Effects of
Nuclear War
on Health
and Health Services

SECOND EDITION

Report of the WHO Management Group on Follow-up of Resolution WHA36.28: "The Role of Physicians and Other Health Workers in the Preservation and Promotion of Peace..."

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[1] The text of the resolution is reproduced on the inside back cover.

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FOREWORD

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 that was presented to the World Health Assembly in 1983 and later published.[1] 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 to the present report, 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 publication of this revised report.

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

REPORT OF THE WHO MANAGEMENT GROUP ON FOLLOW-UP OF RESOLUTION WHA36.28

The role of physicians and other health workers in the preservation and promotion of peace

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 result in huge 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. After the extinction of the fires, the clouds of smoke, 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 Group to outline the political steps by which this threat can be removed or the preventive measures 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.

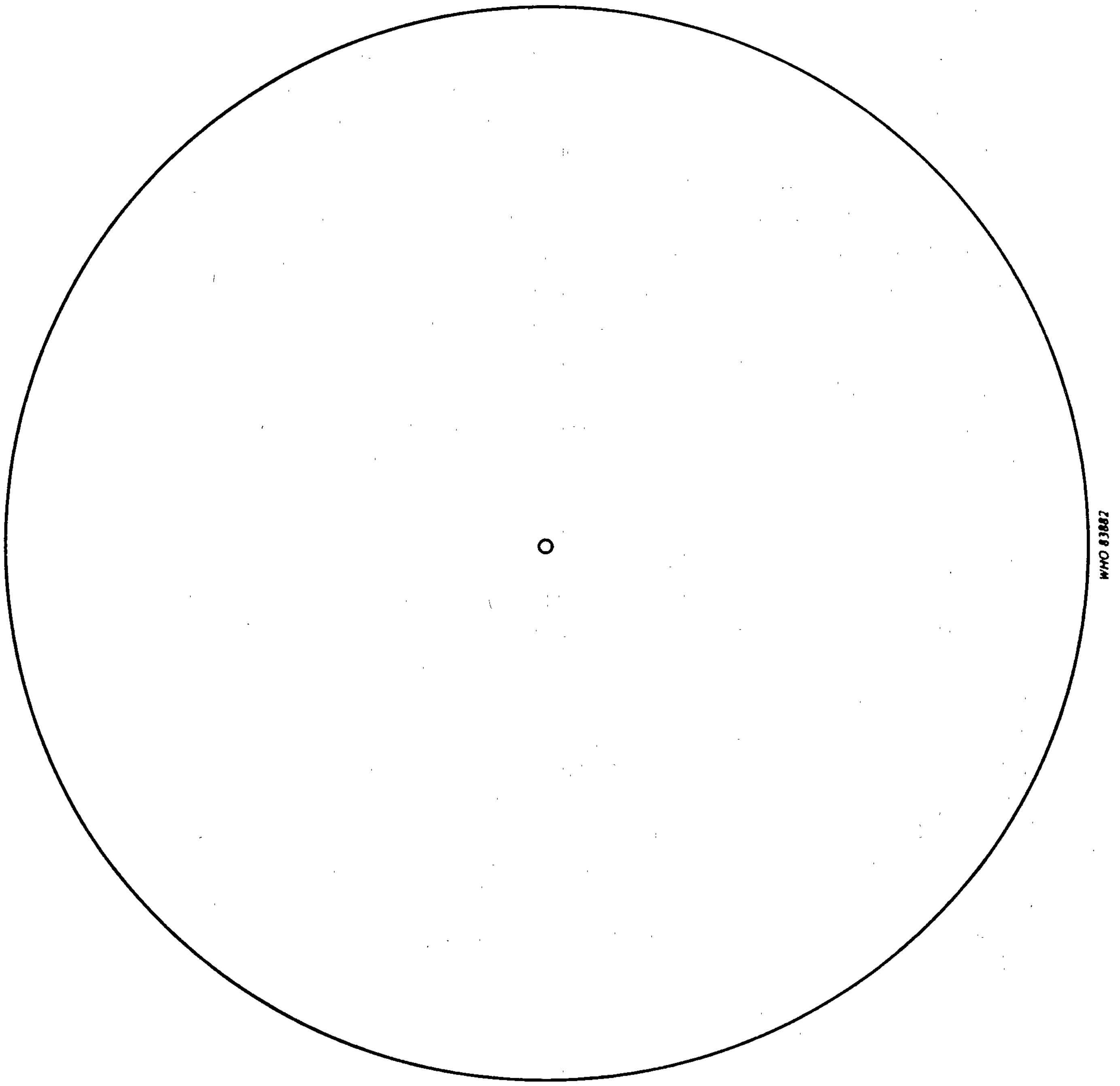
I. INTRODUCTION

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

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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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.

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.

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.

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.

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

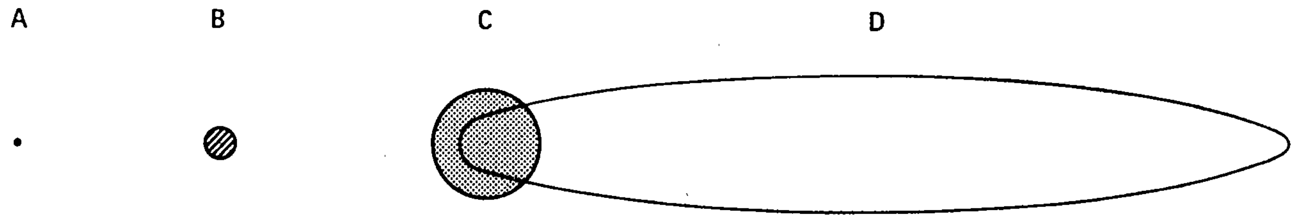
26. A small proportion of the energy released by the explosion of most nuclear weapons appears in the form of neutrons and gamma-rays emitted in the first minute. An exception is the enhanced-radiation warhead commonly known as the neutron bomb. The proportion of the energy carried by the neutrons in 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. Once absorbed, these radionuclides are relatively slowly 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

* 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.

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 subsistance 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.

