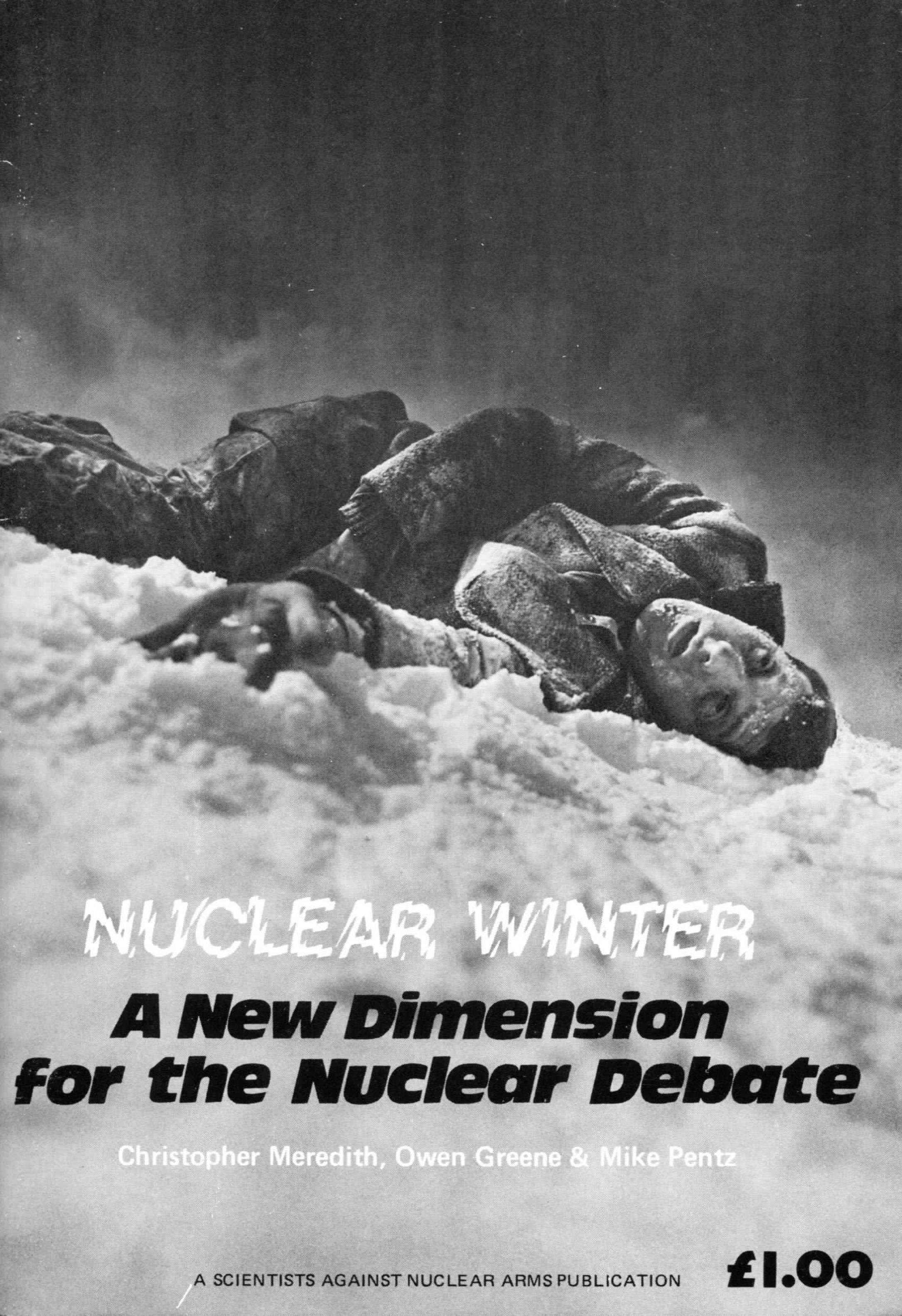

NUCLEAR WINTER

A New Dimension for the Nuclear Debate

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INTRODUCTION

Recent scientific studies have shown that the survivors of the direct effects of even a 'limited' nuclear war could face months of darkness and freezing cold. Many plants, animals and humans would die from worldwide climatic and environmental effects, and the scale of the casualties could equal those from the short-term effects of blast, fire and radiation. Civilised life as we know it could come to an end. In a large-scale nuclear war, exceeding what has been termed the 'doomsday threshold', it is at least possible that the human species would become extinct, along with many of the animal and plant species that share the Earth with us today.

