electric fields are generated is then much smaller, of the order of a few kilometres.

The spectrum of the electromagnetic radiation in the pulse is extremely wide and includes the whole frequency band of radiotransmission, but the intensity of the electric field is up to 10^{11} times greater than that usually reaching a radio receiver.[13] The pulse rises in an exceedingly short time, of the order of 10^{-9} second, and its duration is about 10^{-7} second. These characteristics result in a huge electric surge in circuits in which the EMP is absorbed, with consequent damage to equipment vital to communications and essential supplies, thus hindering rescue operations and medical help.

In most countries there exist vast arrays of efficient collectors of electromagnetic energy; they include not only antennas but also cables for electric power, telephone lines and railways, even aircraft with aluminium bodies. The energy picked up is transmitted to important systems, such as telecommunication, electricity, water supplies, which are controlled by computers or other devices employing transistors and integrated circuits; these are extremely sensitive to the EMP. Many of these systems contain a very large number of components; although not all of the components are likely to be damaged, the probability is very high that a sufficient number will be affected to make the whole system useless.

The EMP can influence events relating to nuclear war in two significant ways: by affecting military strategic planning, and by damaging the civilian system of communication and supply, thus aggravating the consequences of the war.

The disabling, by a single high-altitude nuclear explosion, of the military command, control, communication and intelligence system (C^3I), just at a time when critical decisions may have to be taken about the use of nuclear weapons, may have catastrophic results in that it may lead to the initiation of the use of such weapons, or the escalation of a nuclear conflict, by breaking the links between governments (the hot line) or between the strategic military commands.

The disruption of civilian networks, which are controlled by computers, may deprive people of electricity, gas and water supplies, telephone and radio communication, and many other life-supporting systems which depend on electronic equipment.

One such piece of equipment is the cardiac pacemaker. Most pacemakers are sensitive to external electric fields. The very strong electric field produced by the EMP is very likely to interfere with the action of the pacemaker or even to damage it altogether. Thus, the lives of many people would be put at risk by the EMP. Together with the above-mentioned indirect effects, the EMP may contribute to a large increase in the casualty toll of a nuclear war, which itself may have started inadvertently by a high-altitude explosion.

For these reasons, great efforts are being made, and billions of dollars spent, to protect equipment from the damaging action of the EMP. Such protection, commonly described as "hardening", includes shielding, filtering and isolating the various components of a system. In telecommunication networks a very efficient method of hardening is to use fibre optics instead of metal conductors. These remedies are expensive; moreover, the entire communication system, with all its components, has to be changed to make the protection effective. Because of this, the introduction of fibre optics and other hardening methods is at present limited to key points of C^3I and government communications. Even so, if past history of the arms race can serve as a guide, new weapons with an enhanced EMP effect are likely to be designed to obviate the protection measures. The projected deployment of space-based systems of defence against nuclear missiles, in Strategic Defence Initiative projects, may increase the potential of high-altitude explosions.

Other related effects, such as System Generated EMP, Dispersed EMP, or Transient Radiation Effects, may result in damage similar to that produced by the EMP, but affecting particularly space communication satellites and the earth's natural ionosphere.

Fall-out

In descriptions of the radiation aspects of nuclear warfare, two types of fall-out have usually been discussed: local and global. Local fall-out is the deposition on the ground of radioactivity within 24 hours after the explosion. It occurs in ground bursts, that is in detonations sufficiently close to the surface for the fire-ball to touch the ground. Huge quantities of earth and debris are then sucked up, together with fission products of the bomb, and rise in the familiar mushroom cloud. As the fire-ball cools, the radioactivity condenses on the particles of the material sucked up, many of which are large and fall to the ground by the force of gravity at different distances from the explosion in the downwind direction. About half of the total radioactivity produced in the explosion comes down as local fall-out. The other half - containing finer particles - ascends with the mushroom cloud into the upper regions of the atmosphere.

If the detonation is at such a great height that the fire-ball does not touch the ground, then nearly all the radioactivity goes into the atmosphere, and there is no local fall-out (but see rain-out below). The critical height for local fall-out to occur is a function of the yield of the weapon and is given by the formula

$$H = 55 \times W^{0.4}$$

where H is the altitude in metres and W the yield in kilotons.[14] For example, the critical altitude is 350 metres for a 100-kiloton bomb, and 870 metres for a one-megaton bomb.

The radioactivity from air bursts - that is from those not producing local fall-out - as well as the other half of the radioactivity from surface bursts, used to be considered as global fall-out. It was assumed that all of it will reach the stratosphere, where it would spread out all over the globe before descending to the ground. Since the circulation in the stratosphere is very slow, it takes months to years before it is deposited on the ground; during this long delay the radioactivity becomes so weak that the external hazard from the penetrating gamma-rays is no longer significant, and only the internal hazard from the ingestion of long-lived radioactive nuclides, the most prominent being strontium-90 and caesium-137, needs to be considered.

Intermediate fall-out

The assumption that all the radioactivity is initially deposited in the stratosphere is valid only for very big bombs, with yields in the megaton range. The radioactivity from weapons of lower yield is largely deposited in the troposphere. This can be seen in Fig. 4, where the heights of the mushroom clouds are plotted as a function of the yield of the bomb, according to a model developed by Peterson.[15] The solid curves in the figure give the tops and bottoms of the mushroom clouds. For a given explosion yield the mushroom cloud is higher in the equatorial zone, which in this model is defined as 0-30° (Fig. 4a), than in the polar zone (30°-90°) (Fig. 4b). The tropopause, that is the border between the troposphere and the stratosphere, varies with the latitude. As shown by the dashed lines, in the equatorial zone the tropopause is at a height of 17 km, whereas in the polar zone it is much lower, at 9 km.

The percentage of the total radioactivity deposited in the troposphere is given in Table 3 for bombs of various yields. It is seen that even in the polar zone the tropospheric deposition is very high for low-yield bombs: it increases from 1%, for a one-megaton bomb, to 80% for a 100-kiloton bomb. In the equatorial zone the percentage tropospheric deposition is much higher, but the polar zone is of greater interest because in practically all war scenarios it is assumed that the explosions occur north of 30°.

The importance of tropospheric deposition arises from the rapid circulation in the troposphere and the high deposition rate. After the explosion, the radioactivity circulates several times round the globe and is then deposited on the ground within a few weeks. Most of it comes down in a band 20° wide round the latitude of the explosion. Because of the shorter time of occurrence of the tropospheric fall-out, the radioactivity is much stronger than from stratospheric deposition, and the external gamma-ray exposure constitutes the major hazard. These differences justify the introduction of the tropospheric fall-out as a separate, intermediate type. The characteristics of the three types of fall-out are listed in Table 4.

More attention is now given to the intermediate fall-out because of the change in recent years in the yield of nuclear warheads in the arsenals. In the earlier years of the nuclear arms race the emphasis was on high-yield weapons. Thus, the Titan ICBM in the USA had an explosive yield of 9 megatons; in the later missile, Minuteman II, the warheads were 1.2 megatons. The ICBMs of the Soviet Union had even higher yields: 20 megatons of the SS-18, and 5 megatons of the SS-19. However, the development of MIRVed launchers, each of which can carry a number of warheads, and – more importantly – the greater accuracy of hitting a target, achieved through advances in guiding systems, have made it possible, and necessary, to introduce warheads with lower explosive yields, such as the Minuteman III, with 170 kilotons, or 50 kilotons of the Poseidon. The Soviets are still behind in this respect, but the same trend is observed, with their arsenals now containing large numbers of 200 kiloton warheads. The average yield of US warheads has gone down from 1.2 megatons in 1979 to 0.3 megatons in 1984. In the USSR arsenals, the corresponding change has been from 2.2 to 0.5 megatons. A glance at Table 3 shows that the non-local fall-out from current weapons has shifted dramatically from the global to the intermediate type. It should, however, be mentioned that there is now the reverse tendency, to increase the yield, to overcome the "hardening" of ICBM silos.

A computer model developed at the Lawrence Livermore Laboratory[16] has made it possible to calculate the radiation doses likely to be received from non-local fall-outs. Application of this model to war scenarios with detonations of about 5000 megatons has shown[17] that the average gamma-ray dose to people living in the latitude band 30°-50° north, and exposed in the open, could be about 0.4 Gy, with smaller doses in other latitudes. On a global basis, the dose from non-local fall-out comes out to be more than 10 times higher than given in the 1975 Report of the United States National Academy of Sciences.[18]

The above values assume a uniform distribution of the fall-out within each band. In reality, meteorological conditions could cause precipitation of the radioactivity, resulting in "hot-spots" in which the doses might be greater by an order of magnitude. Such hot-spots may cover a region the size of France. Since most of the tropospheric dose is received within a short time, in the hot-spot areas people might receive lethal doses if they stayed in the open. On the whole, however, the intermediate fall-out would not produce acute effects. It would mainly result in long-term effects, namely an increased incidence of

cancer and genetic defects. Including the long-term effects of local fall-out, the number of radiation casualties would be more than double the number calculated without taking into account the tropospheric fall-out.

Rain-out

Even air bursts, that is detonations at such heights that the fire-ball does not touch the ground, may produce some local fall-out by a phenomenon called "rain-out". Two mechanisms for rain-out have been suggested.

The first comes into operation if the ascending mushroom cloud encounters a rain cloud. The latter scavenges some of the radioactive particles which then come down together with the rain in the vicinity of the explosion. The amount of rain-out depends on the extent of the overlap of the mushroom and rain clouds, and on the amount and duration of the rainfall. Rain lasting one hour could scavenge almost all the radioactivity in the nuclear cloud, but this may happen only with low-yield weapons, of the order of 10 kilotons. For higher yields the amount of scavenging is much less and decreases with increasing yield. However, should the nuclear cloud encounter a thunderstorm region, then even with bombs in the megaton range rain-out may produce local deposition of radioactivity.[19]

In both Hiroshima and Nagasaki radioactive fall-out occurred in some localities (3-4 km west of the hypocentre in Hiroshima, and in Nishiyama, 3 km east of the hypocentre in Nagasaki) even though the altitudes of the detonations (580 and 504 metres) were well above the values to produce local fall-out with the bombs used (15 and 22 kilotons), as can be verified from the equation on page 4. However, in neither of the cities was there a rain cloud at the time of the bombing; indeed, clear visibility was the required criterion in the choice of target. (Nagasaki was bombed because the first target, the city of Kokura, was overcast.) Therefore, a different mechanism for rain-out must have operated.

Such a mechanism, self-induced rain-out, was put forward by C. R. Molenkamp of the Lawrence Livermore Laboratory.[20] The nuclear detonation itself can initiate the formation of a convective cloud by the heat from the explosion. This cloud rapidly scavenges a certain amount of radioactive debris and deposits it on the ground in the downwind direction. A computer model developed for this purpose enabled Molenkamp to calculate the amounts of radioactivity that might be deposited under the atmospheric conditions prevailing in Nagasaki at the time of the bomb. The calculated result agreed very well with the observations in that city, thus lending support to the hypothesis of self-induced rain-out.

In some circumstances of nuclear warfare, particularly in the use of so-called tactical nuclear weapons, rain-out may result in sufficiently high doses to produce acute radiation effects, even if only air bursts were employed.

Attack on nuclear power installations

Another aspect of nuclear warfare is the consequence of an attack on nuclear power installations. Nuclear reactors are likely to be destroyed in a nuclear war which includes attacks on industrial targets, because of the large contribution they make to a country's economy. A reactor of capacity 1 gigawatt electric (1GWe) is said to make the same contribution as an oil refinery with a capacity of 40 000 barrels per day.

A surface burst of a nuclear weapon, even of the relatively low yield of 100 kilotons, creates a crater of nearly 100 metres radius, within which everything is vaporized. Should such a bomb hit a nuclear reactor, or an associated facility, such as a storage tank or reprocessing plant, their radioactive contents would be sucked up with the fire-ball and carried with the mushroom cloud together with the fission products from the bomb. The main effect of an attack on nuclear installations would therefore be to augment the fall-out hazard in a nuclear war.

However, the time distribution of the effect from reactors is different from that of the weapons; the decay of the radioactivity is much slower and the radiation hazard persists much longer than from nuclear bombs alone. Chester and Chester,[21] who were the first to study this problem, estimated that in an attack on a nuclear industry based on an 850 GWe capacity, the residual radioactivity after one year would be equivalent to that from a nuclear war in which 30 000 megatons were exploded.

The fission reaction, whether in a reactor or in a bomb, results in the formation of the same variety of radioactive materials (some 300 different nuclides) with half-lives varying from a fraction of a second to many millions of years. The difference between a bomb and a reactor is that in the former all the radioactivity is created in one instant, whereas in the reactor it is being produced continually. Since, almost invariably, the decay of the short-lived nuclides results in the creation of longer-lived nuclides, there is a gradual build-up of the latter in a reactor. The proportion of long-lived fission products is thus much greater in a reactor than in a bomb, and it increases the longer the fuel elements remain in the reactor. After about three years the fuel elements are usually removed from the reactor and put into storage tanks for about 10 years. During that time there is further decay so that the proportion of long-lived nuclides in the tanks is even higher than in reactors. The same goes for reprocessing plants which receive the materials from the storage tanks.

Fig. 5 (adapted from Chester & Chester[22]) illustrates the different rates of the radioactive decay in the several cases studied. It is expressed as the dose rate (gray per hour) from the gamma-rays of the radioactive products if they were deposited on an area of 1 km[2]. Curve A shows the rate of decay in the case of a one-megaton bomb. Curve B gives the decay in the case of a 1 GWe reactor after three years of operation, the time starting from the moment of shut-down. Curve C applies to a storage tank containing the spent fuel from such a reactor after 10 years. Curve D gives the decay of the radioactivity in a reprocessing plant with a capacity of 1800 tonnes per year. As is seen, although initially the activity of the bomb was about 100 times greater than that of the reactor, after about one week they become equal and thereafter the reactor activity becomes increasingly greater. Table 5 shows the ratio of the dose rates from the reactor and the bomb at different times after the explosion. Clearly, the reactor presents a radiation hazard long after the fall-out from the bomb has decayed to an insignificant value. This applies much more so to storage tanks and reprocessing plants.

In an all-out nuclear war, it may be assumed that all nuclear reactors in the targeted countries would be attacked. By the end of 1985, 531 reactor units, with a total capacity of 390 GWe, were in operation or under construction.[23] Adding the units being planned, a scenario based on an attack on reactors with a total power output of 500 GWe is therefore conceivable.

In addition to the reactors, it is possible that other nuclear facilities would be destroyed, even if not deliberately aimed at. These include reprocessing plants of a total capacity of some 6000 tonnes per year, and storage tanks near reactors containing some 5000 reactor-years of high-level storage.

In a nuclear war the largest number of radiation casualties would be caused by local fall-out (in a scenario with ground bursts), the bulk of the radiation dose being delivered with the first seven days after the explosion. As is seen from Table 5, by that time the dose rates from a one-megaton bomb and a 1-GWe reactor, after three years of operation, are about the same. In a scenario in which a nuclear industry based on a 500-GWe capacity was attacked, while the total explosive power of the weapons was 5000 megatons, the dose resulting from the reactors would initially be a very small proportion of that from the weapons. During the first seven days, the additional dose from the nuclear installations would add about 4% to that from the weapons. This is well within the uncertainties of the scenario and can therefore be disregarded.

After one week, however, the dose due to reactors etc. becomes progressively the dominant factor. A further contribution to the radiation hazards from an attack on a nuclear industry would be made by the intermediate and global fall-outs. Combining the effects of all three types of fall-out, the average per capita dose to the world population, received over 50 years, would be about five times larger than if nuclear installations were not attacked. In addition to the external gamma-ray doses there would be internal doses accumulated over the years from ingested radioactive materials.

Altogether, the effect of nuclear power installations, if attacked, could be a serious radiological hazard to present and future generations. The actual magnitude of that hazard depends on the assessment of the long-term effects of exposure to radiation (see next section).

Radiation dosimetry in Hiroshima and Nagasaki

Estimates of cancer risks due to exposure to radiation are mainly based on data from Hiroshima and Nagasaki, derived from the Life-Span Study of the A-bomb survivors.[24] A quantitative relation between cancer risk and radiation dose requires knowledge of the doses received by the survivors. A vast project, which included test explosions of nuclear weapons in the Nevada desert with replicas of Japanese houses, was carried out in the 1950s and early 1960s, mainly in the United States. The result[25] was the establishment of a system of dosimetry known as T-65, which gave the radiation doses received at various distances, outside or inside houses. The observed incidence of leukaemia and other cancers, in the Life-Span Study, was then used to derive dose-response relationships.

An analysis of the data revealed significant differences between the effects in the two cities. Fig. 6a shows the mortality from leukaemia in Hiroshima and Nagasaki, as a function of the radiation dose.[26] Fig. 6b shows similar dose-response relations for chromosome aberrations.[27] For both effects there appears to be a linear relation for Hiroshima, and a non-linear relation - implying an insignificant effect at low doses - in Nagasaki. A ready explanation was provided for this difference: due to the different structures of the two bombs, there was a large component of neutrons in the Hiroshima bomb, whereas in Nagasaki the initial radiation consisted almost entirely of gamma-rays. It was thus concluded[28] that in Hiroshima the leukaemia effect was due principally to neutrons, which give a linear relation with dose, whereas in Nagasaki the gamma-rays produced the non-linear response.

However, a new analysis,[26] first published in 1980, has thrown considerable doubts on the validity of the T-65 dosimetry. These doubts concerned the actual yield of the Hiroshima bomb, the energy spectrum of the initial radiation, and the effect of humidity of the air on the passage of neutrons through it. The major new finding that followed the re-analysis of data was that in Hiroshima too the neutron contribution to the effect was very small, perhaps by a factor of 30 lower than was assumed before. It turns out that in both cities, the radiation exposure was due almost entirely to gamma-rays, particularly at greater distances from the hypocentre; the differences shown in Fig. 6 must therefore have been due to artefacts in the previous survey.

The effect of these changes was so radical that it necessitated the establishment of an entirely new dosimetry, as well as the reallocation of survivors to different dose groups. The task was allocated to a US-Japan Atomic Bomb Radiation Dosimetry Committee, which has held a number of Dosimetry Workshops since it was set up in 1982. The aim of this Committee is to establish a new dosimetry system - to be called DS86 - based on a re-analysis of physical data and new dosimetry techniques, as well as a reassessment of doses received by individual survivors, their exact location, orientation and posture inside buildings at the time of the explosion. This task turned out to be much more demanding than anticipated; the final report of the findings has been postponed several times and is expected to be published late in 1987.

An estimate of the number of casualties in a nuclear war from long-term effects of radiation has to await the publication of that report. But in the meantime it is of interest to consider the revised values of the parameters that influence the dosimetry, based on results already published[29,30] and which are unlikely to be changed significantly. These are: the variation of tissue kerma in air with the distance from the hypocentre; the shielding factor of buildings; and the organ factors.

(a) Kerma. One of the chief tasks of the revised dosimetry was to establish the contribution which the different components of the radiation emitted from the bomb made to the total dose at various distances from the explosion. The quantity required, related to the dose a person would have received if he were in the open, is given by the tissue kerma in air, which is a measure of the intensity of the radiation field at a given location. Although different from the absorbed dose, kerma is measured in the same unit, the gray. The main contributors to the kerma are: prompt primary gamma-rays, prompt secondary gamma-rays, delayed gamma-rays, and neutrons. The gamma-ray components are shown in Fig. 7a. Fig. 7b shows the total gamma-ray kerma and the neutron contribution according to the new calculations (solid curve), while the dashed curve shows the gamma-ray and neutron kerma based on the T-65 dosimetry.[29] While the gamma-ray component shows a slight increase, particularly at larger distances from the hypocentre, the most dramatic difference is in the neutron component of the kerma. The greatly reduced neutron contribution means that the effect of neutrons can be ignored for practical purposes.

(b) Shielding of buildings. Apart from the effect on kerma, the elimination of neutrons made a very big change to the attenuation of the radiation by walls and roofs of buildings, in the sense that persons who were inside houses at the time of the explosion are now found to have received smaller doses than thought previously. When neutrons pass through a thickness of matter their absorption is accompanied by the production of secondary gamma-rays. Therefore, if a mixture of gamma-rays and neutrons passes through a wall, the attenuation of the primary gamma-rays is to a certain extent compensated by the generation of secondary gamma-rays. But without the neutron component, there is only the attenuation of the gamma-rays, so that a much smaller fraction of the initial radiation gets through. The transmission factor depends not only on the structure of the given building but also on the proximity to other buildings; it also varies with the distance from the explosion, since the energy spectrum of the gamma-rays is a function of distance. Table 6a shows the average values for house transmission factors in Hiroshima at several distances from the hypocentre.[30] A comparison with the value from the T-65 dosimetry shows that the proportion of gamma-rays that penetrate through the walls and roofs of the houses is about one-half the previous value.