* * *

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 (1 GW = 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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ANNEXES

ANNEX 1

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 60-90 x 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 48. 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

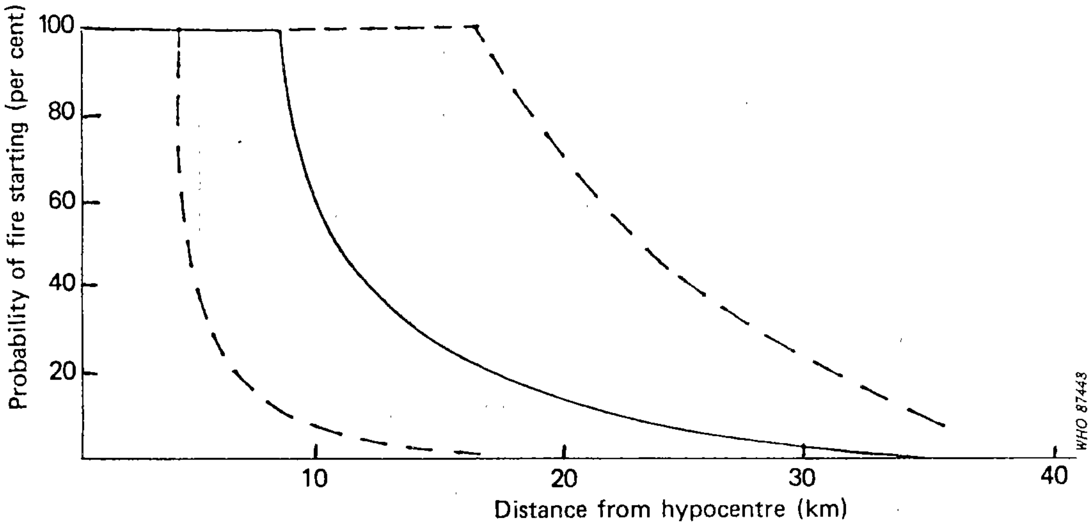


Fig. 2. Initiation of superfires

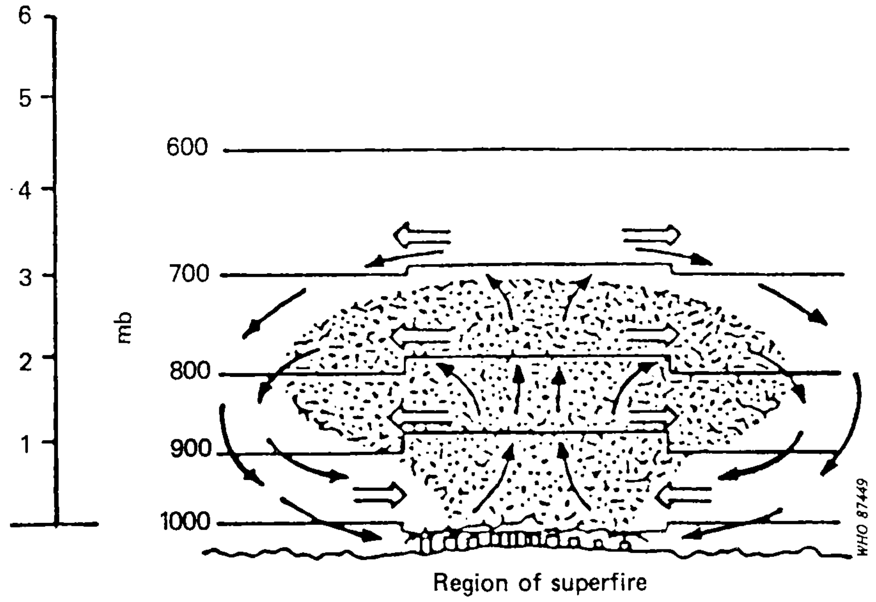
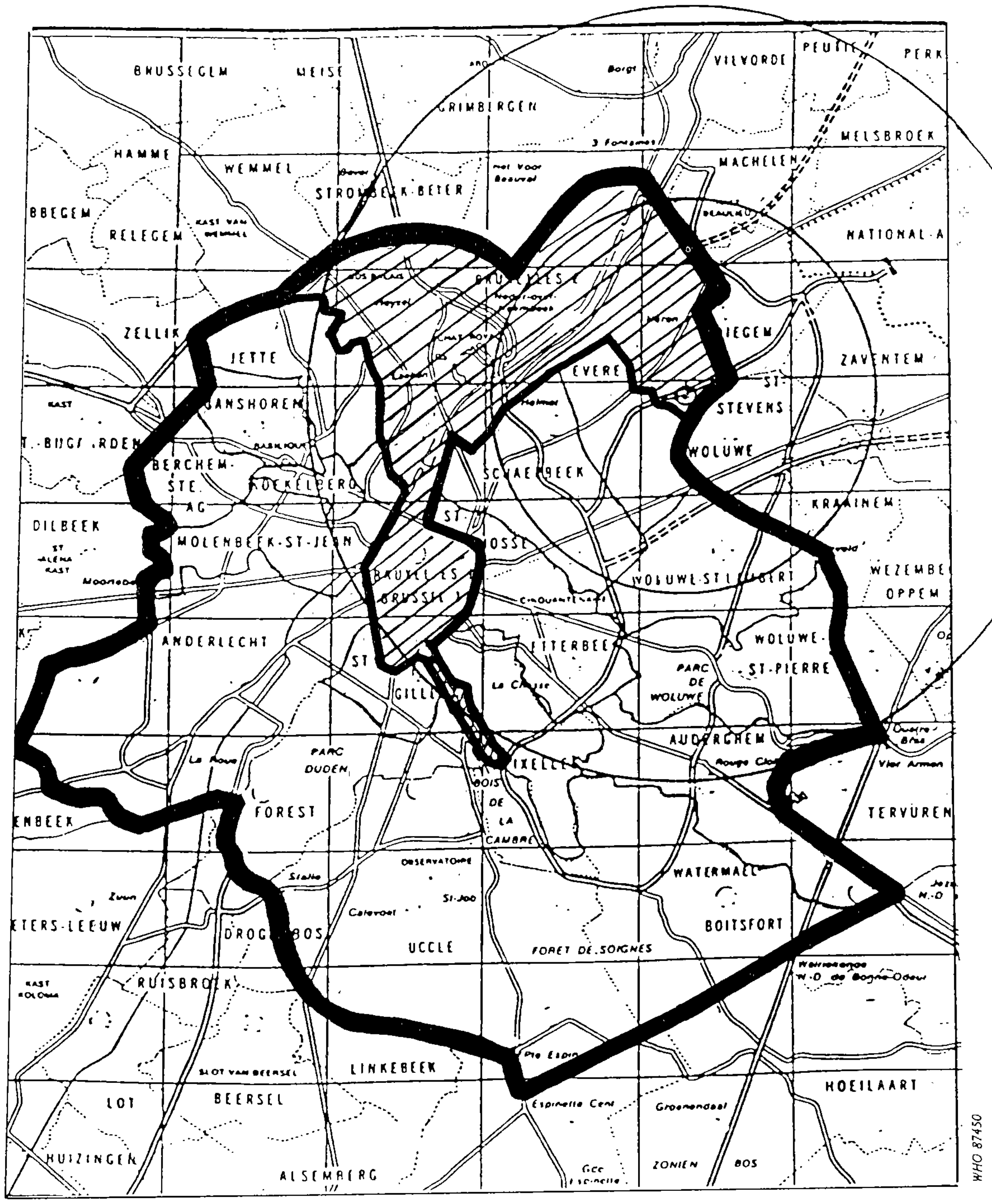