These 'nuclear winter' predictions are shocking and unexpected. They add a new dimension, a new urgency, to the nuclear debate. Whereas previously optimistic forecasts claimed that there would be 25 million or more survivors of a nuclear attack on Britain, and pessimistic ones predicted there might be 5 million or fewer, it now seems that fewer than one million, perhaps many fewer, might survive. Whereas previously the neutral and non-aligned countries remote from the nuclear powers — above all those in the southern hemisphere — might hope to survive even a holocaust wiping out most of North America, Europe, the USSR and China, they now are seen to face the same catastrophic climatic effects as the rest of us. Whereas previously it has been argued that, as a last resort, a nuclear war might be the only way 'to defend freedom', the stakes have now been raised high that this loses all credibility.

It is not only the present generation that is at risk, but all the generations yet unborn. Who among us could bear the responsibility that the past and future of humanity, as well as the confused and strife-torn present, might be utterly obliterated, not by natural calamity or act of God, but by our own actions and inactions, fears and prejudices?

We ought not to forget, however, that nuclear war would be a catastrophe even without considering the nuclear winter. In a major conflict, the direct heat, blast and radiation effects alone could kill between 300 million and 1 billion people and injure as many more. Survivors would have contaminated water and little or no food, shelter, fuel, medical aid or other services. People would starve and die of wounds or disease in filthy conditions. Industry would collapse and the economy and social structure we call civilisation would disintegrate. Harvests would be ruined, many farm animals would die, and agricultural production would probably be minimal for years. Even if they had not been directly affected by the war, people in developing countries, vulnerable at the best of times, would be likely to starve as a result of the disruption of the world economy.

Even without the nuclear winter, one to two billion people — between a quarter and a half of the world's present population — are likely to perish after a global nuclear war. Nuclear winter threatens the survival of the rest.

WHAT IS THE NUCLEAR WINTER?

A nuclear war — assumed to involve the USA, the USSR and their allies — would start fires over enormous areas, including forests and cities. Nuclear explosions near the ground would hurl vast quantities of dust high into the atmosphere. This dust and the black, sooty smoke from fires would be spread by the wind. Within days, a dark cloud would cover large sections of the northern hemisphere, where nearly all the likely targets are located. Almost all the sunlight normally reaching the Earth's surface would be blacked out, causing the average temperature of the continental interiors to drop, probably by between 15°C and 30°C. This is enough to change a mid-latitude summer into a severe winter or to change winter into arctic conditions.

In the weeks and months after the war the cloud would continue to spread, soon covering the whole northern hemisphere. One unexpected conclusion is that the prevailing wind systems that govern the world's weather would be so distorted that the cloud would probably spread over large parts of the southern hemisphere as well.

Later, as the dust and smoke particles settled out, or were washed to the ground, light levels and temperatures at the Earth's surface would gradually increase. It might take a year or more for conditions to return to normal. As the cloud thinned out, dangerous amounts of ultraviolet light would reach the Earth's surface, because of partial destruction of the protective ozone layer high in the atmosphere. This would create a hazard of skin cancer and blindness, possibly for two or more years. It would also reduce resistance to infection by damaging the human body's immune system.

In addition to all these hazards, anyone who survived the immediate effects of nuclear attack would, in the following weeks and months, face the hazards of radioactive fallout at higher levels than previously expected, and of poisonous fumes from the fires.

Nuclear war

If present trends continue, nuclear war is very likely. If such a war does occur, we cannot predict exactly how it will be conducted. In spite of the arguments of 'limited nuclear war' theorists, most experts think it likely that any nuclear exchange between the Warsaw Pact and NATO would rapidly escalate to a global nuclear war in which a large proportion of the nuclear arsenals would be used.