(c) Organ factors. In order to calculate the dose that causes a given effect, say cancer in a certain organ of the body, it is necessary to know the fraction of the radiation falling on the surface of the body which penetrates to the organ. This organ factor depends on the energy of the radiation, and therefore on the distance from the hypocentre, as well as on the orientation of the person in relation to the point of the explosion, e.g. whether facing towards or away from the explosion. The new values for bone marrow, which are relevant for the induction of leukaemia as well as for the acute effects of radiation, are given in Table 6b.

The new dosimetry evaluation may require the reallocation of people who were previously assigned to the control group, so that the question may arise about an adequate control population. This and other criticisms of the Life-Span Studies (for example, the selection factor[31,32]) will leave some doubt about the usefulness of the Japanese data for the evaluation of long-term effects.

The recent tragedy at Chernobyl may provide a better opportunity for studying these effects. Following the accident and fire in one of the reactors, on 26 April 1986, a huge amount of radioactivity was released into the atmosphere. Some of it was carried by the wind and deposited all over Europe and beyond, but the dilution with distance and time made the doses quite small on the whole. However, in the immediate vicinity of Chernobyl the levels of radioactivity were very high. About 130 000 inhabitants of that area were evacuated, but not before having been exposed to radiation, some to considerable doses, from gamma-rays, and possibly also from beta-rays externally and internally. If the doses received by them could be determined by a suitable method of dosimetry, for example, chromosome aberration, this would facilitate the study of the long-term effects of radiation, through a comparison of these evacuees with a suitably matched control population.

The doubts expressed above about the Japanese data apply less to the study of acute effects of radiation, characterized by the LD_{50} value. For people exposed inside houses, the new dosimetry is likely to lead to a considerably lower value of the LD_{50} (see Annex 3).

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TABLE 1.   VARIABLES IN FIRE DAMAGE PREDICTION

Ignition thresholds

Visibility

Transmissivity

Attenuation by clouds

Enhancement by snow

Combined effects

Type and contents of building

Fire-spread factor

Counter-measures

TABLE 2.   LEVELS OF TOXIC AGENTS WHICH MAY CAUSE DEATH IN 4 HOURS

Temperature	95°C	(hyperthermia)
Oxygen	8%	(anoxia)
Carbon dioxide	20%	
Carbon monoxide	0.04%	

TABLE 3.   PERCENTAGES OF TROPOSPHERIC DEPOSITIONS

Yield (kt)	Equatorial zone	Polar zone
100	97	80
300	87	70
500	80	32
700	74	11
1000	65	1
3000	8	0
5000	0.4	0

TABLE 4.   CHARACTERISTICS OF FALL-OUT TYPES

Type	Time of deposition	Place of deposition	Main form of exposure
Local	24 hours	Hundreds of kilometres downwind	External (gamma-rays)
Intermediate	A few weeks	Round the globe in a wide band in the detonation latitude	External (gamma-rays)
Global	Months to years	Whole globe	Internal

TABLE 5.   RATIO OF DOSE-RATES FROM A 1-GWe REACTOR
TO THAT FROM A 1-MT WEAPON

Time after explosion	Ratio
1 hour	0.01
1 day	0.02
3 days	0.05
1 week	1
2 weeks	2
1 month	3
6 months	8
1 year	15

TABLE 6a.   AVERAGE HOUSE TRANSMISSION FACTORS, HIROSHIMA

Distance from hypocentre (m)	Prompt	Gamma-rays secondary	Delayed	Total
700	0.47	0.50	0.39	0.49
1100	0.46	0.32	0.35	0.42
1500	0.48	0.23	0.36	0.41
T-65				0.90

TABLE 6b   AVERAGE MARROW TRANSMISSION FACTORS, HIROSHIMA

Distance from hypocentre (m)	Prompt	Gamma-rays secondary	Delayed
700	0.79	0.50	0.69
1100	0.82	0.33	0.73
1500	0.84	0.24	0.76

Fig. 1. Range of fire damage
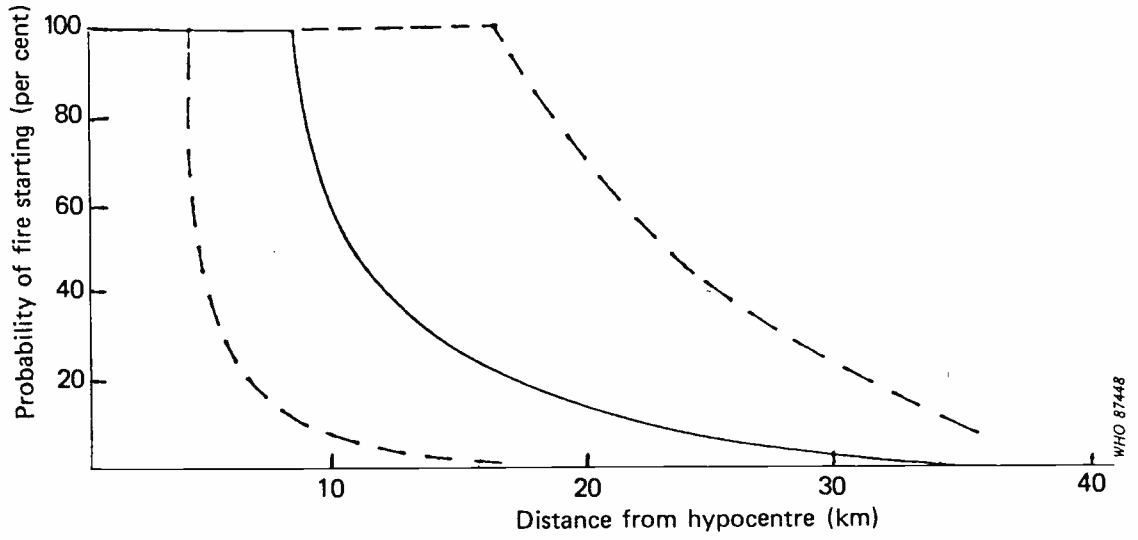
Fig. 2. Initiation of superfires

Region of superfire
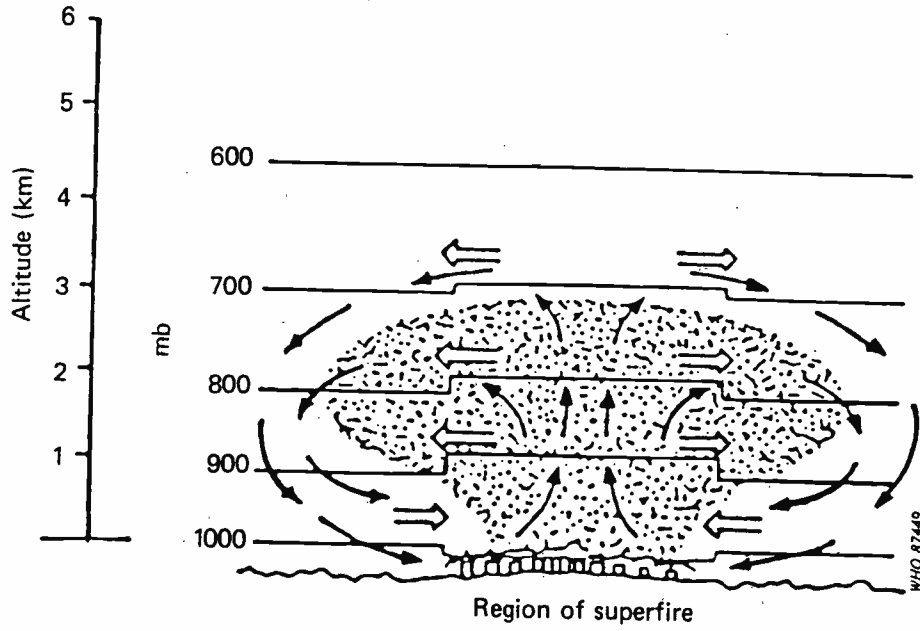
Fig. 3   250 kt bomb on Brussels. Lethal areas for blast and superfire

▬▬▬▬▬   limits of the 19 boroughs

▬▬▬▬▬
+ ///////   Brussels—town borough
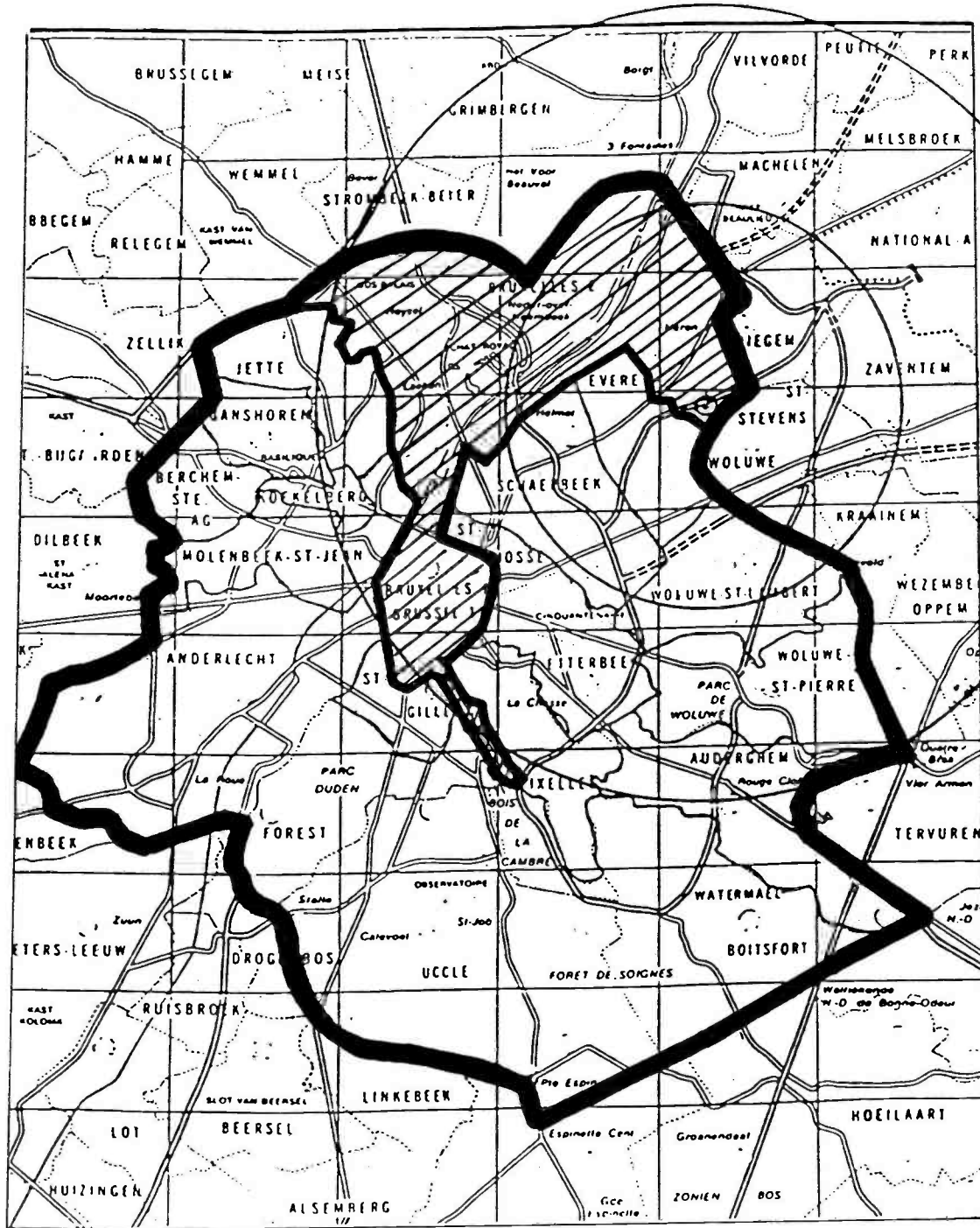
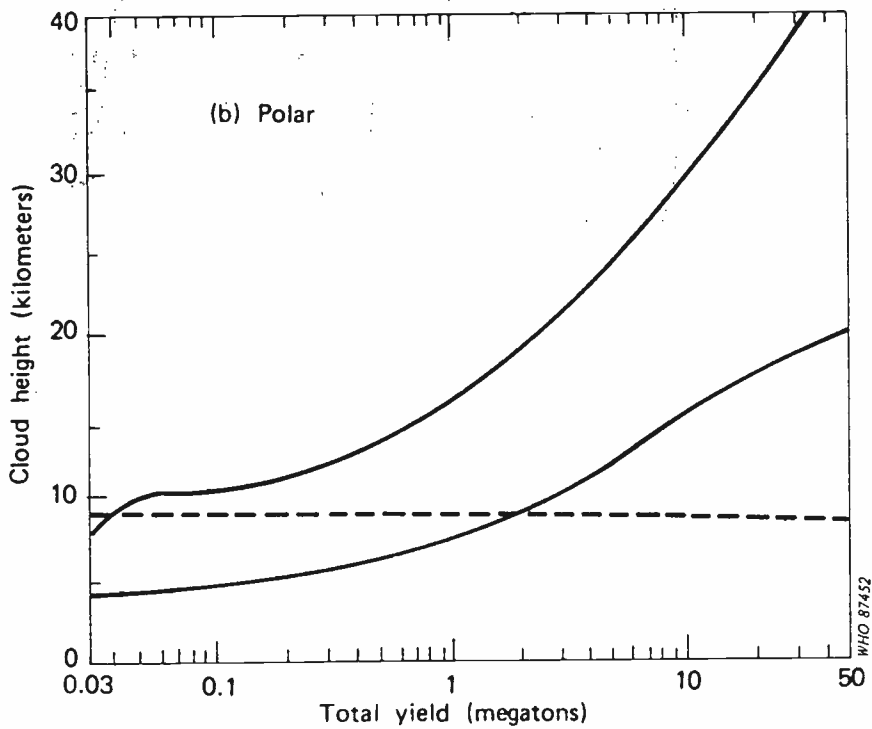Fig. 4. «Mushroom cap» cloud top and base as a function of total yield of device
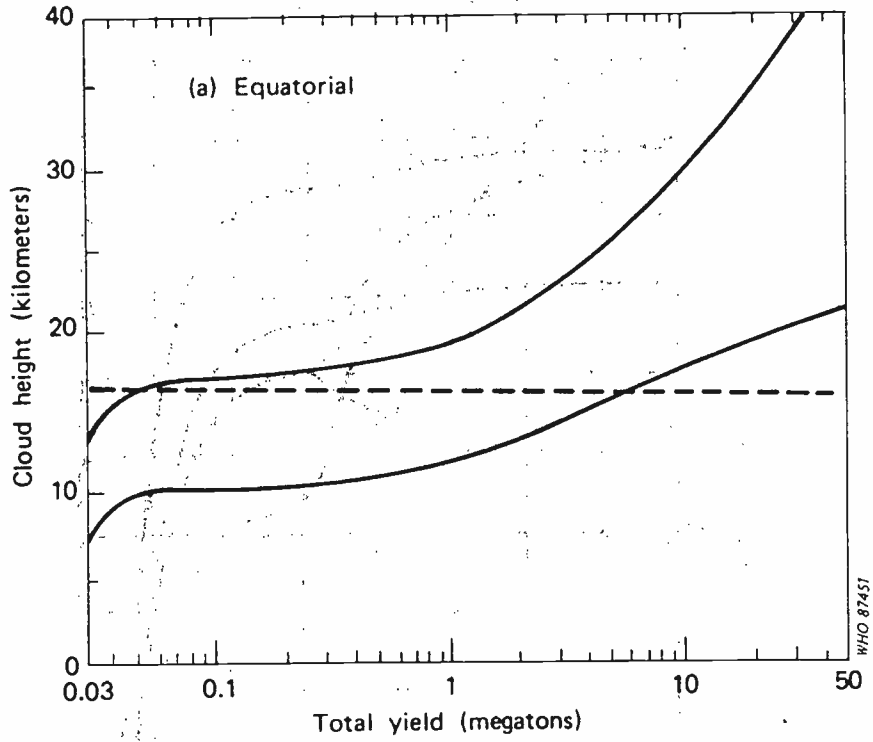
Fig. 5 Gamma—ray dose rate versus time after shutdown or detonation
(see text for explanation of symbols)
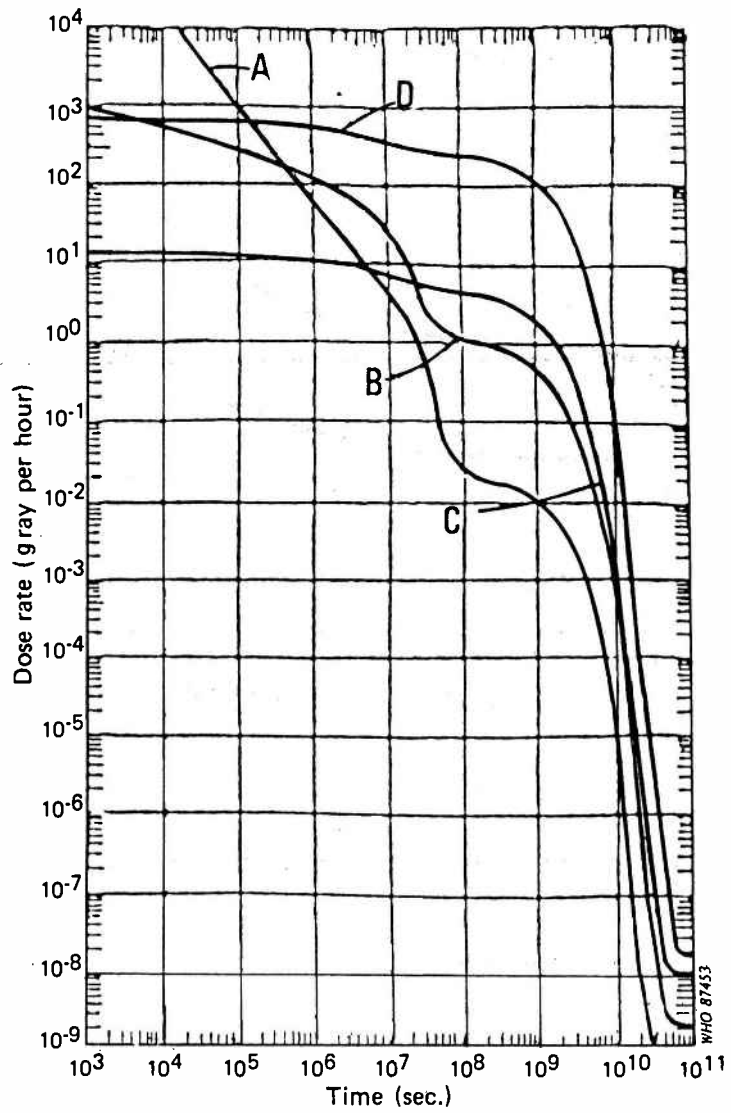
Fig. 6 Dose-response relation for leukaemia and chromosome
aberrations in Hiroshima and Nagasaki

Total leukaemias vs total dose to marrow

(a)

Chromosome aberrations in the adult health study

(b)

Fig. 7a Gamma-ray components of Kerma in Hiroshima
(new estimates)

Fig. 7b Gamma-ray and neutron contributions to Kerma
in Hiroshima (new and old estimates)