Fig. 3 250 kt bomb on Brussels. Lethal areas for blast and superfire



limits of the 19 boroughs

Brussels—town borough

Fig. 4. «Mushroom cap» cloud top and base as a function of total yield of device

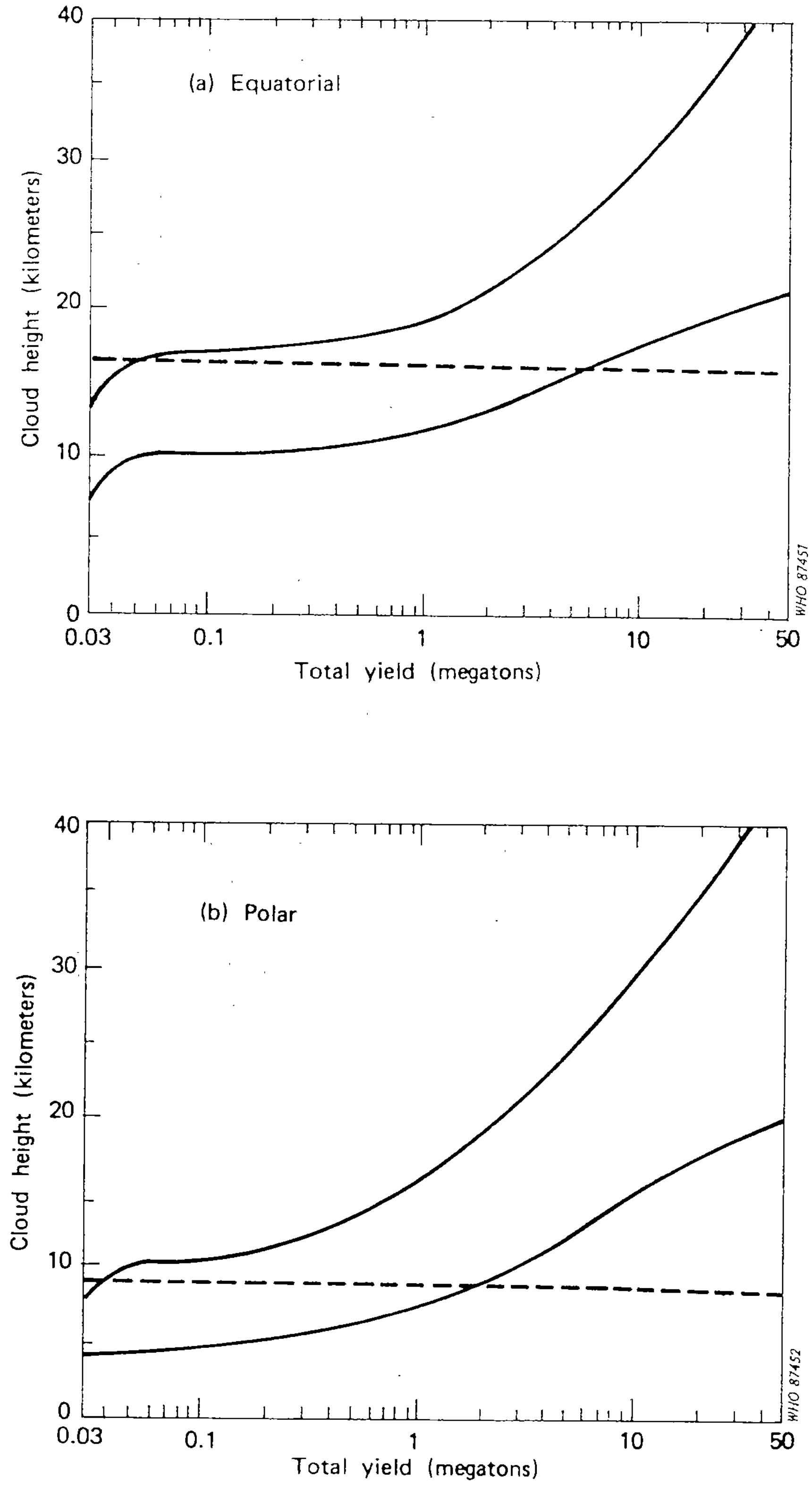


Fig. 5 Gamma–ray dose rate versus time after shutdown or detonation
(see text for explanation of symbols)