Those who remember, or who have read of, the destructive power of the so-called 'conventional' weapons used in World War II (apart from the two single nuclear bombs exploded over Hiroshima and Nagasaki in August 1945) find it difficult to comprehend the escalation that has taken place since then. The total weight of high explosives used in the six years of that war has been estimated at between 3 and 5 million tons. Today, the equivalent in nuclear explosive is being carried, day in day out, in just one nuclear-armed submarine of the USA or the USSR. Even as the Hiroshima bomb exceeded by 1,000 times the 'blockbusters' that devastated London in World War II, so the most powerful nuclear weapons in service today have an explosive power 1,000 times greater again.

There are estimated to be more than 50,000 nuclear warheads in the world today. They have a total explosive power (or 'yield') of about 15,000 megatons, equivalent to 1,200,000 Hiroshimas. Most of these are to be found in the arsenals of the USA and the USSR. However, China, France and the UK each have more than 700 warheads, and two or three other countries may have a few.

More than 80 per cent of this explosive power is accounted for by 20,000-25,000 'strategic' and longer-range 'theatre' nuclear warheads. The remainder is carried by the 25,000-30,000 'tactical' nuclear warheads, such as depth charges and artillery shells, with an average explosive power of not much less than that of the Hiroshima bomb.

Though some details are highly classified military secrets, it is well known that targets have already been selected, by both WTO and NATO planners, for a large proportion of the strategic warheads available. Priority categories are likely to be:

1 Key military installations such as command and control centres, missile silos, missile submarines, naval bases, bomber airfields, nuclear weapons stores, radar warning systems, chemical warfare centres.

2 Conventional (non-nuclear) military installations such as troop and equipment concentrations, headquarters, ports of embarkation.

3 Communications and industry essential to military operations, for example, ports, railways, defence-related industry, power stations, oil refineries, chemical plants.

4 Economic and administrative structures essential for any prolonged war effort or national recovery in the years after the war.

Attack scenarios

The significance of the 'nuclear winter' effects was explained to the public for the first time at a major scientific conference held in Washington D.C. on 31 October and 1 November 1983. The first main paper presented (known by the acronym TTAPS from the names of the five authors - Turco, Toon, Ackerman, Pollack and Sagan) summarised the results of simulating a range of about 30 war 'scenarios' using advanced computer modelling techniques.

Although a major war involving the detonation of 10,000 megatons or more is perfectly possible, the 'baseline' scenario adopted by TTAPS involves about half this amount (i.e. about half the strategic weapons in the Soviet and American arsenals). Details of this and a sample of the other scenarios are given in Table 1.

TABLE 1 Some nuclear war scenarios

	Scenario	Total yield/ Mt	Surface bursts/ %	Urban-indust./ %	Yield range/ Mt	Number of warheads	Sunlight level after 2 weeks % of normal	Land surface temperature change/ °C
1	'Baseline' *	5,000	57	20	0.1-10	10,400	1-2	−24
2	10,000 Mt †	10,000	63	15	0.1-10	16,160	0.5	−27
3	Cities only	100	0	100	0.1	1,000	11	−23
4	'Baseline' *	5,000	57	20	0.1-10	10,400	79	− 6
5	10,000 Mt †	10,000	63	15	0.1-10	16,160	0.1	−41

Notes

* Scenarios 4 and 1 are the same, except that in 4 all smoke effects are omitted.

† Scenarios 5 and 2 are the same, except that in 5 more 'pessimistic' (yet still plausible) assumptions are made about such things as smoke generation and particle size.

Sunlight levels are averages over the northern hemisphere. Levels will be lower than average in many areas, particularly in the mid-latitudes (including Europe, USA, USSR and China). It is assumed that the sun is directly overhead. Coming in at an angle, the sunlight's path through the cloud is longer and the amount of light reaching the surface will be further reduced.