CLIMATIC EFFECTS OF NUCLEAR WAR

by

Paul J. Crutzen

1. Introduction

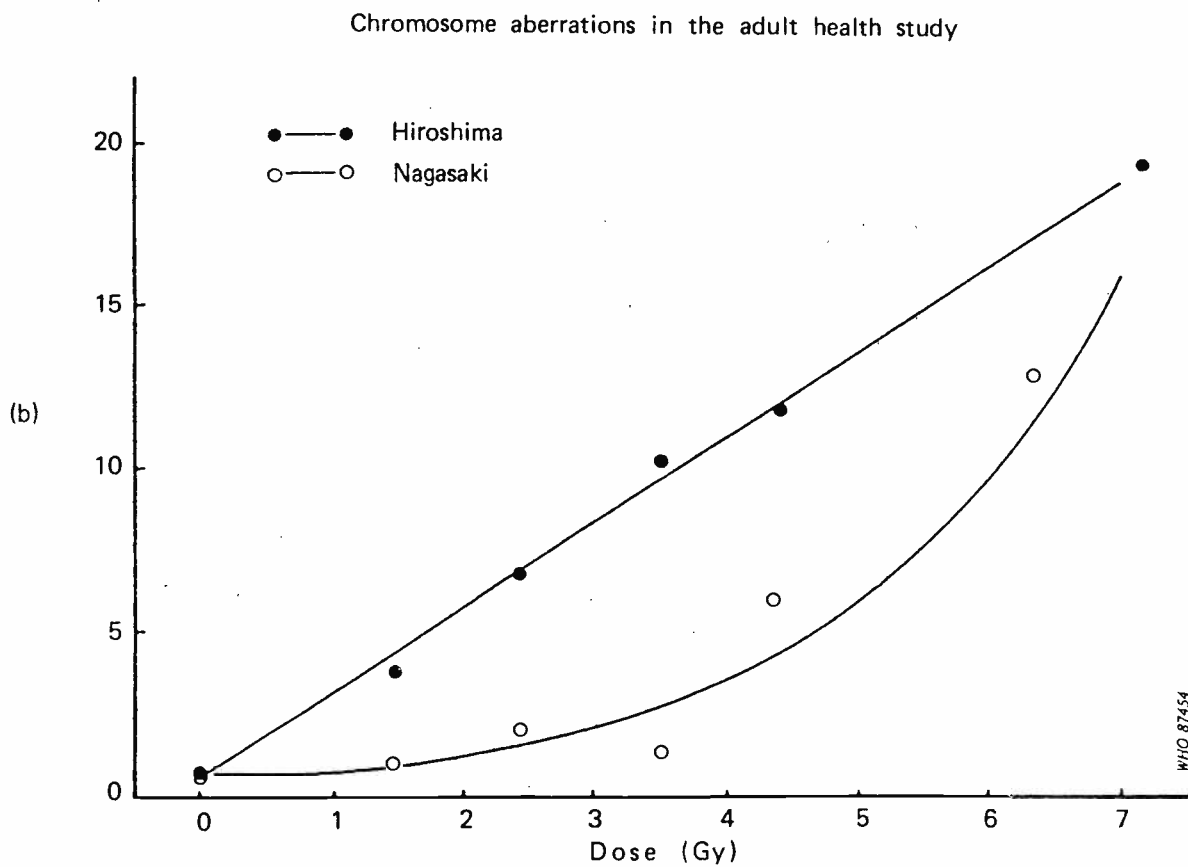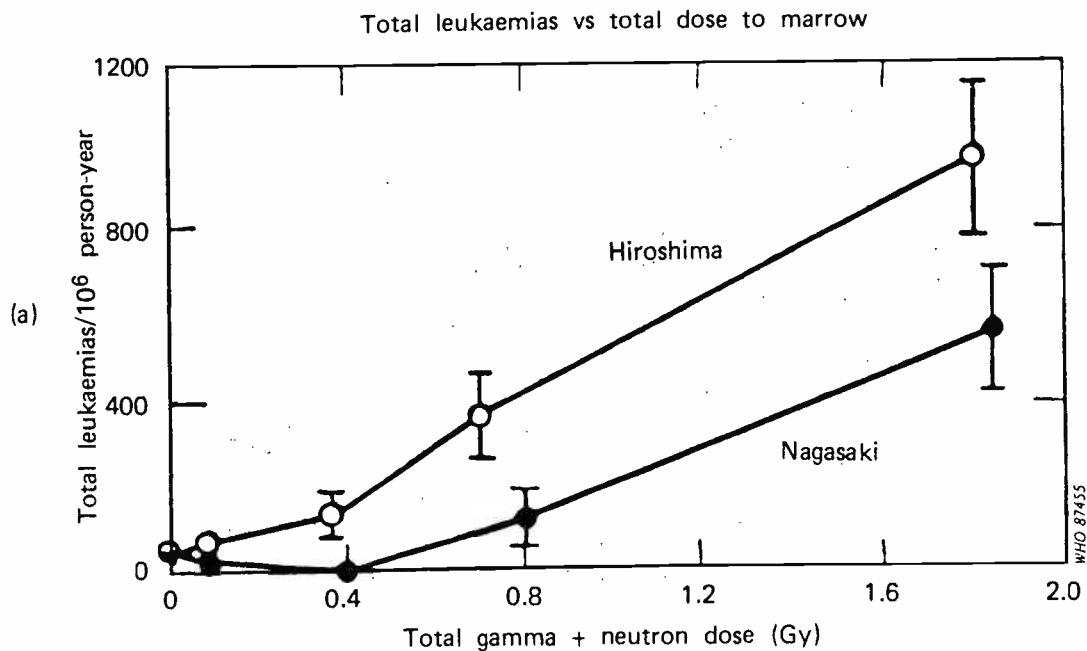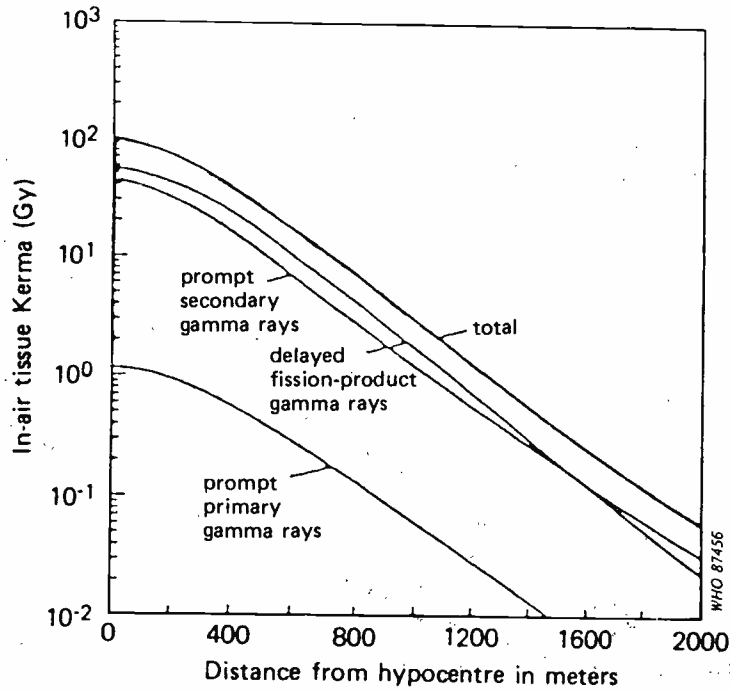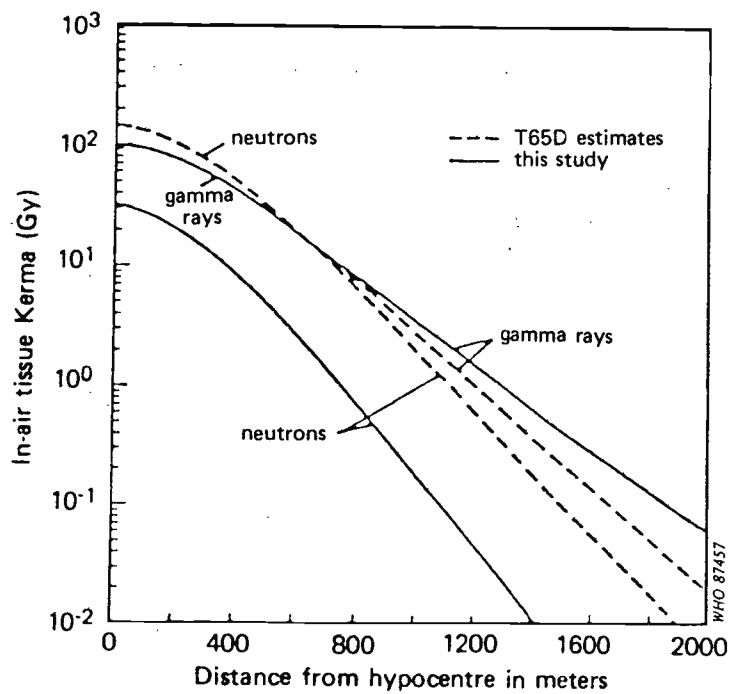The destructive effects of a nuclear war would not be limited to those caused immediately by the nuclear explosions. It has been pointed out during the past few years that severe climatic perturbations could be caused by the large amounts of black smoke that would be produced by extensive fires in urban and industrial centres of the NATO and Warsaw Pact nations, and maybe elsewhere (Crutzen & Birks, 1982; Turco et al., 1983). The black smoke from such fires would be spread through the atmosphere over extensive areas of the globe. An impressive recent example of large-scale spreading of material through the atmosphere is provided by the deposition of radioactive material from the Chernobyl plant in many countries in Europe. The presence of significant amounts of soot in the atmosphere would severely disturb the radiative heat balance of the earth's surface and atmosphere and the effects would not be confined to the war-fighting nations. Many important military targets, such as headquarters and command centres, are located in or near large population centres. Moreover, industrial centres, fossil fuel storage and electric power generating facilities could be prime targets in the event of a nuclear war. Such targeting occurred extensively during the Second World War and is presently the basis for the deterrence doctrine of mutually assured destruction (MAD). It is therefore plausible that in a nuclear war many urban areas would burn and produce large amounts of soot.

Following the original papers on the potential climatic effects of nuclear war, several further studies have been devoted to this problem (Aleksandrov & Stenchikov, 1983; Covey et al., 1984, 1985; Crutzen et al., 1984; MacCracken & Walton, 1984; Cess, 1985; Malone et al., 1985, 1986; Thompson & Schneider, 1986; Thompson et al., 1987). A number of national and international research organizations have now issued critical assessments of the climatic effects. All published assessments and studies agree that serious climatic and other environmental impacts could result from a major nuclear war, particularly if cities and industrial centres were targeted. Following reviews in the United States of America (NRC, 1985) and in Canada (Royal Society of Canada, 1985), the most extensive, international assessment conducted so far has recently been published by the Scientific Committee On Problems of the Environment (SCOPE) of the International Council of Scientific Unions (ICSU). More than 200 scientists from many nations and scientific disciplines participated in this study. The results have been published in two volumes, the first one dealing with the atmospheric effects (Pittock et al., 1986), the other one with the biological impacts, especially on agriculture (Harwell & Hutchinson, 1985). The present review of the current state of knowledge on this subject is substantially based on the SCOPE reviews, updated with the latest findings from recent and ongoing studies.

2. Estimated production of black smoke from a nuclear war

Black carbonaceous smokes are produced during flaming combustion of organic materials. These absorb solar radiation very efficiently and can disturb the atmospheric radiation balance substantially, if large amounts accumulate in the atmosphere. Large quantities of combustible materials are now stored in the developed nations of the world. These are listed in Table 1 (Pittock et al., 1986). According to these estimates, 1-1.5 thousand million tonnes ($1-1.5 \times 10^{15}$ g) of liquid fossil fuels and a similar amount of bitumen are now stored above ground in the developed world. In the latter category about 15-20% is used for roof protection, which would burn readily. The amount of organic polymers that has accumulated in the developed world is almost 0.5×10^{15} g. This quantity is steadily increasing. Turco (1986) has estimated that in 20 years it may amount to 10^{15} g. The quantity of coal stored above ground amounts to about 10^{15} g. Large quantities of wood and wood products, maybe about 15×10^{15} g, have accumulated in the developed world.

Since the publication of the SCOPE study (Pittock et al., 1986), independent estimates on these quantities have also been made by Bing (1986). His estimated quantities of wood and wood products in the NATO and Warsaw Pact nations is about 40% of the amount derived by SCOPE; his total for liquid fossil fuel and polymeric materials is, however, quite close to the SCOPE estimate. The difference in estimated amounts of cellulosic materials reflects uncertain statistics and different ways of derivation. The SCOPE study used available, accurate statistics on the annual production of the various combustible materials. However, in estimating the available quantities of these materials, average lifetimes for these materials were assumed that are uncertain. Bing (1986) attempted to estimate the available quantities of combustible materials from uncertain extrapolations of surveys of fuel loadings in a few locations in the United States of America. As the most important category of combustible materials for soot formation are fossil fuels and fossil fuel derived products, when it comes to the potential production of soot the estimates on potential soot production by Pittock et al. (1986) and Bing (1986) agree quite well with each other.

Different materials produce smoke with different yields, expressed as Y (gram smoke produced per gram matter burned), and different degrees of blackness. The blacker the smoke, the more it absorbs sunlight and the greater its climatic impact. The blackness of the smoke is determined by its amorphous elemental carbon content (r_{EC}) expressed as a percentage. Fossil fuels, such as oil and coal, and materials derived from fossil fuels, such as asphalt and plastics, produce relatively large quantities of black sooty smoke. From small sample test fires in the laboratory, it can be roughly estimated that for these materials Y = 5-10% and r_{EC} = 60-80%. For wood and many wood-derived products, which contain oxygen, smoke and soot yields are generally much smaller, so that Y = 1-2% and r_{EC} = 25-35%. These values are, however, quite uncertain, maybe by a factor of two. This problem was also discussed by Penner (1986). Furthermore, a major question is whether the given values of Y and r_{EC}, that are obtained from small test fires, are also applicable to the large-scale, mass fire conditions that would develop in the event of a nuclear war. It is possible that under such conditions smoke and elemental carbon yields may be appreciably larger than the estimates given above, because access to oxygen could be substantially limited. This and other complex factors in fire behaviour establish major uncertainties which cannot be resolved from available data. Although some better information can be obtained by larger scale experimentation, major uncertainties will remain because it is not possible to simulate mass fire behaviour on the scale of burning cities.

They are many ways in which a nuclear war might be fought. The potential targets for "counterforce" and "countervalue" attacks number about 100 000. It is conceivable that a nuclear exchange would start with "counterforce" attacks against the war-fighting capability of the opponent. Such targets include missile silos, military bases and airfields, command and communication centres, major airports, fuel depots and military industries. Many of these are, however, located within major urban centres, so that it is practically impossible to distinguish between "counterforce" and "countervalue" attacks. Although there are strategists who believe that a limited nuclear war may be possible (because common sense would end the war before major and uncontrollable escalation would occur), others believe that a limited nuclear war would inevitably develop into a large-scale nuclear war.

Earlier studies published by Ambio (see Peterson & Hinrichsen, 1982) and the United States National Research Council (NRC, 1985) had adopted nuclear war scenarios with a 6000 Mt total weapon yield divided among more than 12 000-15 000 warheads. In these scenarios about 30% of the total yield of nuclear weapons were assumed to be used against urban/industrial centres. Because of ensuing fires, such targeting could lead to the production of large amounts of black smoke. In the SCOPE study (see Pittock et al., 1986) the war is assumed to escalate from counterface attacks against purely military targets (1000 Mt, 5000 warheads) to extended counterforce attacks involving colateral damage to urban centres (1000 Mt, 4000 warheads), bombing of industrial centres (1000 Mt, 1200 warheads), and finally retaliatory attacks aimed against major urban centres (1000 Mt, 2600 warheads). This is, of course, purely hypothetical, and it is quite conceivable that the escalation is stopped at any step. The important question, however, is what would be the consequences if escalation would not stop, so that many major urban centres would start burning, releasing large amounts of black smoke in the atmosphere.

In the SCOPE study, as shown in Table 1, estimates were first made of the total quantities of combustibles that are stored in the industrial and urban centres of the developed world and the assumption was made that about 25% of these combustibles would burn

in a nuclear war. This would imply that about 2000 million tons of wood and wood products, and 700 million tons of fossil fuel and fossil fuel derived products, such as plastics and asphalt, would be consumed by the fires. With the above given estimates of smoke and amorphous elemental carbon yields for these types of materials, a total of about 80 million tons of smoke, containing an estimated 45 million tons of black carbon would be produced. This quantity of smoke could also be produced by nuclear attacks in which about a hundred major cities (see Table 2) and/or major fossil fuel storage facilities would burn. This would require a total use of weapons of less than 1000 megatons, i.e. a small fraction of the available nuclear weapons, which is certainly conceivable as part of a series of escalating retaliatory exchanges. Of greatest importance would be the production of sooty smoke from fires in oil and coal storage facilities and from burning asphalt in cities, especially the 15-20% of the asphalt which is used for roof protection. The black smoke injected in the atmosphere would be rapidly spread by atmospheric winds around the globe.

3.   Removal of smoke by precipitation

Not all black sooty smoke that is produced by fires will stay in the atmosphere long enough to be spread over long distances. A fraction of the smoke entrained in the convective clouds that would be induced by hot mass fires would be removed by precipitation. There is considerable uncertainty about how much. There are arguments both for and against efficient precipitation scavenging of the sooty smoke particles. If most smoke particles consisted of hydrophobic submicron ($<$ 1 μm radius) particles precipitation scavenging would likely be inefficient. On the other hand, if the particles were highly active as cloud condensation nuclei, or would become so by collection of gases or particles, then they could grow by water condensation within the clouds to such sizes that they might be captured by large precipitating cloud drops that tend to form in towering cumulonimbi under normal circumstances. In that case precipitation scavenging would occur. However, both laboratory and field data show that fresh soot particles are poor condensation nuclei with only a few per cent. active at typical cloud supersaturations (Radke et al., 1980a). Moreover, overseeding of the clouds could occur due to the large number of ambient condensation nuclei and dust particles swept up with the smoke. In this case precipitation could be inhibited altogether. Also, if ice forms, any smoke captured by nucleation scavenging may be released, as ice formation will evaporate the drops (Penner, personal communication). It therefore appears that precipitation scavenging might be relatively inefficient. Micro-physical cloud processes may, however, play a substantial role in establishing the morphology of the smoke particles released to the atmosphere, which may become mixed with dust particles. They may also become more spherical than the original soot agglomerates.

It is also often found that only a fraction (15-65%) of the water that condenses in natural, convective clouds comes down as precipitation. The remaining fraction of the water (or ice) is carried upwards in the strong convective currents and deposited in the anvil outflows in the top of the clouds. These anvil clouds would evaporate efficiently during daytime and mix with ambient air as the strongly sunlight absorbing soot particles would heat the air. On the other hand, during a few days following the fires night-time radiative cooling could lead to thermal destabilization of the upper troposphere, followed by cloud formation and precipitation scavenging of some unknown fraction of the smoke, depending on its physical-chemical properties, or its redistribution over the depth of the troposphere. These are clearly very complex processes about which there exists very little observational evidence even for natural atmospheric conditions, let alone for the highly disturbed and unpredictable conditions that would develop after the inputs of massive amounts of smoke by many almost simultaneously occurring mass fires. Clearly, the atmospheric behaviour during the first hours to days after the mass fires have started is an important uncertainty for the assessments of nuclear war effects. In this area much additional research is needed, although uncertainties will remain because achievable experimental scales can never come close to those likely in a nuclear war, and the range of potential extremes is so large that every situation cannot be studied.

In the studies that have been conducted so far to estimate the atmospheric consequences of large-scale nuclear war, it has generally been assumed that 30-50% of the smoke would be removed rather promptly from the atmosphere by precipitation scavenging. According to the conclusions of the SCOPE study, the actual fractions may be larger or smaller (Cotton et al., 1986; Hobbs et al., 1984; Radke et al., 1980), although more recent studies presented since the publication of the SCOPE reports point more towards smaller values (Pruppacher, 1986; Penner, 1986). Sooty smoke is most difficult to remove by precipitation and is also most

important for the climatic effects. Moreover, sooty smoke would be deposited in the atmosphere not only by huge mass fires that can create convective storms, but also by fires that move with the ambient winds (conflagrations) and do not produce strong convection and precipitation. During the Second World War firestorms occurred only in Hamburg, Dresden, Tokyo and Hiroshima.

Of particular interest might be the physical properties of the extremely sooty smoke that is produced in "pool fires" that would be created by the targeting of large oil storage facilities. Although such fires would create sooty smokes extremely efficiently, with yields conceivably much larger than the average assumed in the SCOPE study, it may be that predominantly large soot flakes are formed that can settle out of the air by gravitation or that may be removed efficiently by rains. No observational data are yet available on this important issue.

4. Optical and radiative effects

Although uncertainties remain it appears that, even after "dry" coagulation, the absorption of sunlight by aggregates of black smoke, quite independently of their size, may be expressed by a specific absorption at visible wavelengths that equals about 8-10 m^2 per gram of amorphous elemental carbon (e.g., Ackerman & Toon, 1981; Gerber & Hindman, 1982; Lee, 1983; Roessler & Faxvog, 1980; Rosen & Hansen, 1984; Wolff & Klimisch, 1982). Similar or even larger specific absorption may apply if the soot particles are incorporated in water droplets or snow (Chylek et al., 1983; Warren & Wiscombe, 1985; Ackerman & Toon, 1981). Release of soot particles into the atmosphere after evaporation of water droplets may, therefore, not significantly change the absorption properties of the soot particles. It appears that chain-like soot aggregate particles are so rigid that they do not collapse even after severe physical treatment (Anders, 1986).

Taking into account the probably too high SCOPE estimates of early removal of 30-50% of the smoke particles, about 30 million tons (3×10^{13} g) of amorphous, elemental carbon could be spread through the atmosphere in the days, weeks and months following the outbreak of the nuclear war. We assume that this amount of soot would be injected into the atmosphere within a few days or weeks. Multiplied with the specific absorption of 8-10 m^2 per gram of amorphous elemental carbon for sunlight, 30 million tonnes of black smoke would represent a total absorption area of $2.4-3 \times 10^{14}$ m^2, which is roughly equal the total area of the northern hemisphere. From this simple analysis it is clear that a substantial fraction of sunlight could be absorbed in the atmosphere instead of at the earth's surface.