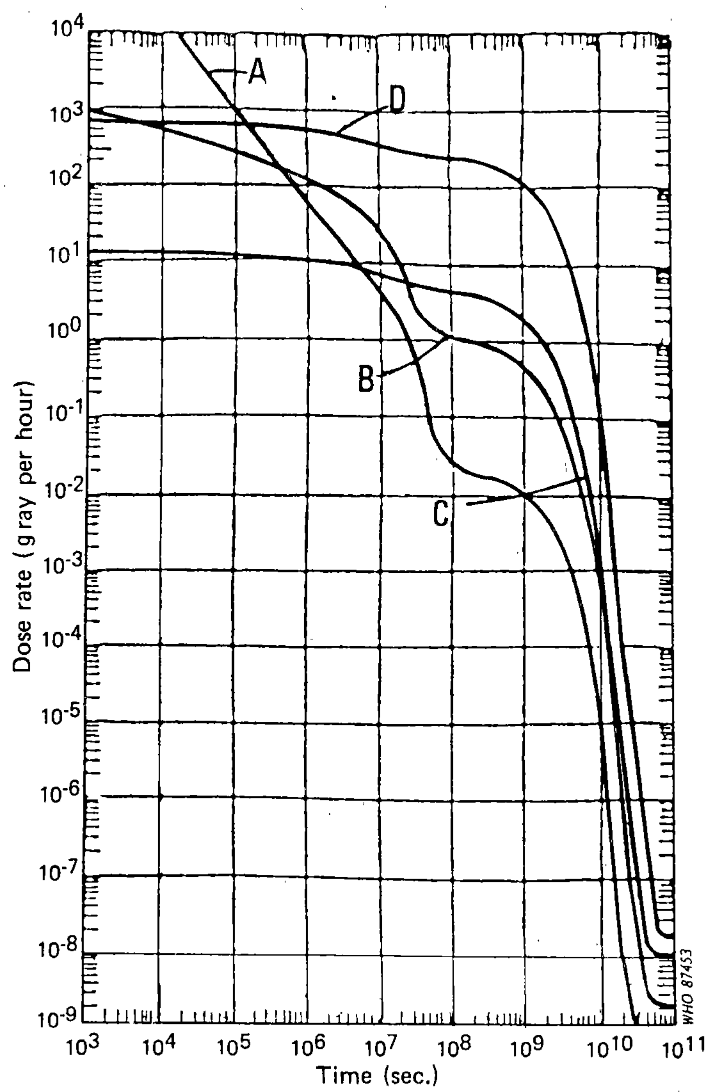
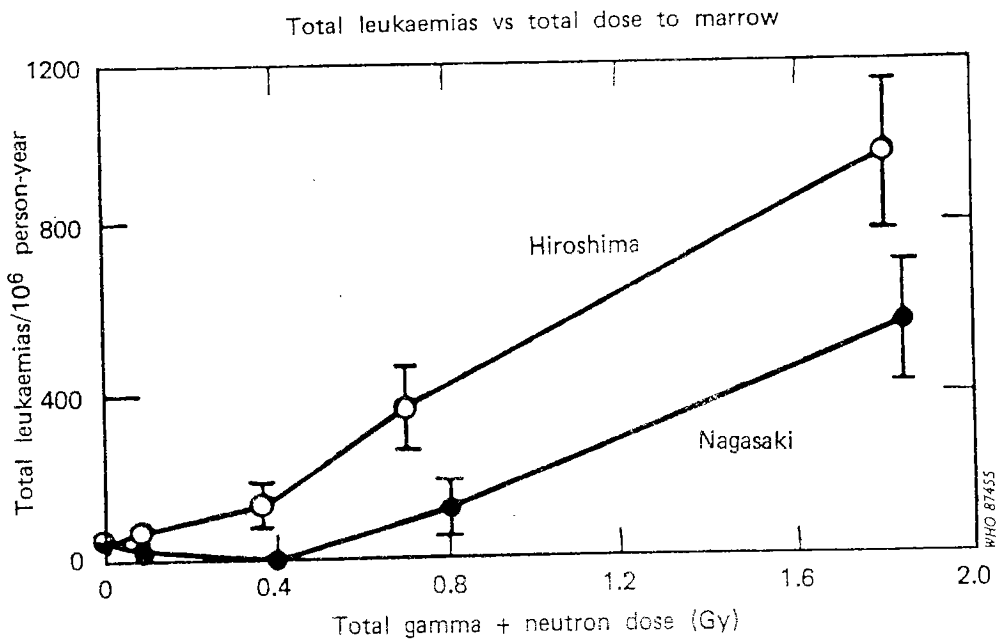


Fig. 6 Dose-response relation for leukaemia and chromosome aberrations in Hiroshima and Nagasaki

(a)



(b)