Temperature changes are averages for land areas in the northern hemisphere. The figures given are two-thirds of those predicted by TTAPS.

This baseline attack assumed that 10,400 nuclear warheads were used with yields of between 0.1 and 10 megatons. 57 per cent of the explosions were surface bursts, where the fireball touches the Earth's surface. 20 per cent of the warheads were exploded over urban or industrial areas. This may well be an underestimate: many important economic and industrial targets, and a large number of military targets and command centres are close to urban areas. The other scenarios modelled in this study involved a range of attacks from 'only' 100 Mt (made up of 1,000 warheads exploded over a few hundred major cities) to 25,000 Mt (exceeding the arsenals available today but perhaps possible in ten years time). Now let us consider some of the results of these simulated attacks.

Fires

In the seconds after a nuclear explosion, vast quantities of energy radiate away from the nuclear fireball as intense heat. Materials close to the explosion are vaporised. Exposed plastics, fabrics, wood and paper are ignited over an area of between about 300 and 500 square kilometres per megaton of explosive power, depending on weather conditions.

The many fires started by a nuclear attack soon merge and spread rapidly. This process is helped by the winds and, often, by the effects of blast, which distributes combustible debris and damages electrical cables, fuel stores and gas mains. Areas damaged by blast are also more vulnerable to the heat from any second weapon exploding nearby. Vast quantities of smoke are produced by fires in urban areas, forests and fuel stores such as oil refineries or gas wells. Grassland and agricultural crops generate less smoke for a given area because of the lower fuel density; however, as the areas involved are likely to be extensive, they may make a significant contribution to the total quantity of smoke injected into the atmosphere.

Urban areas, particularly inner cities, have particularly high fuel density. TTAPS assume, plausibly, in the baseline attack that about 250,000 square kilometres of cities and towns are set alight and burn for a day or so. This corresponds to half the area of all cities in NATO and Warsaw Pact countries with more than 100,000 inhabitants. If half the available fuel is assumed to burn and just over 2 per cent of this is converted into smoke, then about 135 million tons of smoke is produced. This is carried to altitudes of several kilometres in thick smoke plumes (Figure 1).