If the black smoke would be located above several kilometre altitude, which is most likely, strong cooling at the ground, especially at locations removed from ocean influence, would follow. This cooling is, however, not only caused by the strong reduction of solar radiation of the earth's surface, but even more so because the atmospheric "greenhouse" warming is strongly diminished as outgoing infra-red terrestrial radiation would be trapped much less efficiently by CO_2 and H_2O than under normal conditions, when most heat radiation emanates from deep down in the atmosphere or from the earth's surface (see Fig. 1). Under disturbed conditions, when most sunlight is absorbed high in the atmosphere, the infra-red radiation emission to space from the heated, smoke containing, atmospheric layers is much less efficiently trapped by the much smaller amounts of CO_2 and H_2O in the overlying atmosphere. The soot particles are far more efficient in absorbing incoming, short wavelength, solar radiation than outgoing, infra-red, terrestrial heat radiation. Their presence would not only lead to a cooling of the earth's surface but also to a heating of higher layers in the atmosphere by the absorption of solar radiation by the black smoke particles. This would cause strong meteorological inversion conditions and reduced rainfall over large areas of the continents.

5. Estimations of climatic effects

Several of the atmospheric disturbances following a nuclear war that were first calculated with simple one-dimensional models (Turco et al., 1983; Crutzen et al., 1984) have now also been simulated with three-dimensional climate models of the atmosphere. Adopting the estimated amounts of atmospheric smoke inputs as given before (about 30 million tons of black carbon), advanced global climate models calculate sharp temperature

drops in continental interiors, especially during summer. Outbreaks of cold air could, however, affect locations with more maritime types of climate as well (Aleksandrov & Stenchikov, 1983; Covey et al., 1984, 1985; Malone et al., 1985, 1986; Thompson & Schneider, 1986; Thompson et al., 1987).

From available studies at the time of writing, the SCOPE scientists estimated a range of possible temperature drops for summer and winter war conditions. Taking into account the most recent results from model calculations, as shown in Figs 2-5 (Thompson & Schneider, 1986; Thompson et al., 1987) the SCOPE estimates would have to be reduced by 30-50%. About 70% of this reduction was caused by the full consideration of the role of smoke particles in the transfer of terrestrial infra-red radiation; the remaining 30% is due to the inclusion of precipitation scavenging of smoke particles. Despite the reductions in estimated climatic effects, Thompson & Schneider (1986) reconfirm their potential severity for agriculture in extensive areas around the world. Furthermore, the new model results by Thompson & Schneider probably underestimate the climatic effects for the following reasons:

(a) precipitation scavenging is overestimated because it is assumed that each precipitation event leads to total scavenging of the smoke;

(b) the simulation of boundary layer processes in the model is such that dynamic heat transfer from warmer air to the cold surface remains quite effective despite the development of a strong temperature inversion near the ground, which tends to inhibit it.

Taking into account these factors, a reduction in land surface temperatures by less than 25% may be proposed tentatively compared to the SCOPE estimates, leading to the values given in Tables 3 and 4. Although the very deep temperature drops estimated before may now seem less likely, ecologically important reductions of land surface temperatures, especially far away from the coastal zones, remain a credible outcome of a nuclear war (Harwell & Hutchinson, 1986), including some occurrence of temperatures near and below freezing in regions under dense smoke clouds.

An important finding of recent climate modelling is also the possibility that the absorption of solar radiation by the black smoke would heat the air, causing it to rise into the stratosphere and from there to move into the southern hemisphere. Such transport would be particularly important from March to September. As a consequence, the average atmospheric residence time of a significant fraction of the smoke would become much longer, extending its impact to maybe several years (Crutzen & Birks, 1982; Thompson & Schneider, 1986; Malone et al., 1985; Haberle et al., 1985). Under those conditions chemical oxidation of the soot particles by ozone may become an important chemical removal mechanism. A typical removal time for pure soot particles may be about one month (Silver et al., 1986). A question herewith is, however, whether the soot particles might not become coated with other materials that are resistant to attack by ozone. In this likely event, the lifetime of the soot particles would become appreciably larger.

6. Other important atmospheric effects

Many other, potentially serious, physical and atmospheric perturbations could result from nuclear war, such as the deposition of radioactivity on the earth's surface, the input of soil dust in the atmosphere (leading to some additional surface cooling), depletion of stratospheric ozone, and releases of air pollutants and toxic chemicals from fires and chemical industries. All these factors are individually significant, especially locally or regionally. In combination with the climatic disturbances pictured above, the atmospheric consequences could become severe. Synergistic biological effects would most likely strongly multiply the individual impacts.

The direct input of NO into the stratosphere in the fireballs of nuclear explosions by itself can lead to significant hemispheric total ozone depletions by 10-30% within a few months. In addition, however, strongly altered atmospheric temperatures and circulations driven by the absorption of solar energy by the high altitude sooty smoke could lead to much larger ozone depletions. Higher temperatures in the stratosphere strongly favour such reactions that destroy ozone. Upward motions triggered by the absorption of sunlight at high altitudes in the northern hemisphere would move tropospheric air containing little ozone into the stratosphere. After the tropospheric smoke is removed large enhancements in the

penetration of biologically harmful radiation to the earth's surface would become possible, despite the absorption of UV-B by the stratospheric smoke itself. The reason is that the level of ultraviolet radiation is particularly sensitive to the total, vertical ozone column, so that simultaneously visible solar radiation fluxes might be reduced and ultraviolet radiation fluxes enhanced.

The large amounts of common air pollutants and hazardous chemicals that would be injected in the lower atmosphere from smouldering fires and industrial chemical releases under normal meteorological conditions could lead to severe hazardous atmospheric pollution conditions in the immediate vicinity of the pollution sources. Furthermore, the rapid cooling of the lower troposphere and heating of the higher layers of the atmosphere would favour formation of very strong and shallow temperature inversions that would trap chemical emissions near the ground, especially in densely populated lowland areas and valleys. This might allow concentrations of many air pollutants and chemicals, and of cold polluted fogs to reach hazardous levels for man, animals and biosphere over substantial areas of mid- and high-latitude continents. Among the fire effluents carbon monoxide would be most critical in most situations, but synergistic effects in combination with high concentrations of other air pollutants may create critical health problems. Evaporative losses from chemical industries may substantially aggravate the situation in highly industrialized areas.

7.   Summary of major atmospheric effects

The SCOPE scientists realized that there are many uncertainties regarding input, removal, and physical properties of smoke, but nevertheless reached what may be called a consensus report in which every effort was made to describe the scientific uncertainties, and specific proposals for further research were made. In making assumptions about scenarios, physical processes, and magnitudes of smoke injections, the study avoided extreme assumptions and "worst case" analyses. Therefore, it was, for example, decided not to use the term "nuclear winter" in the report because it has become associated primarily with the potentially most severe climatic consequences of a nuclear war, that of the simultaneous coverage of a large fraction of the earth's surface with subfreezing temperatures. Consequently, the term does not properly imply the range of complexity and uncertainties of the problem. This does, however, not mean to suggest that the environmental consequences of a major nuclear exchange would not be substantial. On the contrary, SCOPE concluded that they could be very serious, far more than was thought possible only a few years ago. All of the simulations of the climatic perturbations following a nuclear war indicate a strong potential for large-scale weather disruptions as a result of extensive post-nuclear fires. The biological SCOPE study in addition shows that relatively small climatic perturbations, far less than "nuclear winter", could have far-reaching consequences (Harwell & Hutchinson, 1986). The main conclusions by SCOPE regarding the possible climatic consequences of a nuclear war, adjusted by the latest developments (Thompson & Schneider, 1986), are the following:

(1) For massive smoke injections, especially if they would occur during the growing season (March to October) in the northern hemisphere, land surface temperatures beneath dense smoke clouds are estimated to decrease in mid-continental sites to 10-25°C below normal within a few days. Some of the smoke clouds may be transported rapidly over long distances, thereby causing episodic cooling, maybe below freezing, over a substantial fraction of the continents of the northern hemisphere. Especially during the first weeks, atmospheric conditions could be extremely variable over large portions of the northern hemisphere, when dense smoke clouds that allow practically no sunlight through alternate with clearer conditions.

(2) Although smoke would be spread in the higher atmospheric layers over much of the northern hemisphere within two weeks, the smoke coverage would be far from homogeneous. For injections during the growing season, solar heating of the smoke-laden air could cause rapid upward transport of a substantial fraction of the smoke into the stratosphere. Here, particles would remain suspended for months to years because they cannot be removed by rainfall. Oxidation by reaction with ozone may then determine the lifetime of the soot particles. The lifetime of the smoke particles at lower heights may also be much prolonged, because warming of the upper troposphere and stratosphere and cooling of the earth's surface would suppress vertical mixing and precipitation scavenging.

(3) Over large areas of the northern hemisphere average land surface temperatures could drop to levels typical of autumn or winter for weeks or much longer even during summertime, with convective precipitation being essentially eliminated. In continental interiors, especially at mid and high latitudes, periods of freezing temperatures are possible. Cold air outbreaks could also rapidly reach into regions with more maritime climates and into more southerly regions that rarely or never experience such low temperatures. In wintertime light would be more strongly reduced, but the initial temperature and precipitation perturbations would be less pronounced. In that case anomalously severe winter conditions would, however, occur simultaneously at least over the mid-latitude regions of the northern hemisphere. Temperatures in the subtropics could drop well below typical cool season conditions.

(4) Transport of a significant fraction of the smoke to the southern hemisphere is possible for that portion that reaches the stratosphere. Although the occurrence of freezing conditions in the southern hemisphere is unlikely, significant long-term meteorological effects are quite possible. The duration of these disturbances is very hard to estimate. For many regions of the globe the most important long-term impacts might not be the lowered air temperatures but less rainfall. A reduction in the summer monsoon rains over Asia and Africa may be a particular concern.

Conclusion

Although considerable further research has been conducted since the writing of the SCOPE study, the main conclusions reached in early 1986 about the potential climatic, atmospheric chemical, ecological, and agricultural consequences of a nuclear war are still valid, also taking into account the latest research results by Thompson & Schneider (1986).

The main finding of the SCOPE study is that severe, large-scale, possibly global, climatic disturbances could result from a nuclear war in which a substantial fraction (10% or more) of the combustible materials in the NATO and Warsaw Pact nations would burn, producing several tens of million tonnes of soot. This could be caused by nuclear attacks on less than a hundred of the most important urban and industrial centres of these nations. As a consequence, it is estimated that surface temperatures might drop by more than 10°C over a large fraction of the continents in the northern hemisphere and that rainfall could also be strongly reduced. These effects could last for weeks, maybe years. In many parts of the northern hemisphere agricultural productivity would be severely reduced, contributing to serious food shortages.
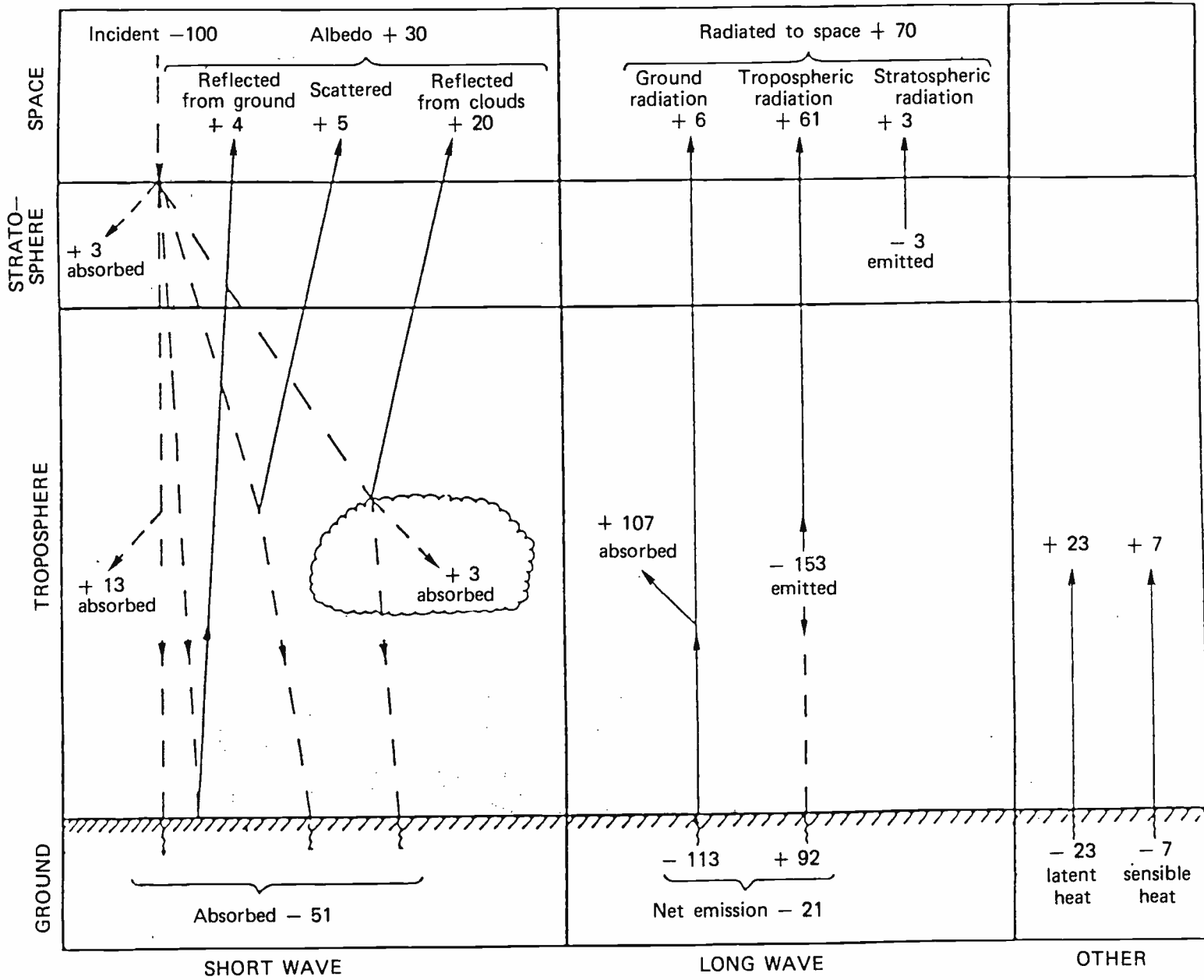
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Legends to the figures

Figure 1: The mean global energy balance of the atmosphere and the earth's surface. Of the incoming solar radiation (see left panel) about 30% is reflected back to space; almost half is absorbed at the earth's surface, and the remainder is absorbed in the atmosphere. The solar energy absorbed at the earth's surface (51 units) is partly given off to the atmosphere by rising warm air currents (7 units) and condensation of water vapour that is released from the surface (23 units). The remaining 21% is given off at long wave terrestrial radiation. This radiation is trapped efficiently by water vapour, carbon dioxide and ozone in the atmosphere, causing the earth's surface to warm to an average temperature of about 15°C. The earth's surface radiates therefore as much as 113 units of radiation, of which 92 are returned from the atmosphere (middle panel). This is the so-called atmospheric "greenhouse" effect. When solar radiation would be absorbed high in the atmosphere, the earth's surface and lower atmosphere would cool, because less solar radiation would reach the ground. Even more important, the "greenhouse" warming would be much reduced, because there is much less H_2O and CO_2 at greater altitudes.

Figure 2: Calculated global distribution of surface temperatures in July for simulated normal conditions in the atmosphere (from Thompson et al., 1986).

Figure 3: Calculated July surface temperatures for day 5 after the outbreak of a nuclear war (Thompson et al., 1986). The infra-red effect of smoke particles and rainout are taken into account.

Figure 4: As Fig. 3, but for day 30 after the outbreak of nuclear war.

Figure 5: Calculated reduction of global surface temperature averages for days 5-15 following the outbreak of a nuclear war (from Thompson et al., 1986). The infra-red effects of smoke and their rainout are taken into account.

Figure 1: revised from London (1957), taking into account more recent information.

Reference: J. London, a study of the atmospheric heat balance, final report contract No. AF 19 (122)-165, New York University, 1957.

FIG. 1

SURFACE TEMPERATURE (°C)

Fig. 2

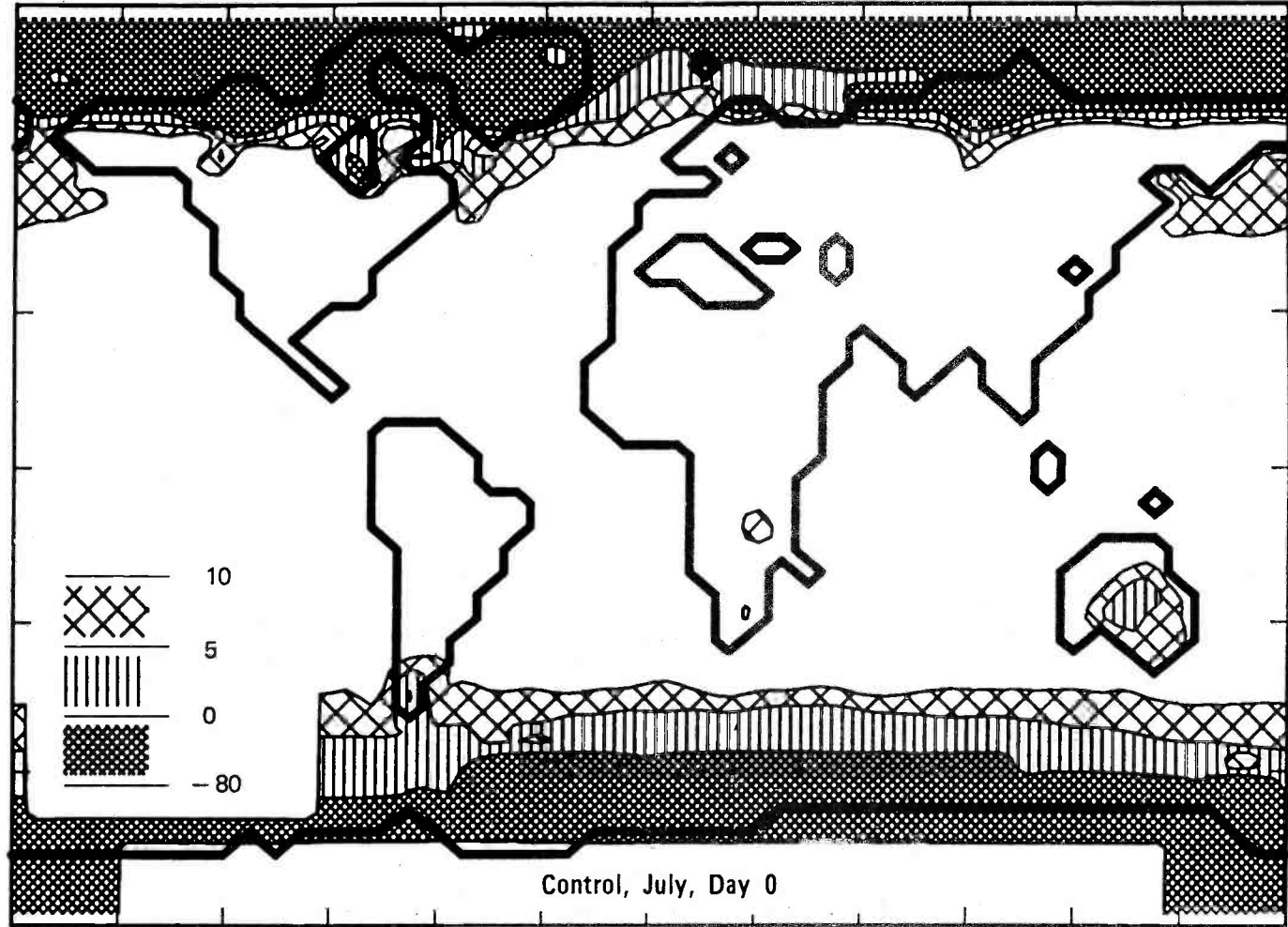Control, July, Day 0

FIG. 2

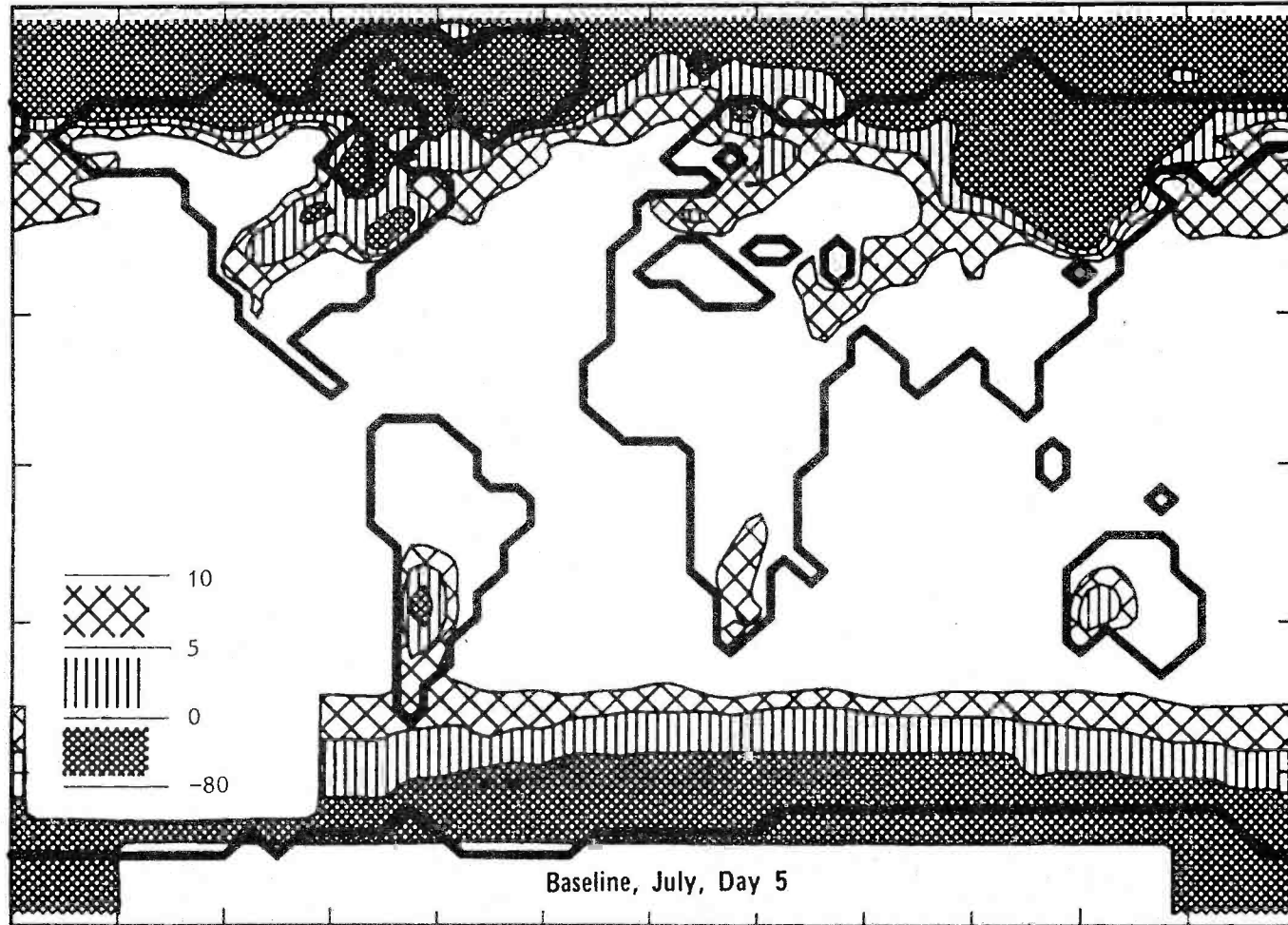Baseline, July, Day 5

FIG. 3

SURFACE TEMPERATURE (°C)