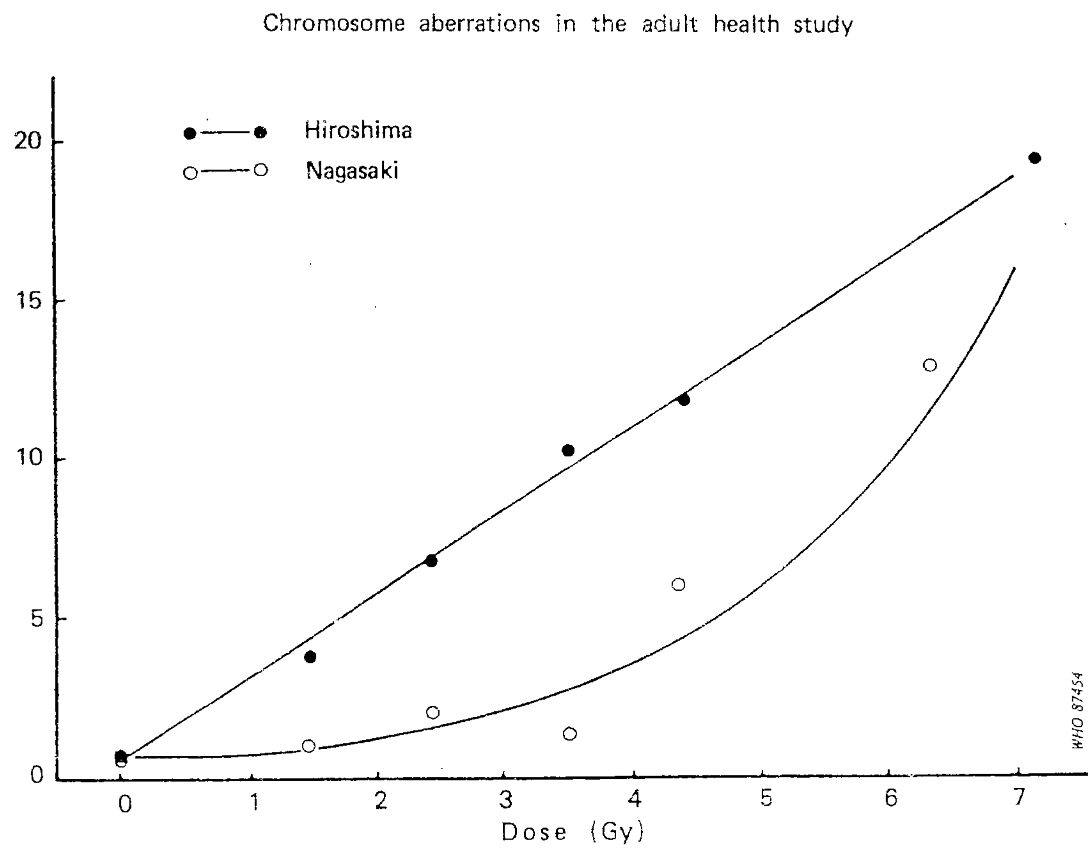


Fig. 7a Gamma-ray components of Kerma in Hiroshima (new estimates)

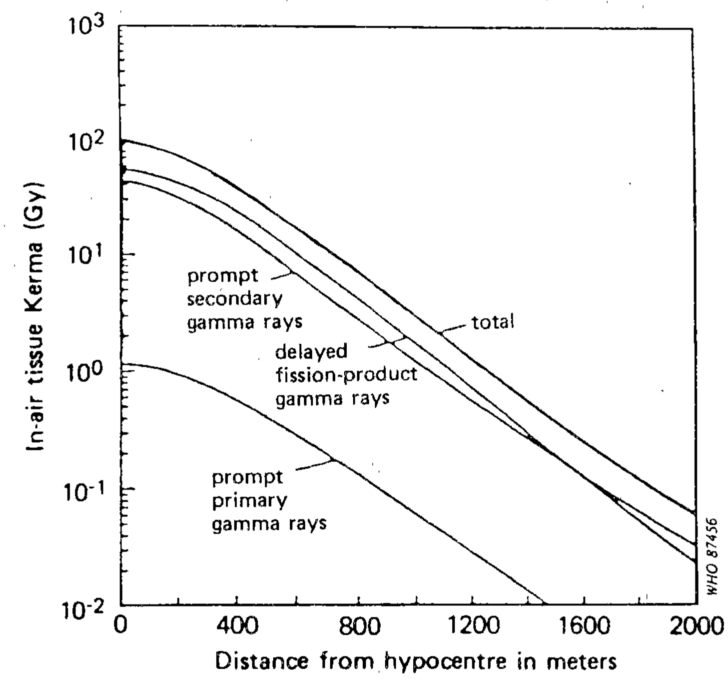
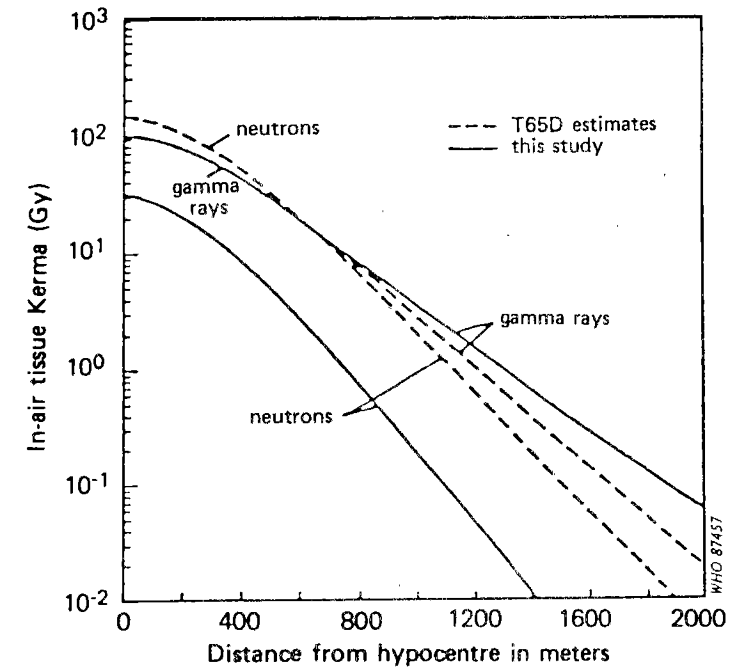


Fig. 7b Gamma-ray and neutron contributions to Kerma in Hiroshima (new and old estimates)



ANNEX 2

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 Υ (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 Υ = 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 Υ = 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 Υ 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 $2.4\text{-}3 \times 10^{14}$ 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.

FIG. 1

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.