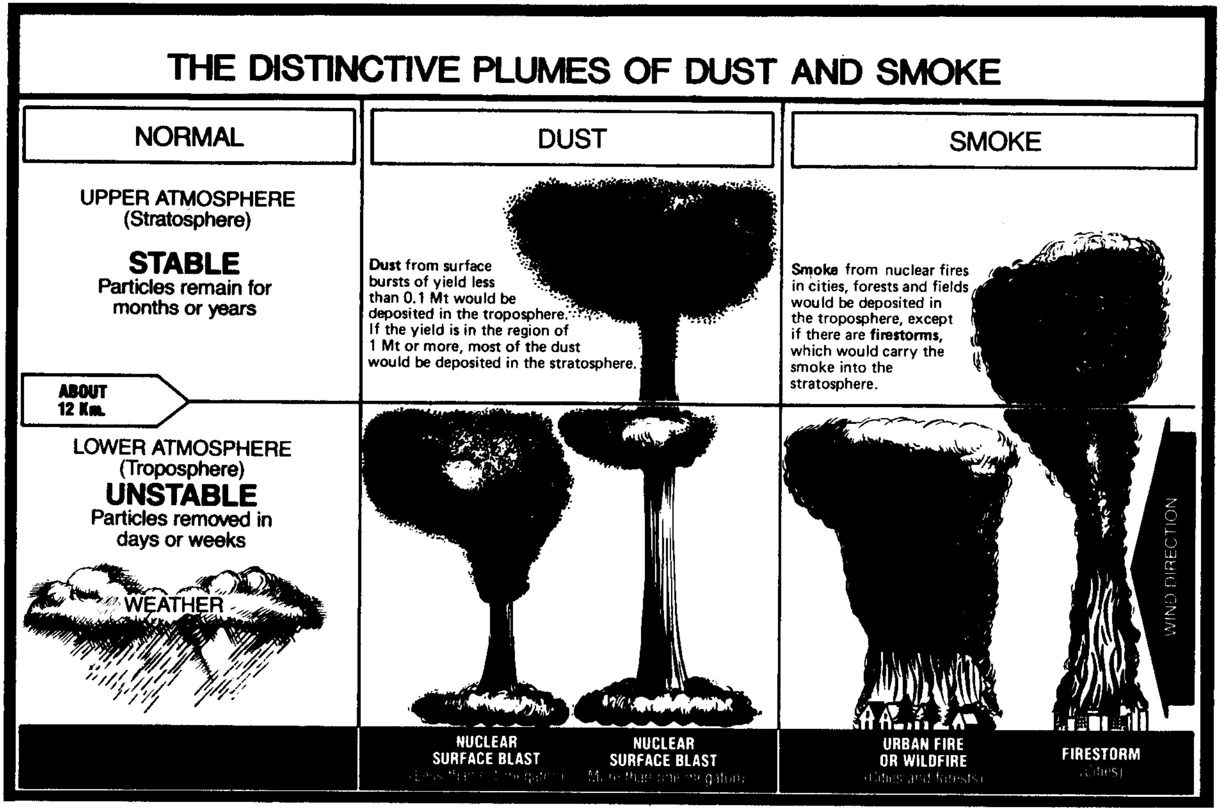

FIGURE 1 Deposit of dust and smoke particles in the atmosphere.

Such fires would also generate large quantities of poisonous fumes such as carbon monoxide and hydrogen cyanide, and hundreds of tons of persistent and highly dangerous dioxins and furans. TTAPS also assume that firestorms develop in 5 per cent of the cities attacked. In these cases, the intense heat sends the smoke into the upper part of the atmosphere, known as the stratosphere. The firestorm resulting from the major attack on Hamburg in World War II produced smoke plumes 14 kilometres high.

Fires in forest areas are likely to involve hundreds of thousands of square kilometres. How far they spread would depend on the season, winds and local conditions, but they would probably burn for ten days or so. Assuming that these 'wildfires' cover half a million square kilometres of forest, some 75 million tons of sooty smoke would be generated. This is just three times the forest and scrubland area that used to be burned every year in the USA before efficient fire control and prevention programmes were developed, and so it would appear to be a plausible, if not conservative, figure. No climatic changes resulted from these fires, however, because they took place piecemeal through much of the year, spread relatively slowly, so that the smoke plumes did not rise to great heights, and were not accompanied by widespread urban fires.

Any comprehensive nuclear attack would also set fire to many oil refineries, oil wells and natural gas fields, and possibly in some areas to coal and peat deposits. Such fires could burn for a month or more. It is difficult to estimate their extent, but the TTAPS estimate that they might produce about 16 million tons of smoke (in the baseline scenario) appears to be conservative.

In total, about 225 million tons of smoke would be produced in a 5,000-Mt. war. Most of it would remain below about 12 km in the lower atmosphere, known as the troposphere, but the widespread fires and the firestorms could send about 5 per cent of it into the stratosphere. Independent studies by Crutzen and others came to similar conclusions.

More than half the smoke would consist of very small particles of soot; perhaps 90 per cent of them would have a radius of less than a micron (a thousandth of a millimetre). These small soot particles would absorb sunlight very efficiently, and would normally, on the average, remain in the upper troposphere for about two weeks. In the altered atmospheric conditions after a nuclear war, they could remain very much longer, which would make the climatic effects even more severe than TTAPS predict. Soot particles that reached the stratosphere could remain there for months or even years.

Dust

A nuclear explosion on or near the ground excavates a huge crater and hurls great quantities of dust high into the atmosphere—between 100,000 and 600,000 tons for each megaton of explosive power. Even airbursts, where the fireball does not touch the ground, generate winds that may carry some 10,000 tons of dust per megaton into the atmosphere. High-yield explosions, of 0.5 Mt or more, send most of the dust into the stratosphere, where it remains for months or years. Dust from explosions of less than 0.1 Mt, on the other hand, remains in the troposphere, where it is washed out by rain or coagulates, and falls to the ground after only a few weeks.