Fig. 4

Baseline, July, Day 30

FIG. 4

WHO 87461

Fig. 5

SURFACE TEMPERATURE CHANGE (°C)   PERTURBED — CONTROL

Baseline, July, Days 5 — 15

WHO 87462
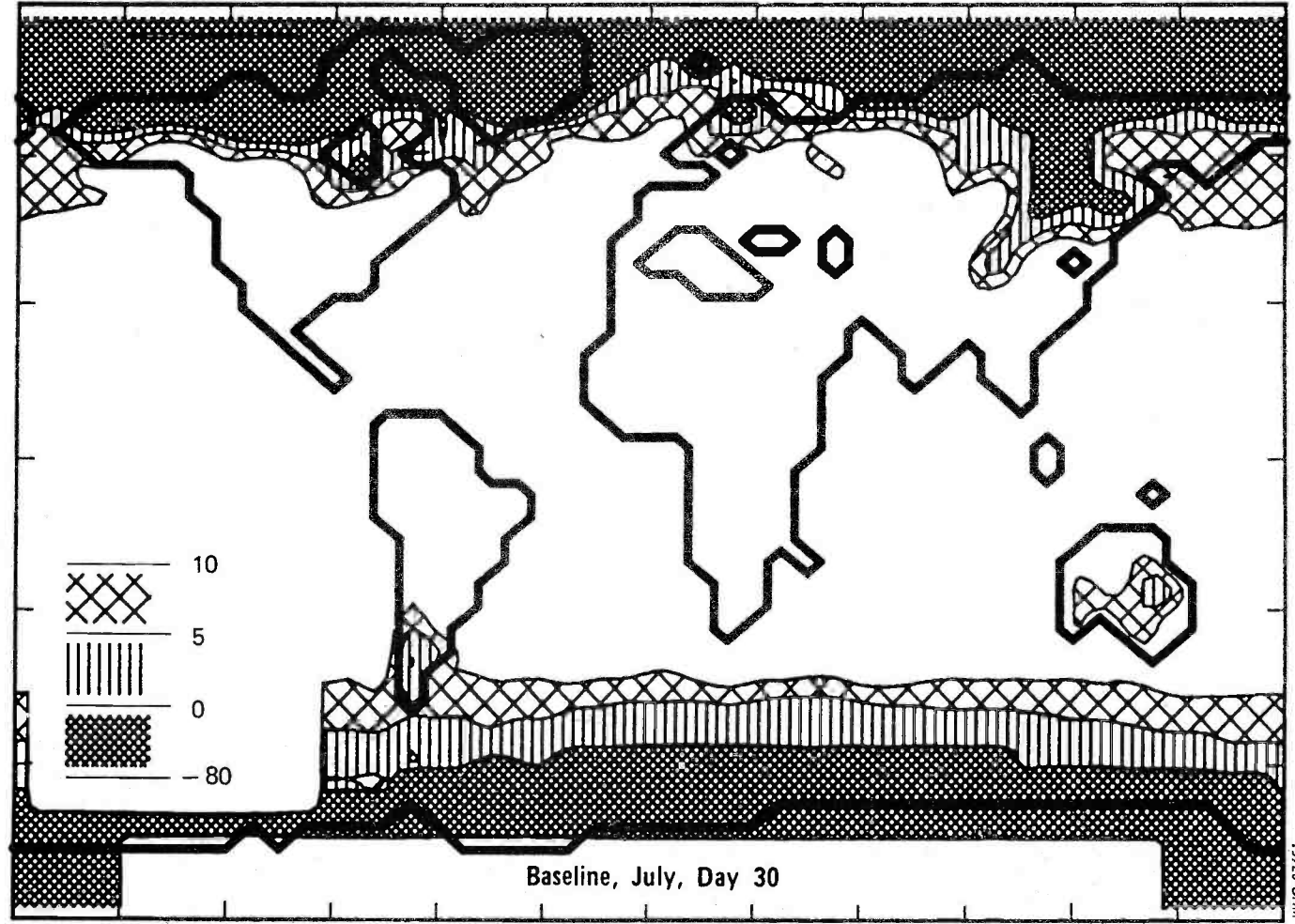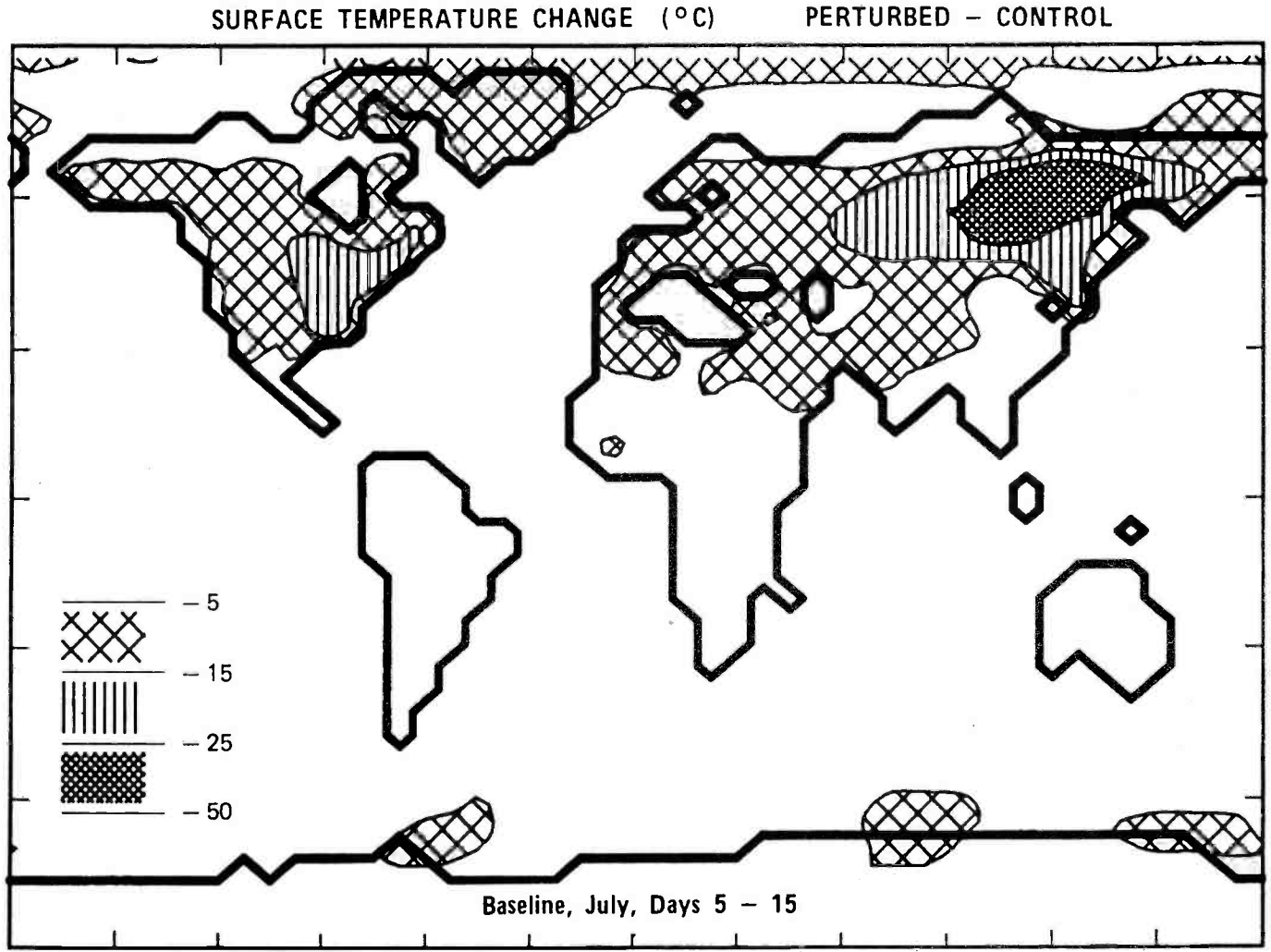
FIG. 5

TABLE 1.   ANNUAL PRODUCTION OF VARIOUS COMBUSTIBLE MATERIALS AND
ESTIMATED ACCUMULATED QUANTITIES IN THE DEVELOPED WORLD

Material	Production (g/y)	Accumulation (g)
Liquid fuels	3.1×10^{15}	$1.1-1.5 \times 10^{15}$
Coal, lignite	3.5×10^{15}	$\sim 10^{15}$
Natural gas and liquids	8.9×10^{14}	1.5×10^{14}
Sawnwood, panels, etc.	3.4×10^{14}	1.4×10^{16}
Pulp, paper, paperboard	9×10^{14}	$\sim 10^{15}$
Bitumen, total	(7×10^{13})	$(1-1.5 \times 10^{15} \text{ g})$
roof protection	10^{13}	$\sim 2 \times 10^{14}$
city roads	3×10^{13}	6×10^{14}
Organic polymers	(7×10^{13})	(4.6×10^{14})
plastics	4×10^{13}	2×10^{14}
resins and paint	1.2×10^{13}	1.2×10^{14}
fibres	1.4×10^{13}	1.4×10^{14}
Cotton	10^{13}	10^{14}
Fats and oils	7×10^{13}	2×10^{13}
Cereals	3×10^{14}	$0.5-2 \times 10^{14}$

Source: from Pittock et al. (1986).

TABLE 2.   POPULATION AND NUMBER OF CITIES IN THE DEVELOPED WORLD
IN GIVEN SIZE CLASSES

Size class (millions)	Number of cities	Total population (millions)
> 4	16	142
2-3.9	27	73
1-1.9	74	99
Sum	117	314
Total urban		834

Source: from Pittock et al. (1986).

TABLE 3.   TEMPERATURE ANOMALIES IN °C FOR SMOKE INJECTIONS
ASSUMED BY SCOPE/ENUWAR FOR A NUCLEAR WAR TAKING PLACE IN
SUMMER IN THE NORTHERN HEMISPERE
(INITIAL SCOPE ESTIMATES BY PITTOCK ET AL. (1986)
WERE REDUCED BY 25%)

Region	Acute (first few weeks)	Intermediate (1-6 months)	Chronic[b] (first few years)
Northern mid-latitude continental interiors	-10 to -25 when under dense smoke[a]	-5 to -20	0 to -10
Northern hemisphere coastal areas[b]	Very variable 0 to -5 unless off-shore wind	Very variable -1 to -5 unless off-shore wind	Variable 0 to -5
Tropical continental interiors	0 to -10	0 to -10	0 to -5
Southern mid-latitude continental interiors	Initial 0 to +5 then 0 to -10 in patches	0 to -10	0 to -5

[a] "Dense smoke" refers to smoke clouds of absorption optical depth of the
order of 2 or greater, staying overhead for several days.

[b] These values are climatological average estimates. Local anomalies may
exceed these limits, especially due to changes in oceanic behaviour such as
upwelling or El Nino-type anomalous situations.

TABLE 4.   TEMPERATURE ANOMALIES IN °C FOR SMOKE INJECTIONS
ASSUMED BY SCOPE/ENUWAR FOR A NUCLEAR WAR TAKING PLACE IN
WINTER IN THE NORTHERN HEMISPERE
(INITIAL ESTIMATES BY PITTOCK ET AL. (1986)
WERE REDUCED BY 25%)

Region	Acute (first few weeks)	Intermediate (1-6 months)	Chronic[b] (first few years)
Northern mid-latitude continental interiors	0 to -15 when under dense smoke[a]	0 to -10	0 to -5
Northern hemisphere coastal areas[b]	Very variable 0 to -5 unless off-shore wind	Very variable 0 to -5 unless off-shore wind	0 to -3
Tropical continental interiors	0 to -10	0 to -5	0 to -3
Southern mid-latitude continental interiors	0	0 to -10	0 to -5
Southern mid-latitude coastal areas	0	0 to -10 in off-shore winds	0 to -5

[a] "Dense smoke" refers to smoke clouds of absorption optical depth of the order of 2 or greater, staying overhead for several days.

[b] These values are climatological average estimates. Local anomalies may exceed these limits, especially due to changes in oceanic behaviour such as upwelling or El Nino-type anomalous situations.

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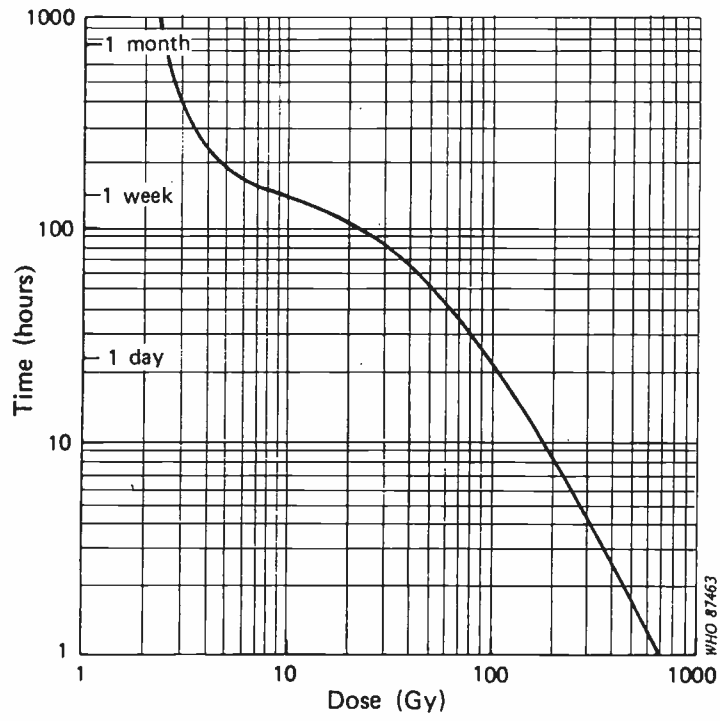
Fig. 2. Acute radiation mortality of mice as a function of dose