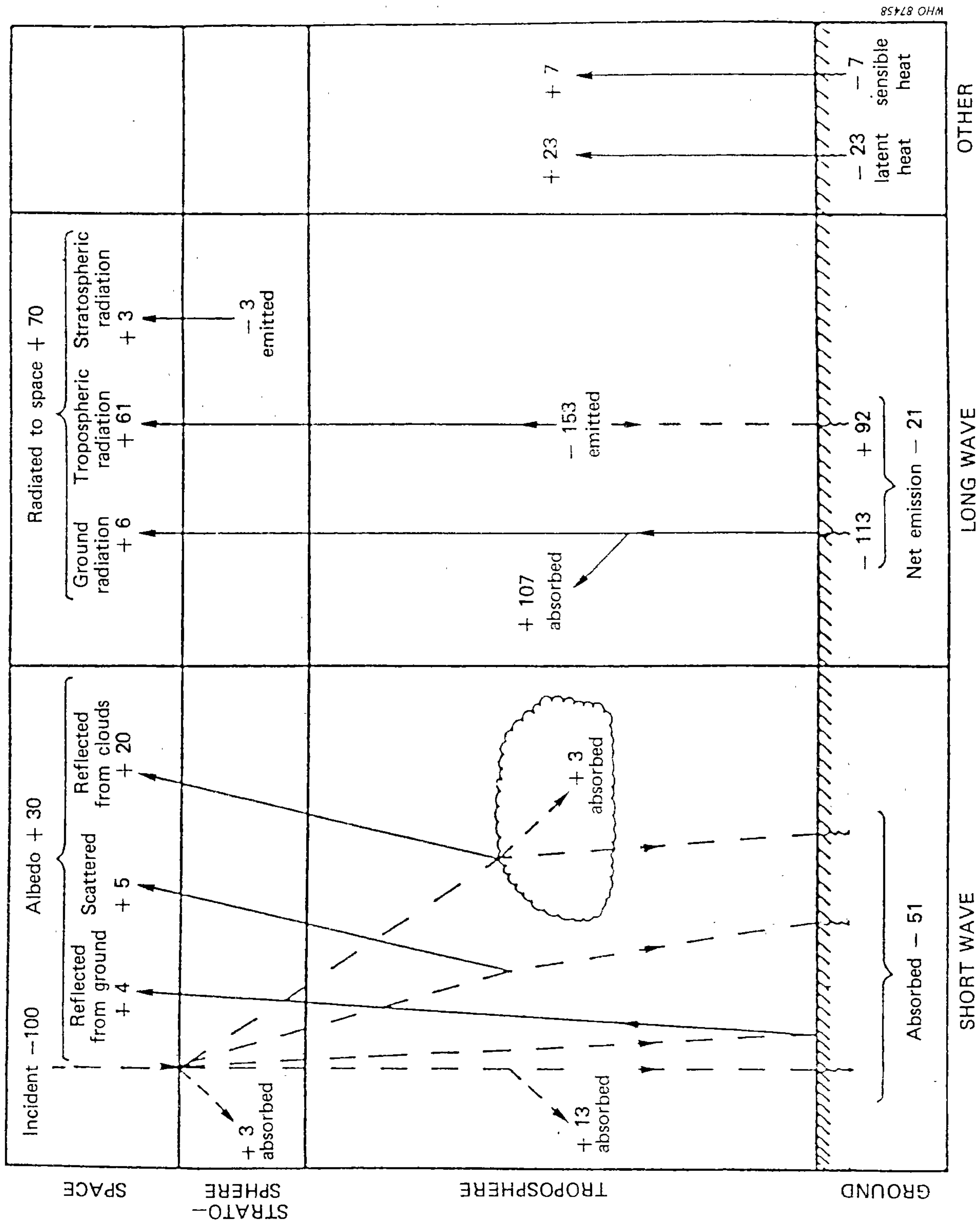

FIG. 2

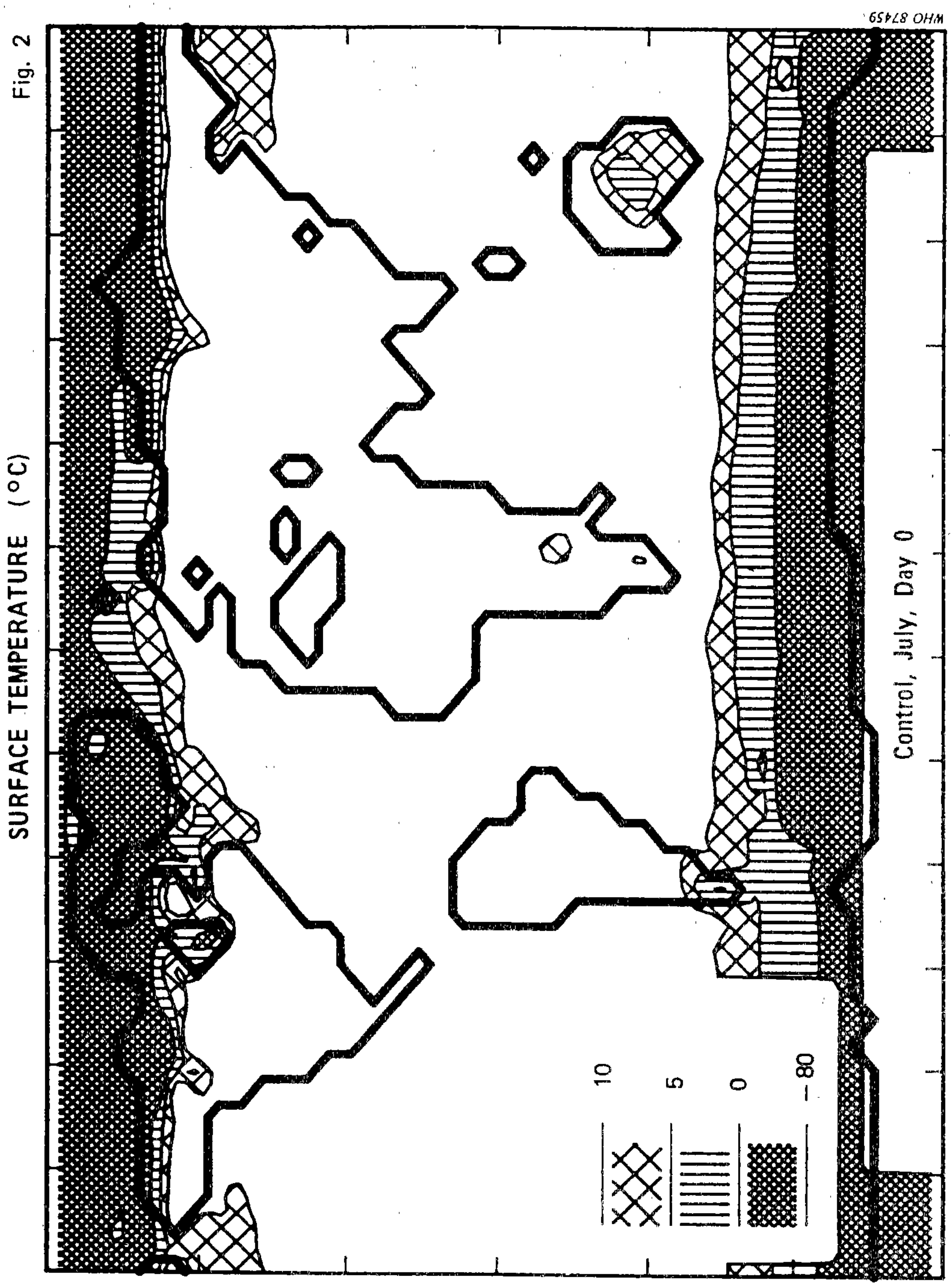
Fig. 2
SURFACE TEMPERATURE (°C)
Control, July, Day 0
10
5
0
−80
WHO 87459