In the 5,000-Mt baseline war, some 960 million tons of dust would be injected into the atmosphere. The range of warhead yields in the present nuclear arsenals is such that about 80 per cent of the dust would go into the stratosphere. This dust injection is an order of magnitude greater than that of the largest volcanic eruptions of recent times. The dust from these eruptions caused average coolings of about 1°C. The nature of a nuclear dust cloud would be somewhat different (for instance, the particle size would be smaller), but these volcanic events provide the only available analogy and indicate a lower limit to the likely effects.

Darkness

Some of the dust and smoke projected into the atmosphere would soon be washed back to the ground by rain. The rest would form a dark cloud which would be carried around the Earth by winds (Figure 2). During the first few days, the cloud would be patchy and confined mostly to the northern mid-latitudes (including Europe, much of China, the USA and the USSR), where the main nuclear targets are concentrated. After a week or so, these regions would probably be covered by an unbroken dark cloud, which would spread to cover the whole of the northern hemisphere in the following weeks.

The dark cloud would reflect some sunlight back to space and absorb most of the rest. The amount of sunlight reaching the Earth's surface would thus be reduced to a few per cent of normal. After about ten days, areas under the densest parts of the cloud would be in near darkness. Even at noon the light might be no brighter than on a moonlit night.

The cloud would probably spread to cover large areas of the southern hemisphere, bringing a (less severe) nuclear winter to those areas as well. This effect was unexpected, because normally

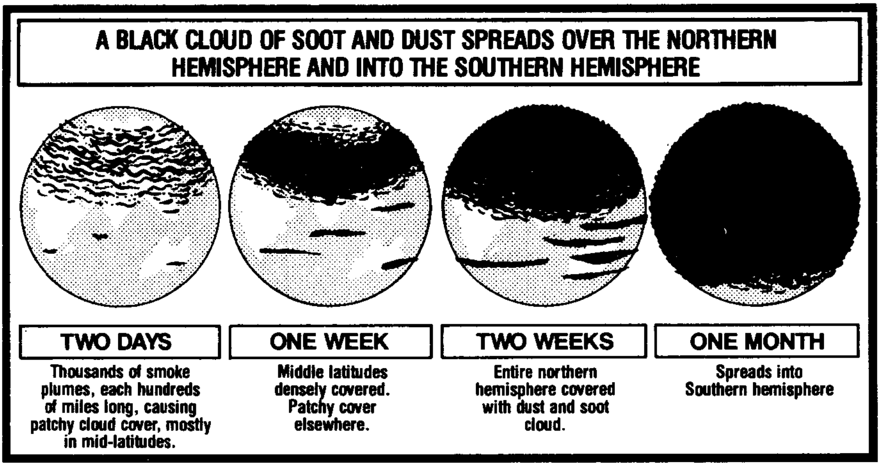

FIGURE 2

global wind patterns do not produce much flow between hemispheres. The black cloud would heat up as it absorbed sunlight, and this would profoundly alter the usual wind patterns. The resulting temperature and pressure contrasts would generate trans-hemispheric winds, carrying dust and smoke particles with them.

The great freeze

With little of the sun's energy penetrating to the Earth's surface, and with heat from the ground radiating relatively easily through the cloud and out into space, surface temperatures below the cloud would drop sharply. Tiny soot particles in high concentration are very effective at blocking visible light but are fairly transparent to infrared (i.e. heat) radiation. Thus, the cloud would have the opposite effect to that of a greenhouse: instead of letting light in and preventing heat from escaping, it would do the reverse.

Detailed computer models are needed to predict the precise temperature drops. The TTAPS group made a series of careful calculations for each of their attack scenarios. For the baseline case, they predicted average temperature drops of about 36°C in inland areas after three weeks. Other scenarios, ranging from 3,000 Mt to 10,000-Mt with similar targeting assumptions, were predicted to cause average temperature drops of between 35°C and 45°C. Even a 100-Mt attack on cities (using a thousand 0.1-Mt warheads) was found to cause a temperature drop of 30°C, though for a shorter period. There would be a more rapid recovery to normal temperature in this case because the effect would be entirely due to smoke in the lower atmosphere, which would clear relatively quickly.