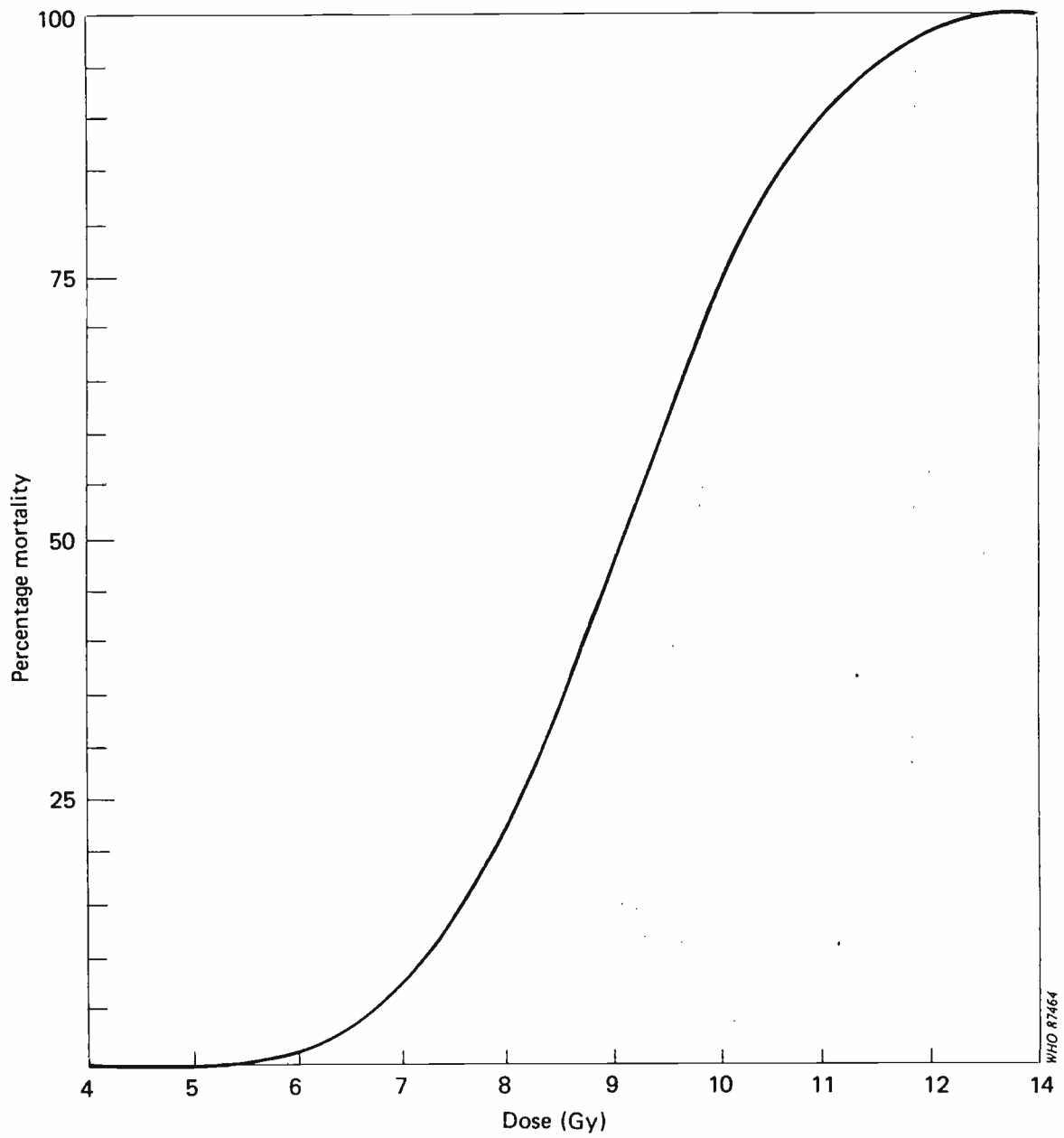Fig. 3a. Percentage mortality as a function of distance from hypocentre in Hiroshima
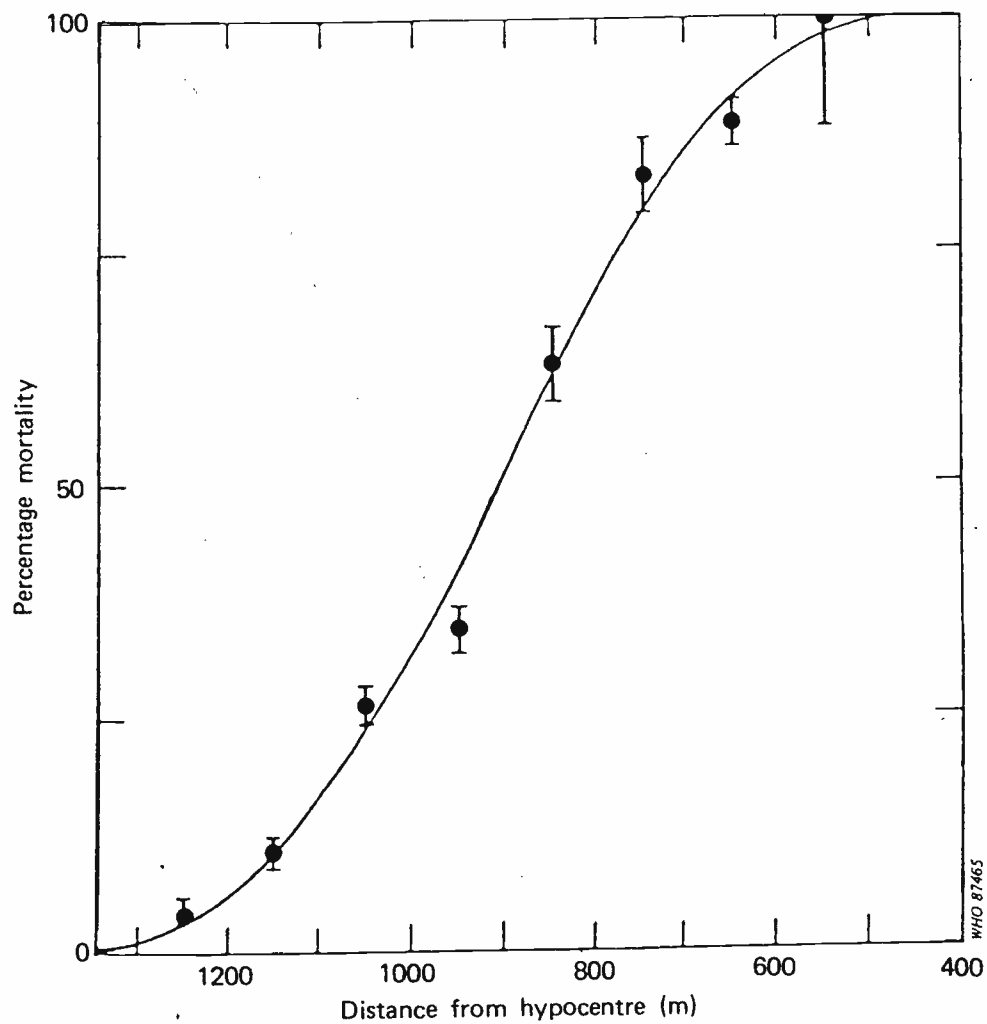
Fig. 3b. Percentage mortality as a function of distance from hypocentre in Hiroshima (note the probability scale)
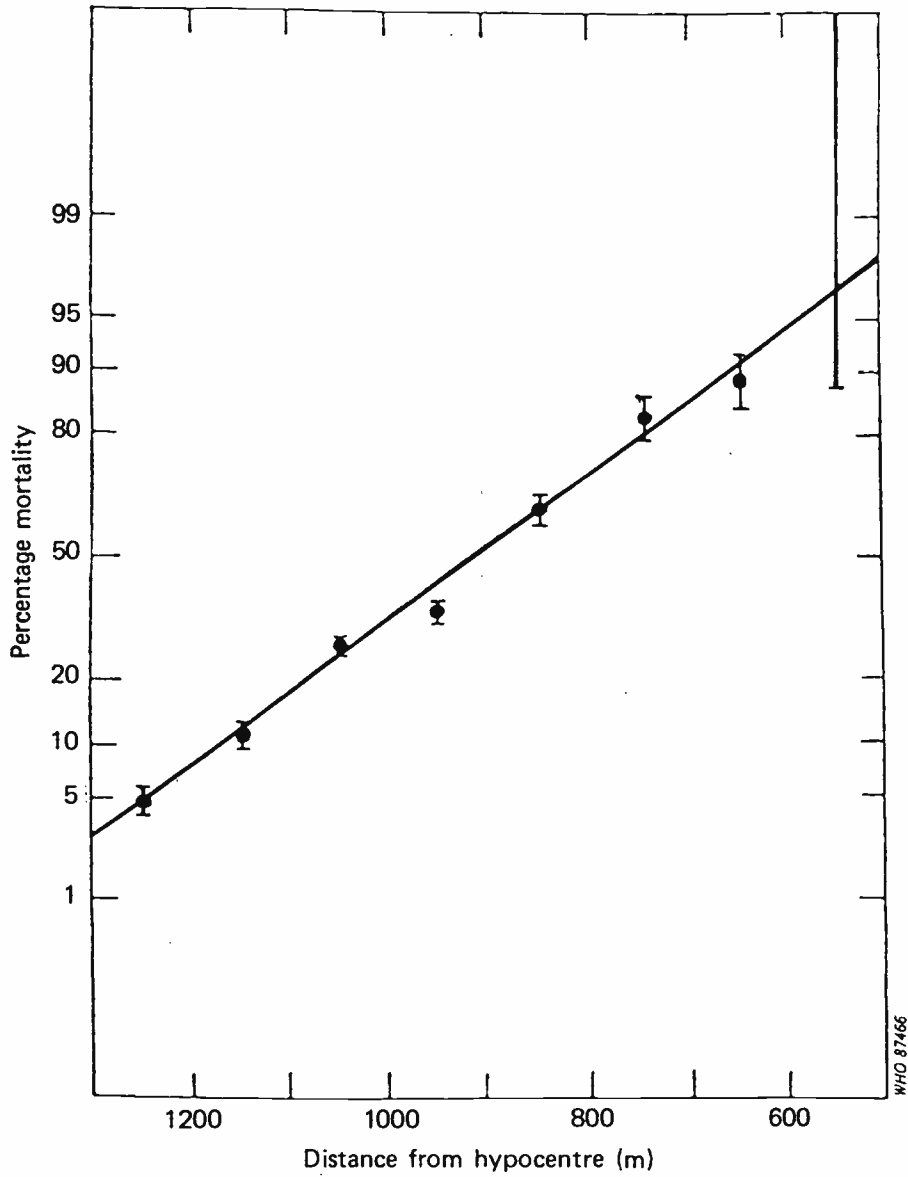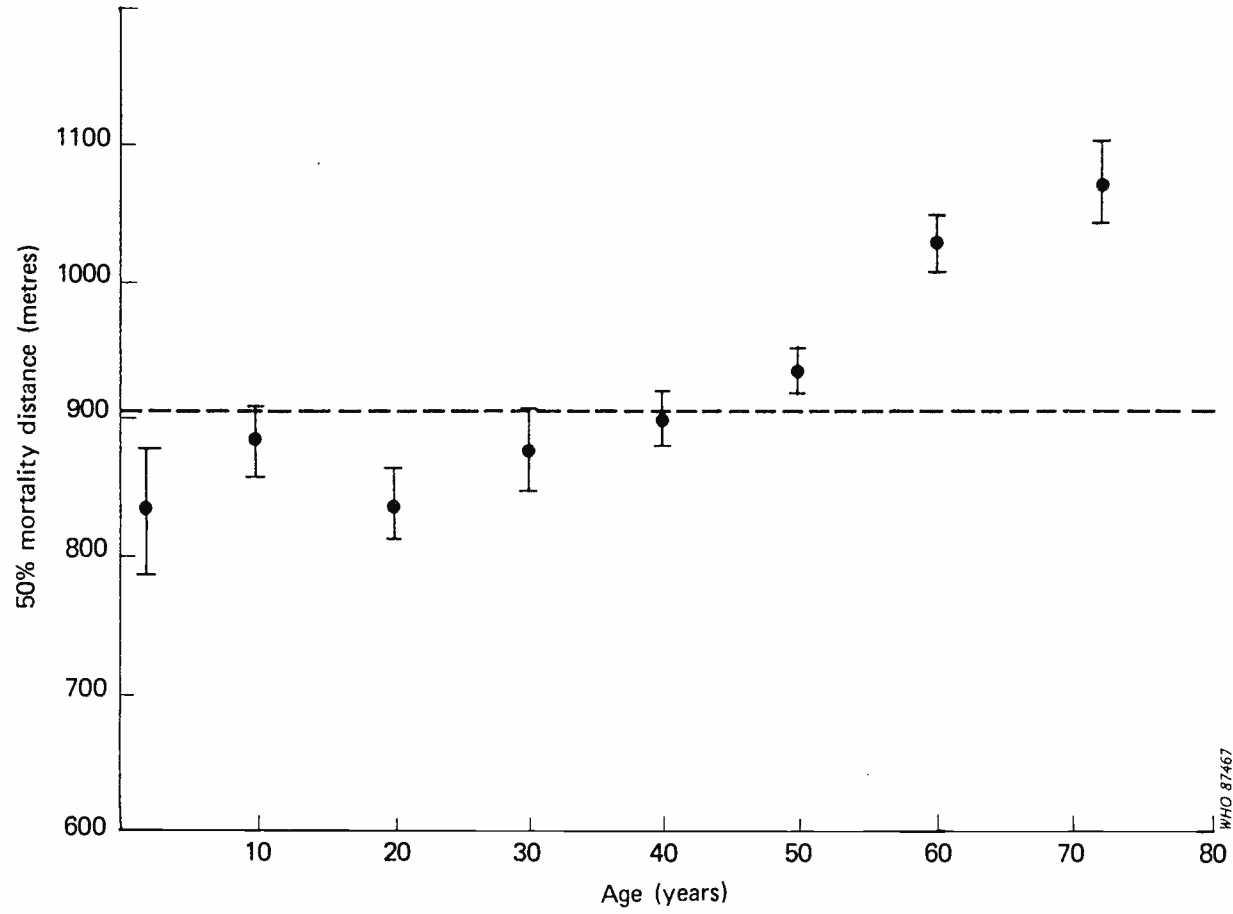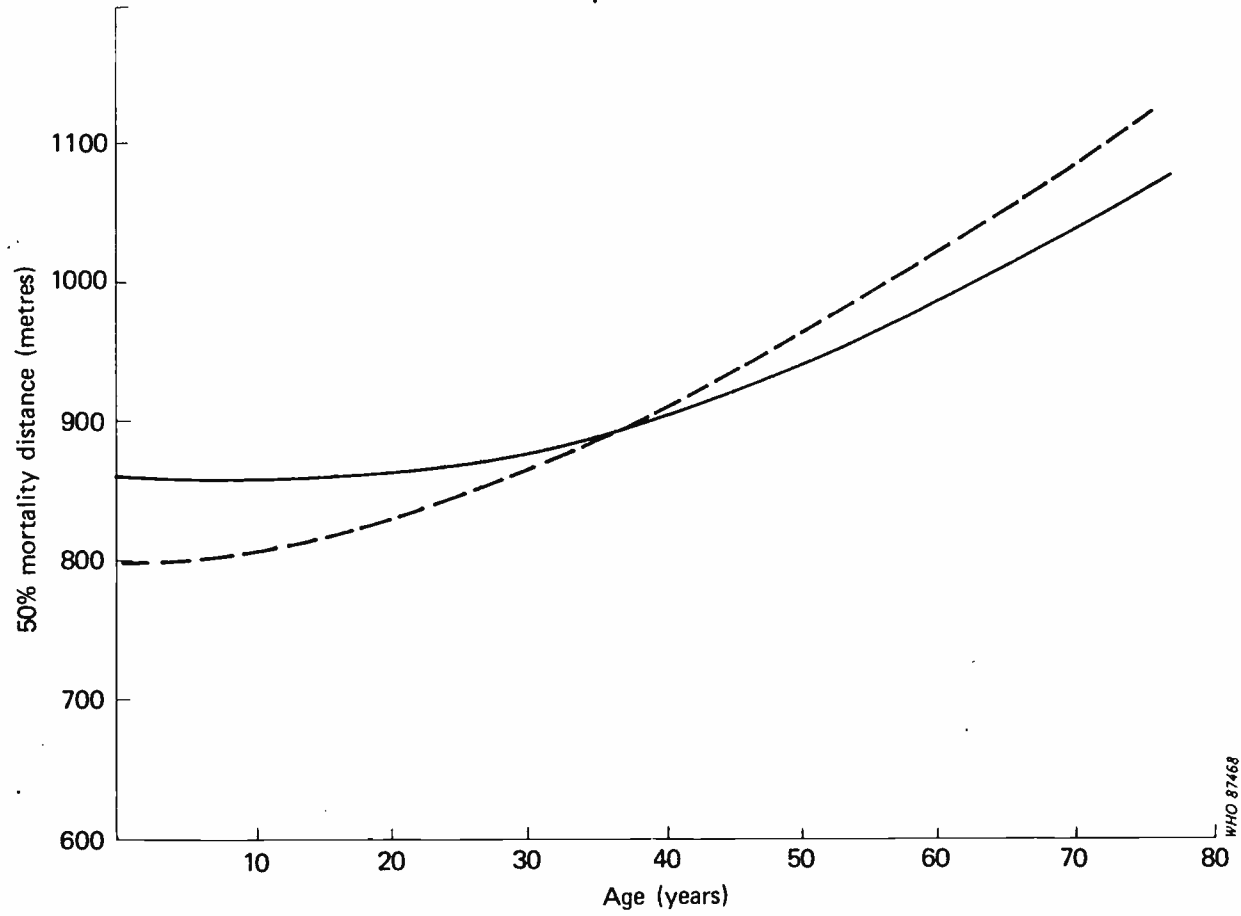
Fig. 4. Variation of the 50% mortality distance with age
at exposure in Hiroshima (both sexes)

WHO 87467

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

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.

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 a 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

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:

o   missile silos;

o   ballistic-missile submarine bases;

o   bomber bases;

o   construction and maintenance facilities at which USA ballistic missiles may be found;

o   actual and planned home ports for other USA naval ships which are equipped with nuclear-armed cruise missiles or aircraft;

o   bases for the refuelling ("tanker") aircraft which would refuel USA bombers on the way to and from their targets in the Soviet Union;

o   underground missile launch-control facilities which are dispersed among the missile silos housing USA operational intercontinental ballistic missiles;

o   major nuclear weapons storage depots; and

o   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]

	Model:	Deaths (millions)		Total casualties (millions)	
		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