FIG. 3

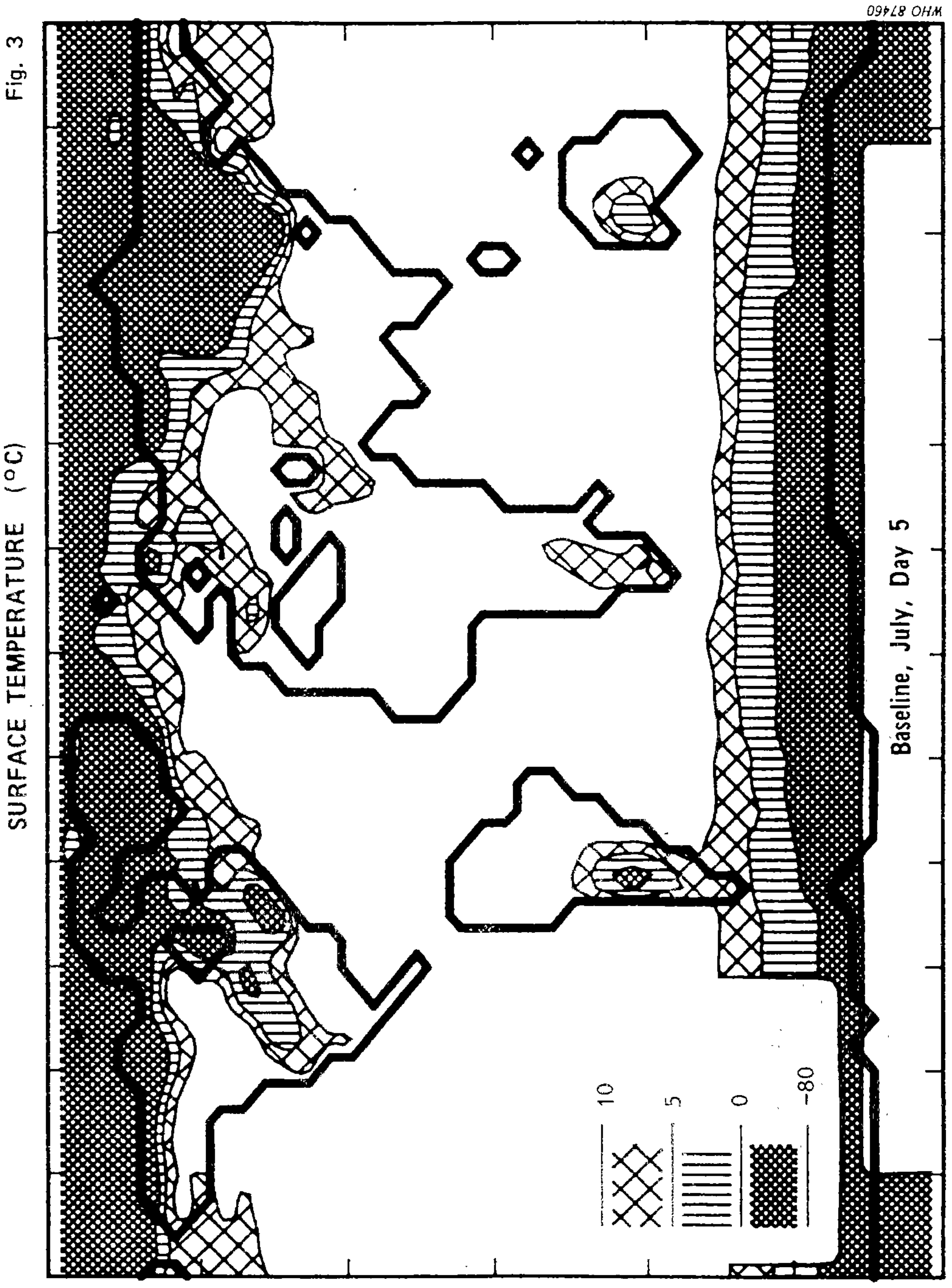
SURFACE TEMPERATURE (°C)
Fig. 3
10
5
0
-80
Baseline, July, Day 5
WHO 87460