Conflagration
model

Overpressure
model

Probability

Kilometers from ground zero
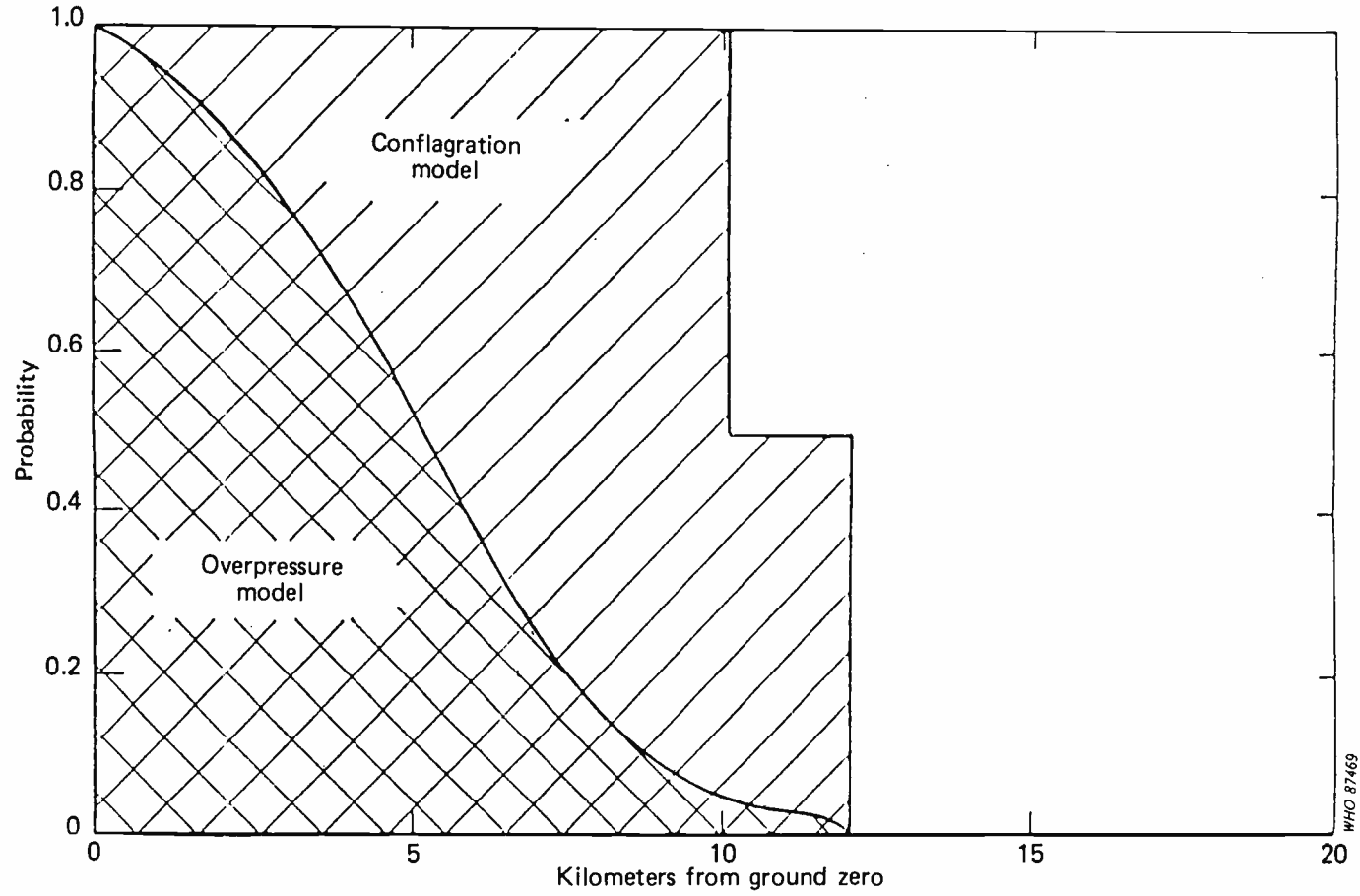
WHO 87469

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

Overpressure model

Medium-radius
conflagration model

Probability

Kilometers from ground zero
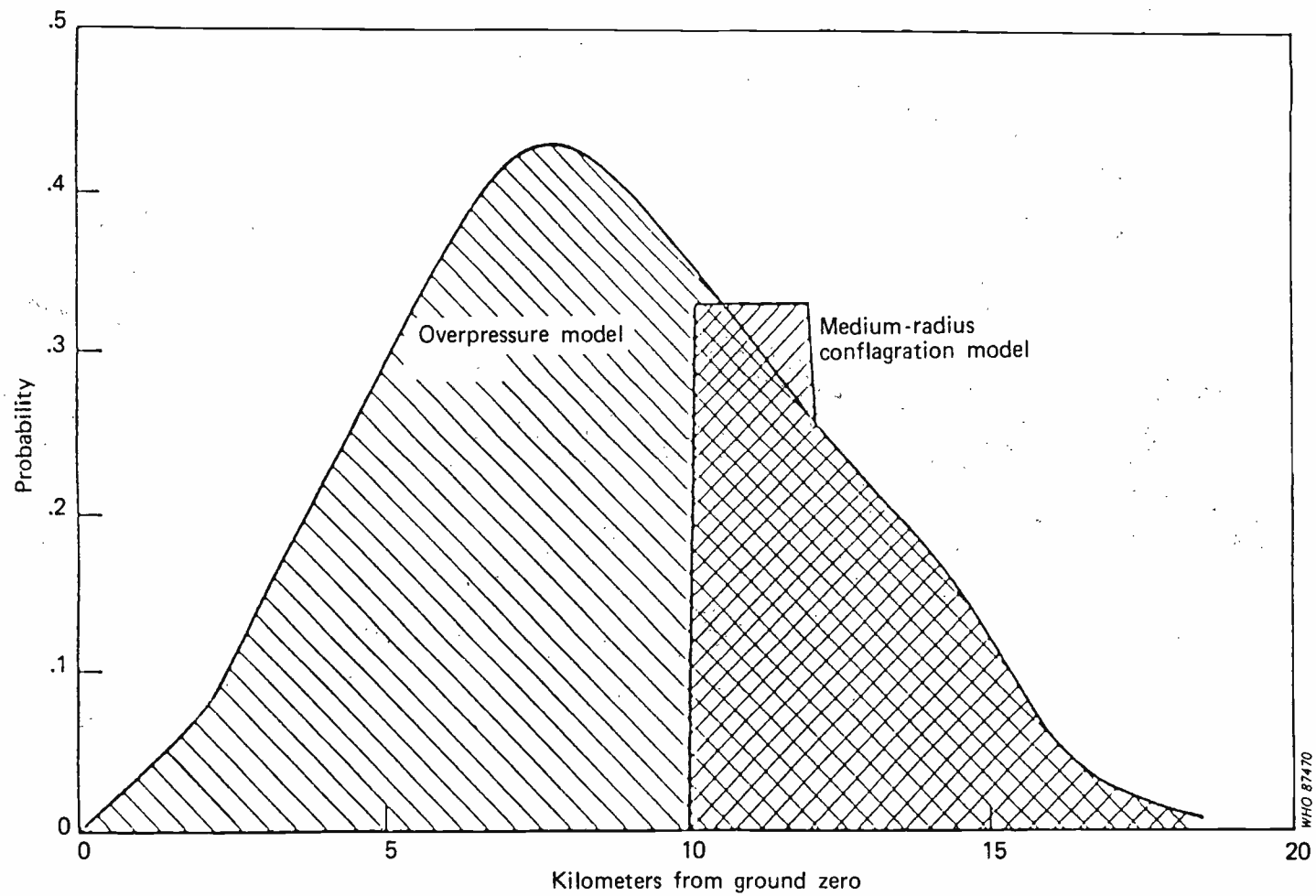
WHO 87470

Figure 2

Fallout pattern
February attack on US strategic nuclear targets

Key

■ > 35 Grays

□ 10,5—35 Grays

▨ 3—10.5 Grays

WHO 87471

Figure 3
Fallout pattern
February attack on soviet strategic nuclear targets

Key

> 35 Grays

10,5—35 Grays

3—10.5 Grays

WHO 87472

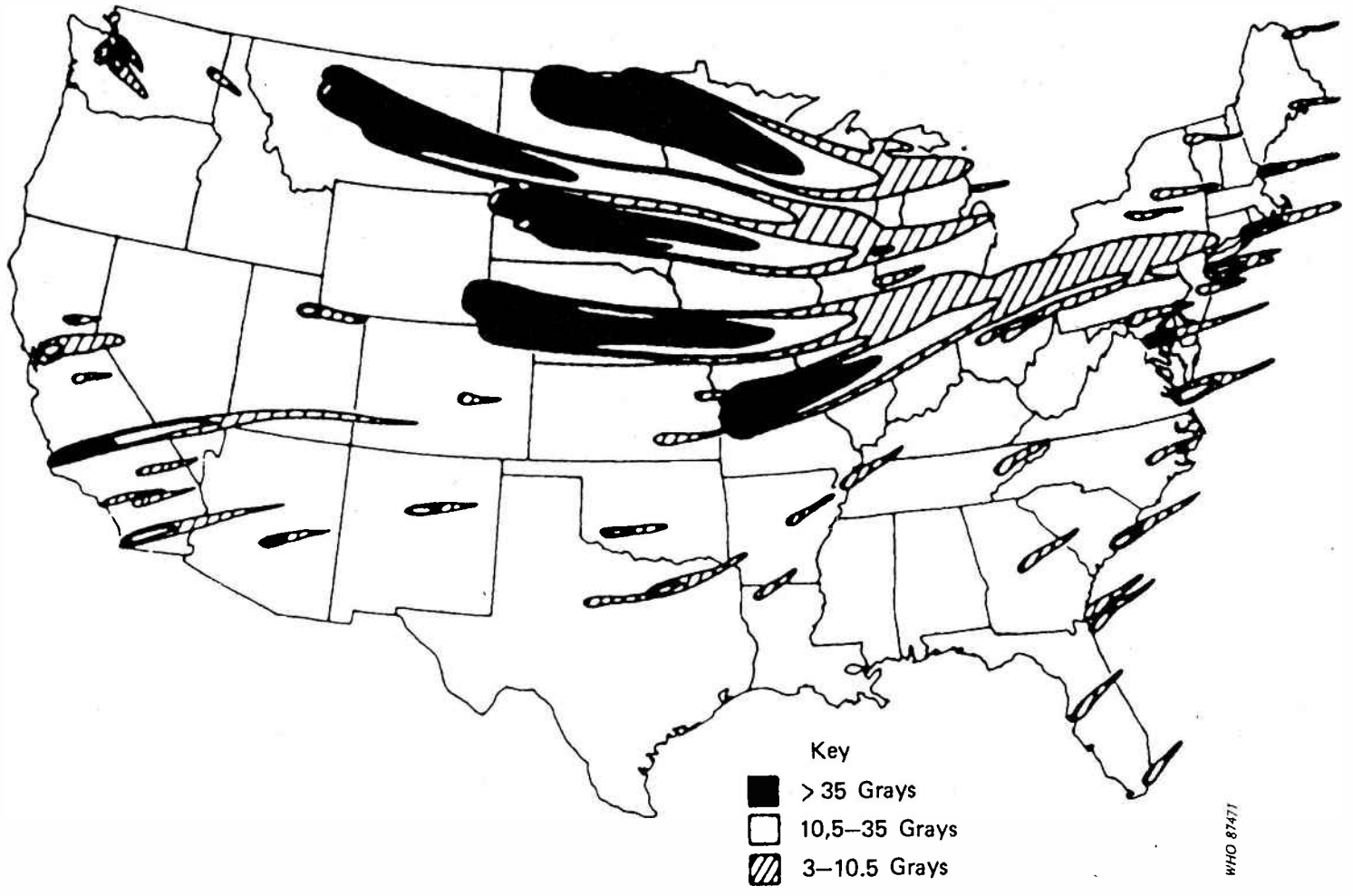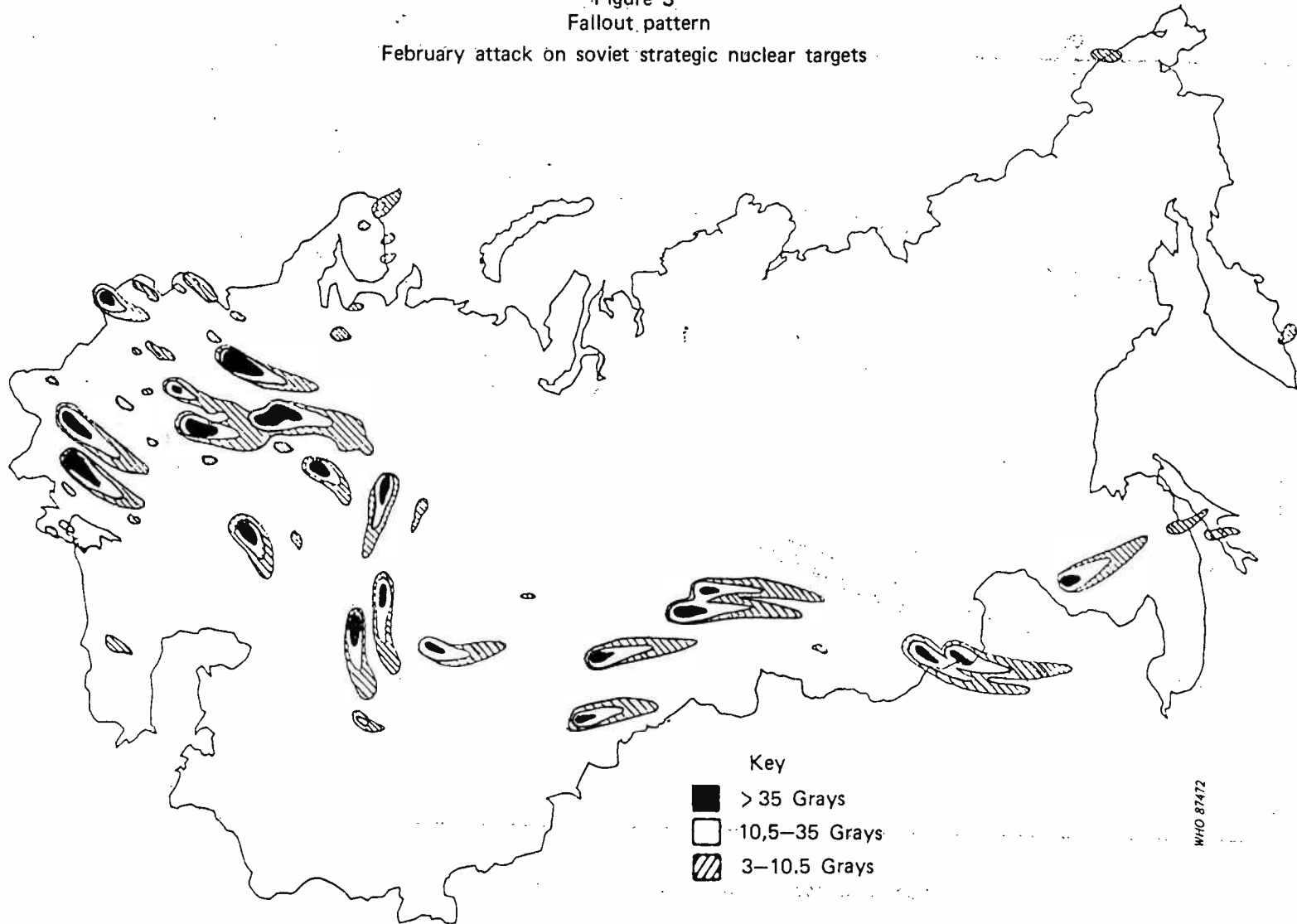Fig. 4. Fatalities from a worst—case city attack

Millions of people

Conflagration model

Overpressure model

Number of one—megaton bombs

WHO 87473
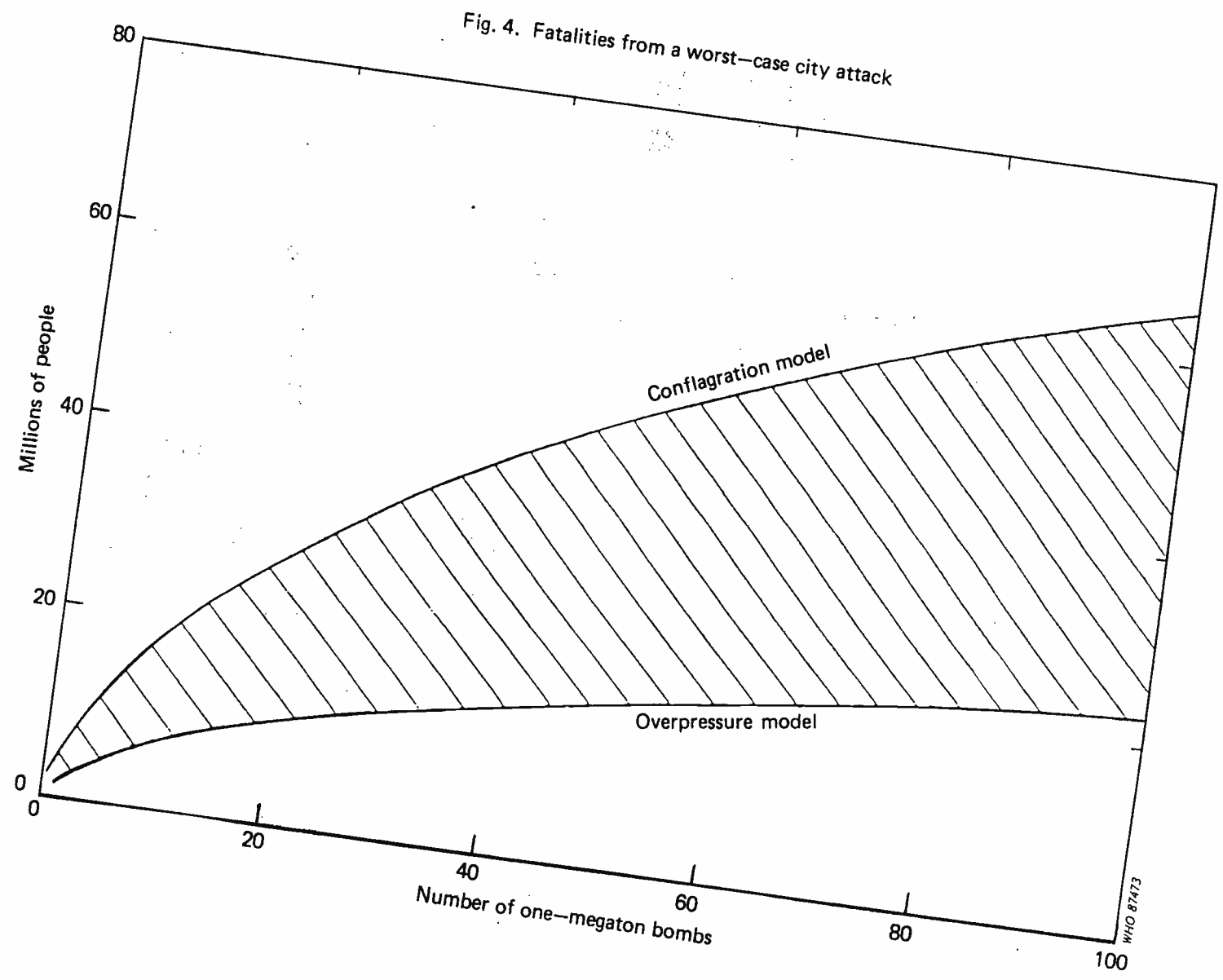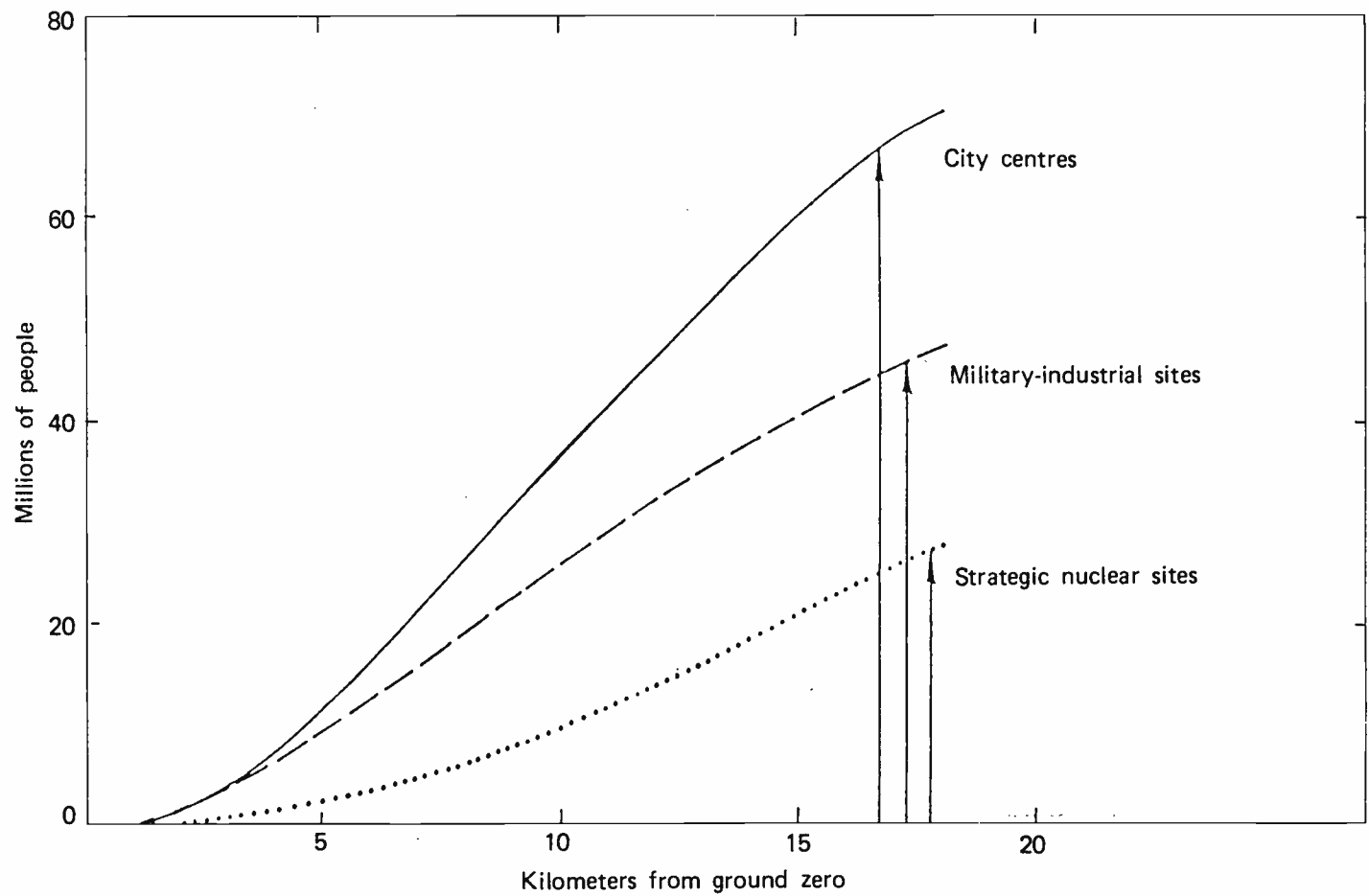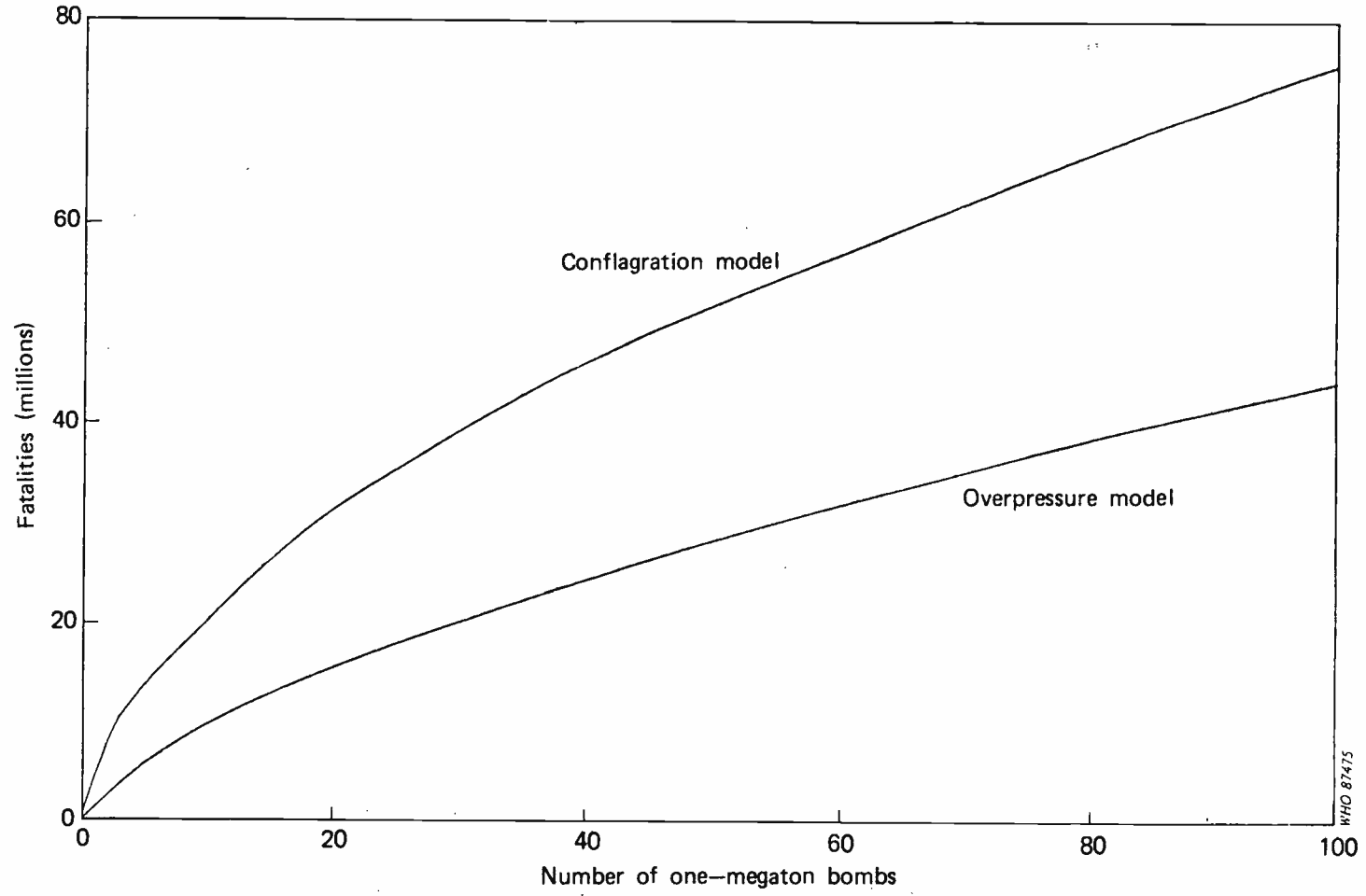
Fig. 5. Cumulative population around ground-zeros for 100 Mt. attacks

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

LIMITED NUCLEAR WAR IN EUROPE

by

Andrea Ottalenghi

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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5. H. G. Norment: DELFIC: Department of Defense Fallout Prediction System, Atmospheric Science Associates, DNA 5159F-1,2 (1979).

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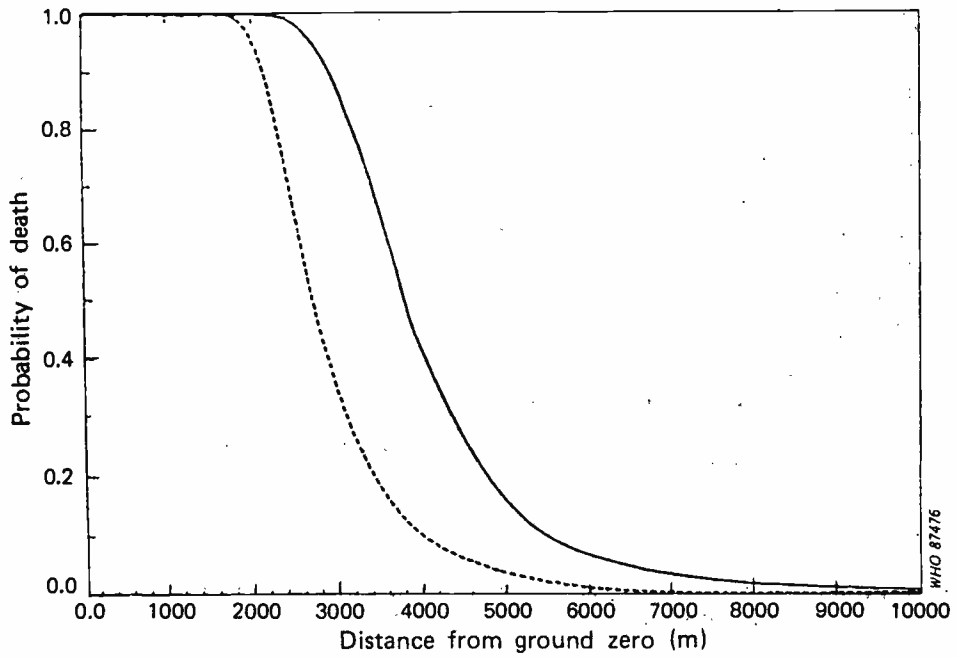
FIG. 2. PROBABILITY OF DEATH (A) AND RADIATION ILLNESS (B) AS A FUNCTION OF
THE DOSE, ASSUMING Do VALUES OF 3.5 AND 1.0 Gy (see text)

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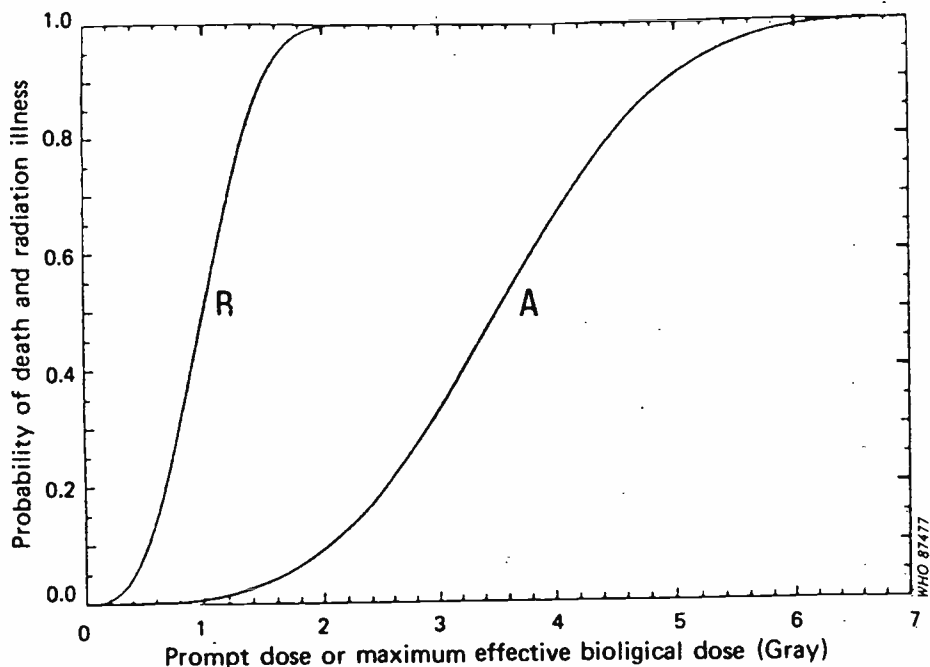
FIG. 3. PROBABILITY OF DEATH (A) AND RADIATION ILLNESS (B) AS A FUNCTION OF THE
DOSE, ASSUMING Do VALUES OF 2.5 AND 0.75 Gy (see text)

Source: Andrea Ottalenghi
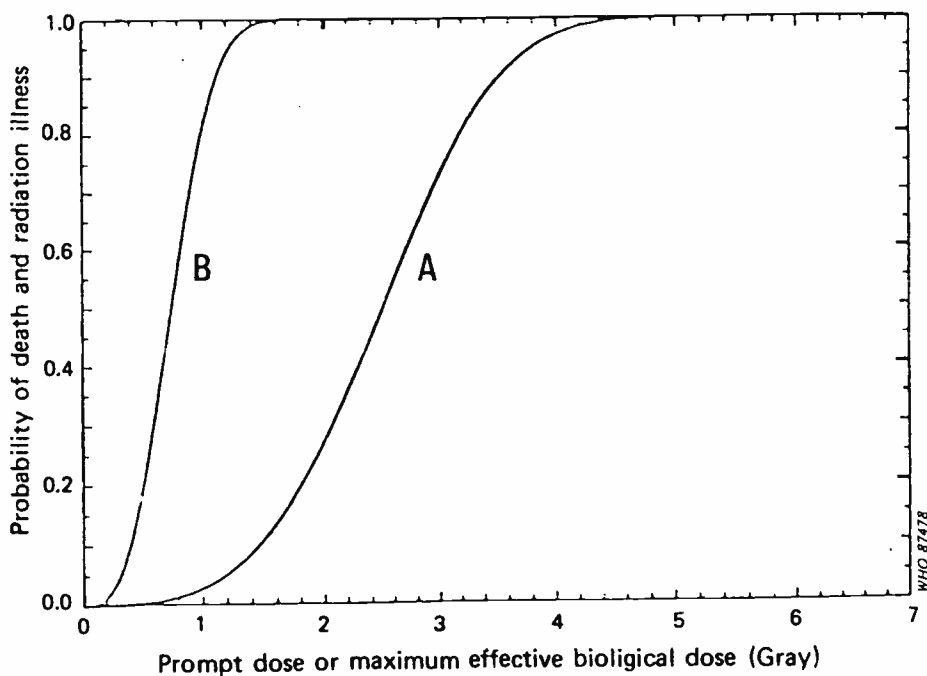
FIG. 4.   MILITARY TARGETS IN EUROPE (EXCLUDING THE SOVIET UNION) ATTACKED IN THE SIMULATION

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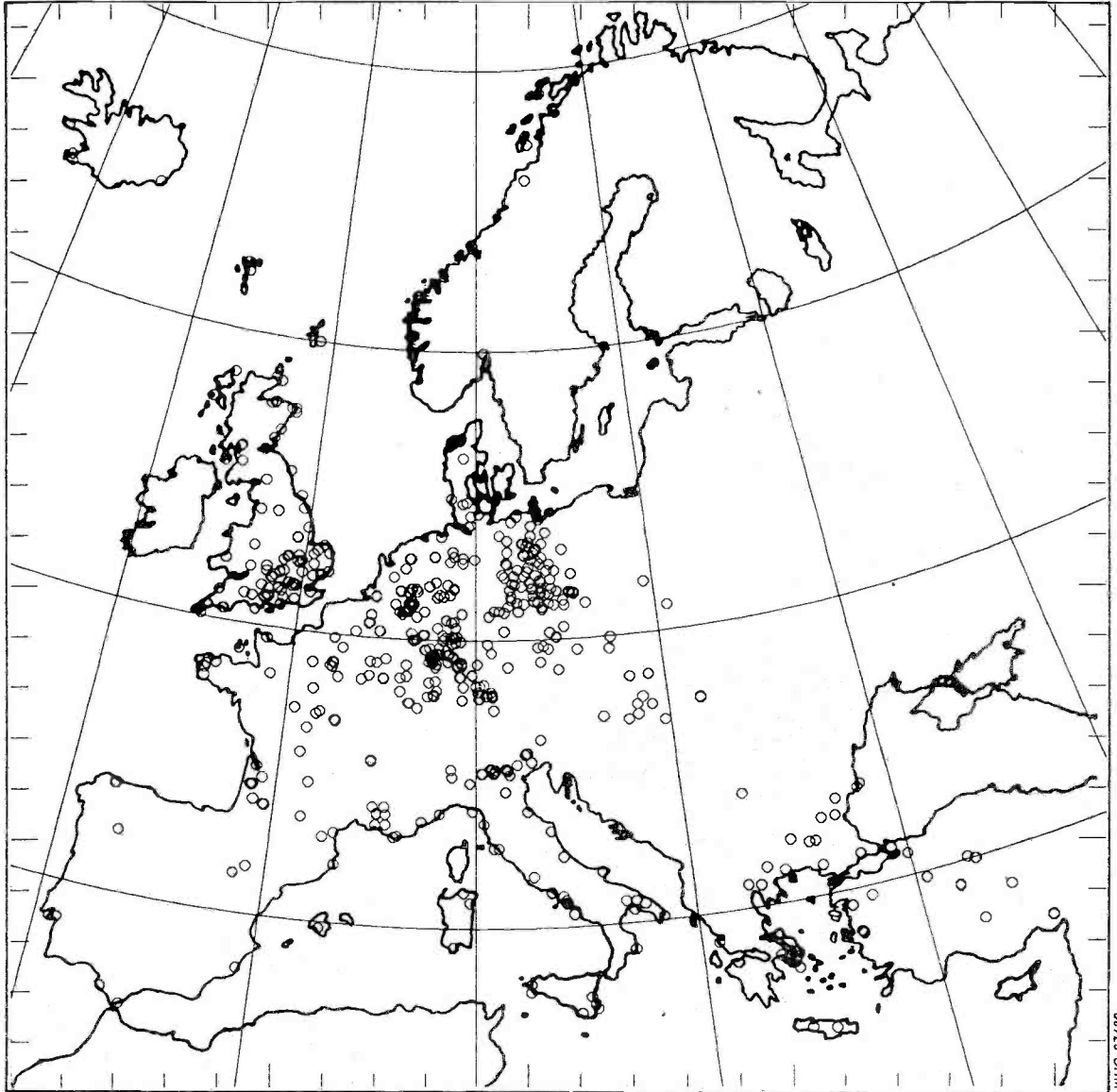
FIG. 5. FALLOUT PATTERN FROM A LIMITED NUCLEAR WAR IN EUROPE, ASSUMING TYPICAL MAY WINDS.
CONTOURS OF "MAXIMUM EFFECTIVE BIOLOGICAL DOSE".

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

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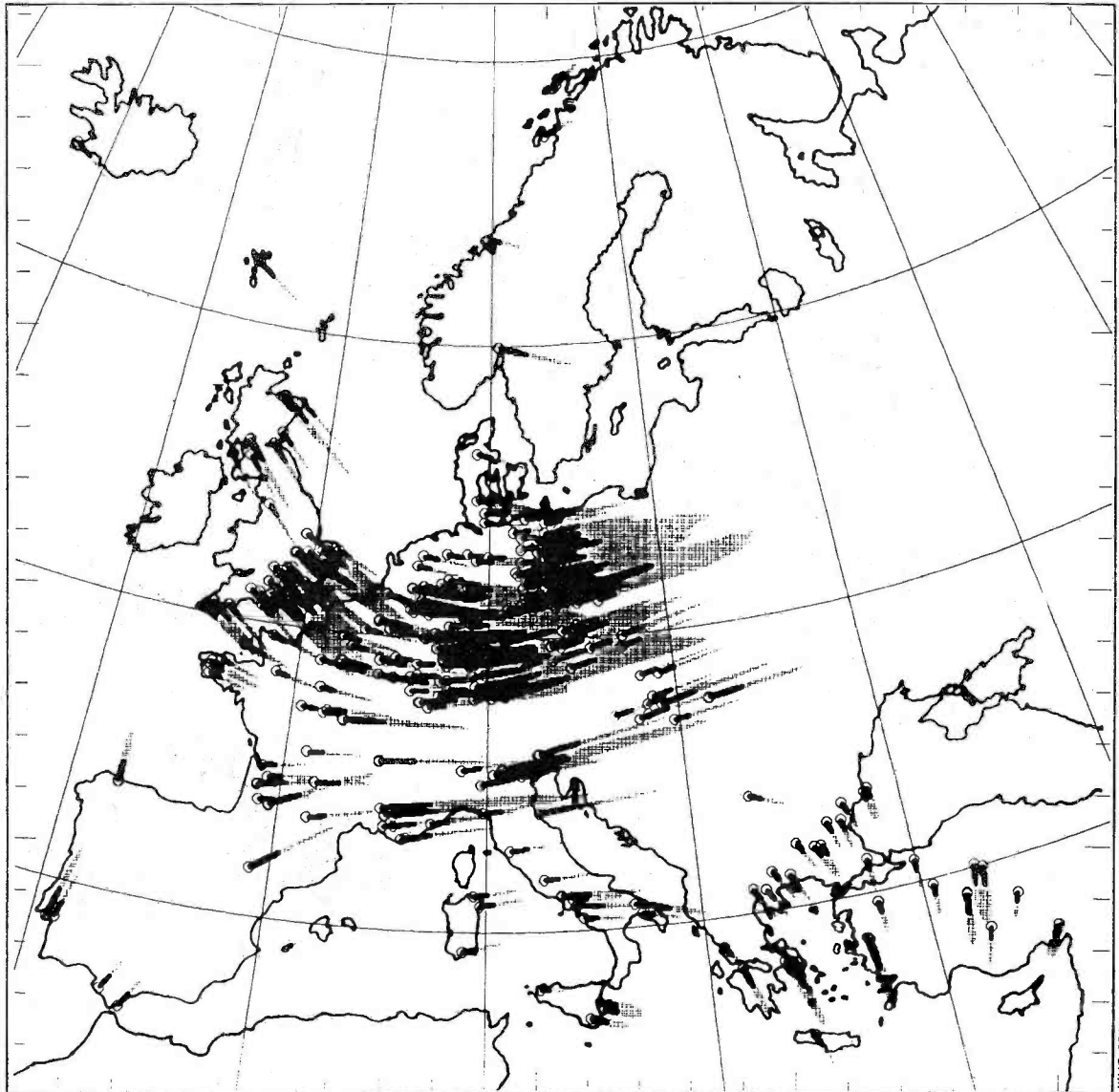
FIG. 6. FALLOUT PATTERN FROM A LIMITED NUCLEAR WAR IN EUROPE, ASSUMING
TYPICAL NOVEMBER WINDS. CONTOURS OF "MAXIMUM EFFECTIVE BIOLOGICAL DOSE.

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

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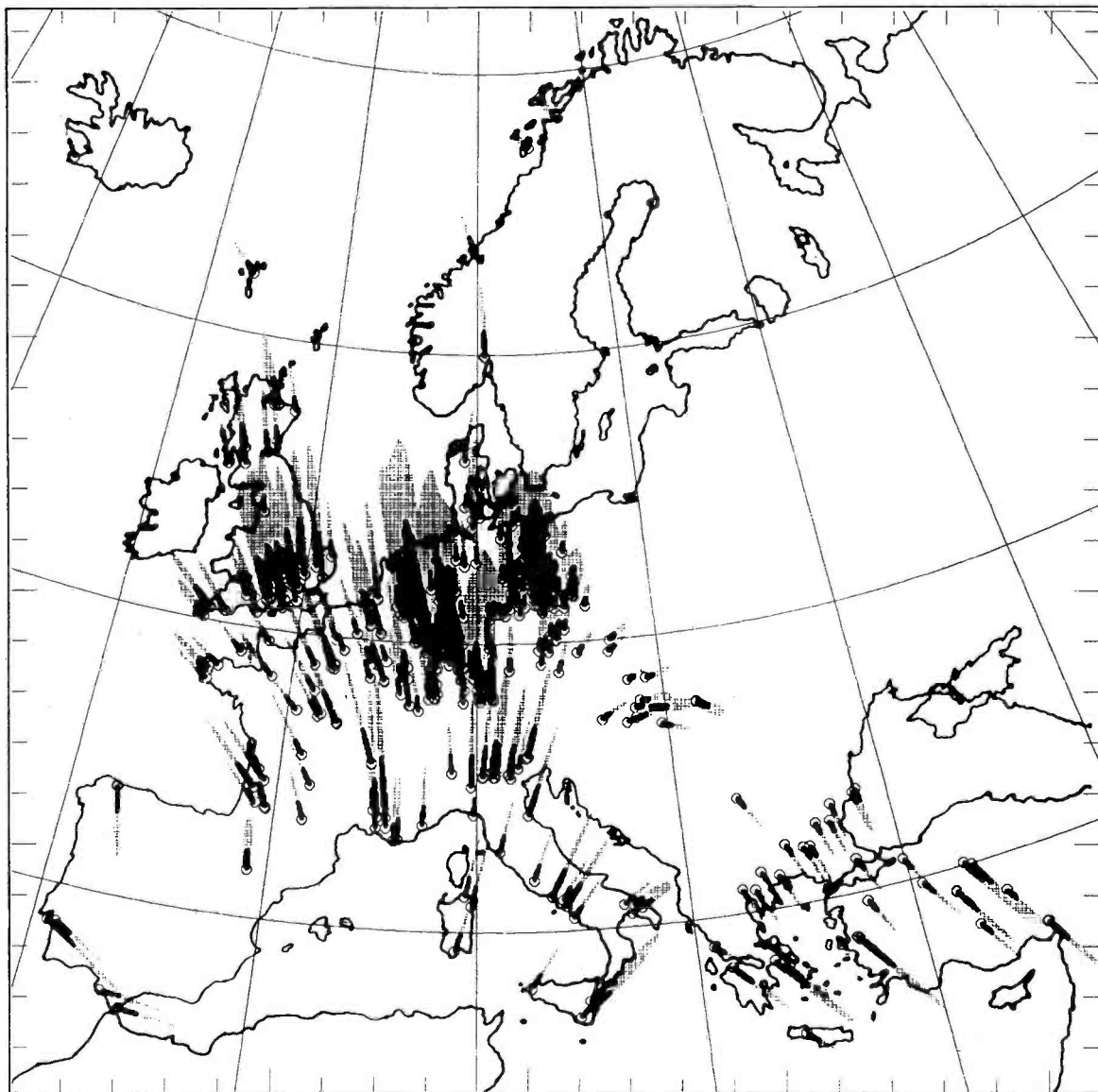
THE PSYCHOSOCIAL ASPECTS OF NUCLEAR THREAT AND NUCLEAR WAR:
ANALOGIES FROM DISASTER RESEARCH

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, disillu ionmment 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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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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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 | | % of |
		Exported	Produced	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
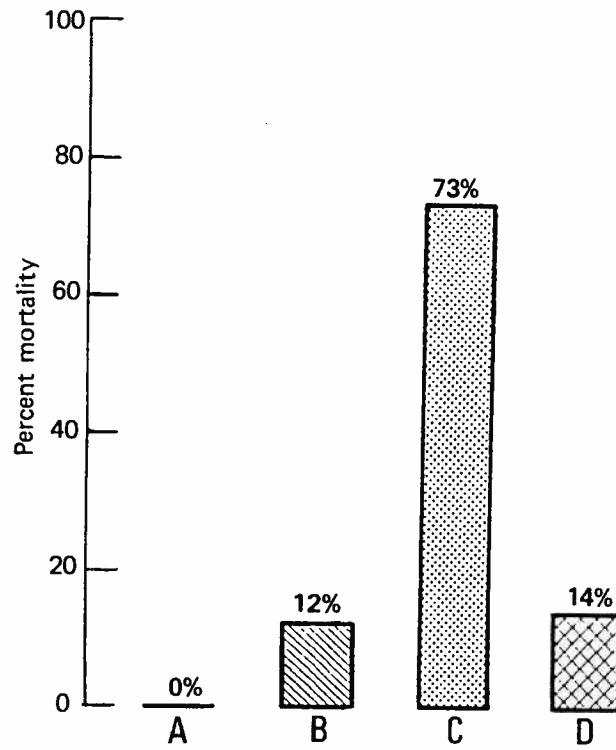
Mortality in dogs subjected to:
A 100r irradiation
B 20% 2nd degree burn
C 100r + 20% burn
D 100r + 20% burn + penicillin

WHO 87479

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