FIG. 4

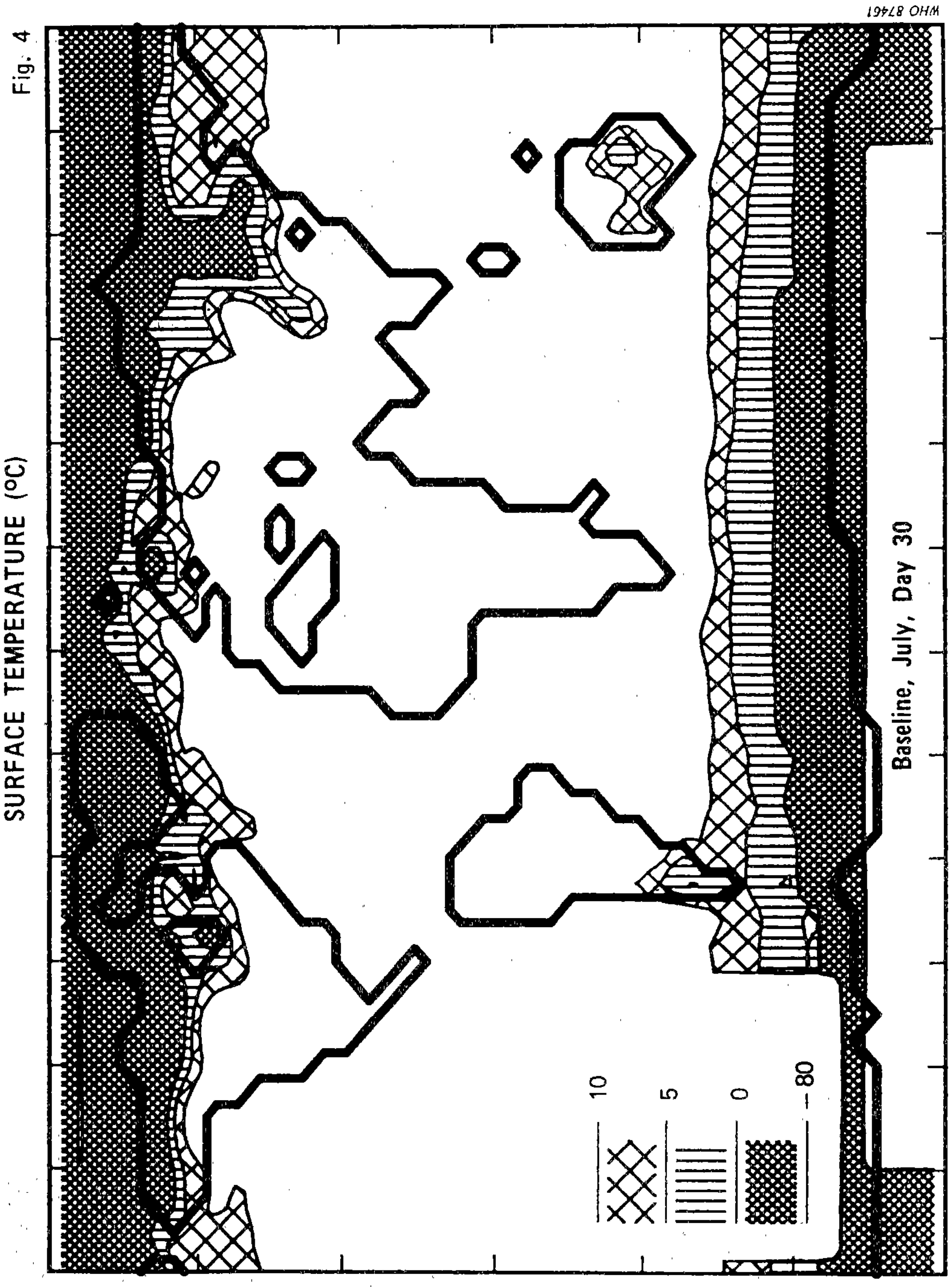
Fig. 4
SURFACE TEMPERATURE (°C)
10
5
0
-80
Baseline, July, Day 30
WHO 87461

FIG. 5

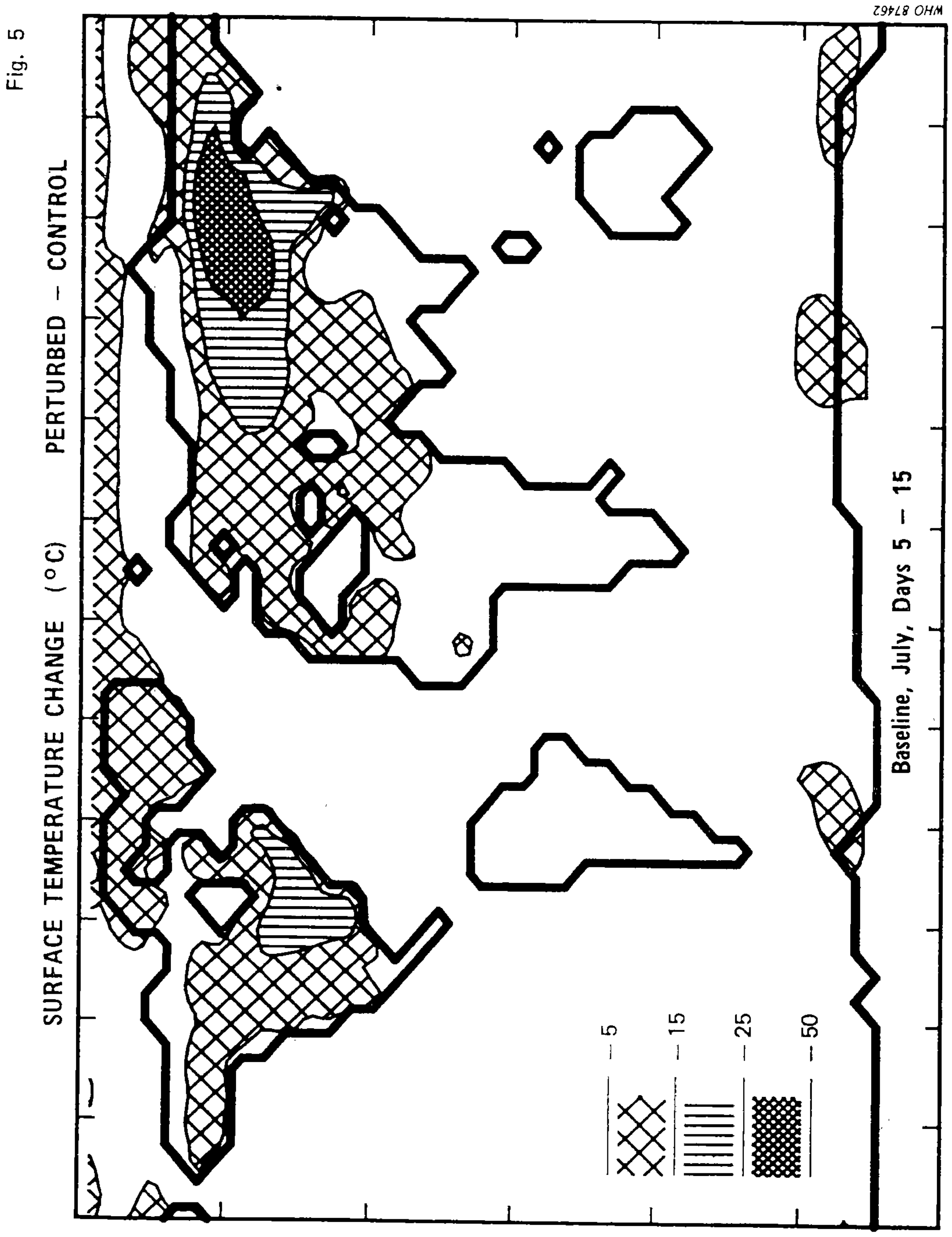
Fig. 5
SURFACE TEMPERATURE CHANGE (°C) PERTURBED - CONTROL
5
15
25
50
Baseline, July, Days 5 – 15
WHO 87462

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})	$(1-1.5 \times 10^{15}$ 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.