(The 100-Mt scenario involved no groundbursts and therefore generated little dust.)

The TTAPS results clearly show the critical importance of smoke: if the effects of fires are omitted from the baseline attack, the temperature is predicted to fall by 5°C to 8°C over a period of several months. The effects of this would be serious, but possibly not catastrophic.

All of the above temperature predictions refer to inland areas, and do not take account of the effects of the oceans. These store much greater quantities of heat than the land surface, so they would take longer to cool down. Also, as the surface water cooled, the warmer water from below would mix with it. As a result, the upper layers of the ocean would not cool by more than a few degrees before the black cloud dispersed.

There are, of course, considerable uncertainties in these calculations. Because of the complexity of the problem and the vast areas and quantities involved, the TTAPS group was forced to make important simplifying assumptions. They themselves suggest that, as a result, their estimates of temperature reductions could be too great by 30 to 40 per cent.

We shall accordingly adopt a conservative attitude and, from now on, reduce the original TTAPS figures for temperature reductions by one-third. Thus, 36°C becomes 24°C for the predicted drop in inland areas in the baseline case.

From the point of view of human survival, however, this difference would in practice be somewhat academic. An average temperature drop of 15-20°C, prolonged over several weeks, would have catastrophic effects.

The first year

As the cloud thinned, light intensity and temperatures at the Earth's surface would increase. How long would it take before they returned to normal?

This is an area of considerable uncertainty. The atmosphere would be greatly altered in the early stages of the nuclear winter, so we cannot assume that the dust and smoke would fall back to the surface at the same rate as they would in the present-day atmosphere. If, however, we assume that the present-day rates would apply, then, two weeks after the baseline attack, the average light intensity at noon in the northern hemisphere would fall to about 2 per cent of normal. After a month, much of the smoke would have been removed and the light would probably be between 10 per cent and 15 per cent of normal, increasing to about 30 per cent after three months. There would be a heavy overcast sky for eight months or more. After a 10,000-Mt attack, light levels could still be below 50 per cent of normal a year later.

Figure 3 shows some of the TTAPS results, with the temperature drops reduced by a third as described above. Shortly after the attack, the temperature plummets, reaching a minimum after three or four weeks (in the baseline case). Then it begins to rise as the smoke clears from the lower atmosphere. After two or three months, nearly all the smoke has gone and the main effect comes from the dust in the stratosphere. The temperature now rises more slowly as dust is gradually removed in the following months. In the baseline case, the temperature takes about a year to return to normal.

As would be expected, if fires are omitted from the baseline scenario, the temperature drops much less severely in the first three months, and then follows the same pattern as for the full baseline scenario. If we look at the *difference* between the full baseline cause and the 'dust only' version of it we get an idea of the effects of the smoke by itself after a 5,000-Mt war. The difference between this and the 100-Mt 'smoke only' attack on cities is strikingly small.

Some scientists have suggested that temperature reductions such as these could trigger another Ice Age, but this seems unlikely. The Earth's climate is more likely to return after some years to a state similar to the present.

Ultraviolet radiation

It is now widely accepted that a nuclear war is likely to disrupt the ozone layer in the stratosphere. This layer protects the Earth's surface from dangerous levels of ultraviolet solar radiation. Very large quantities of nitrogen oxides would be formed in the heat of the nuclear fireball. If the warhead has a yield of more than about 1 Mt, these would be carried high into the stratosphere, where they would react with the ozone, reducing it to ordinary oxygen. The baseline attack is predicted to reduce the ozone by some 30 per cent, as a result of which the amount of ultraviolet radiation reaching the Earth's surface would be doubled.

At first the Earth's surface would be protected by the cloud of dust and smoke but, as the sky cleared, this protection would disappear. After the nuclear winter, surviving plants, animals and people would be exposed to excess ultraviolet radiation for two years and quite possibly longer.

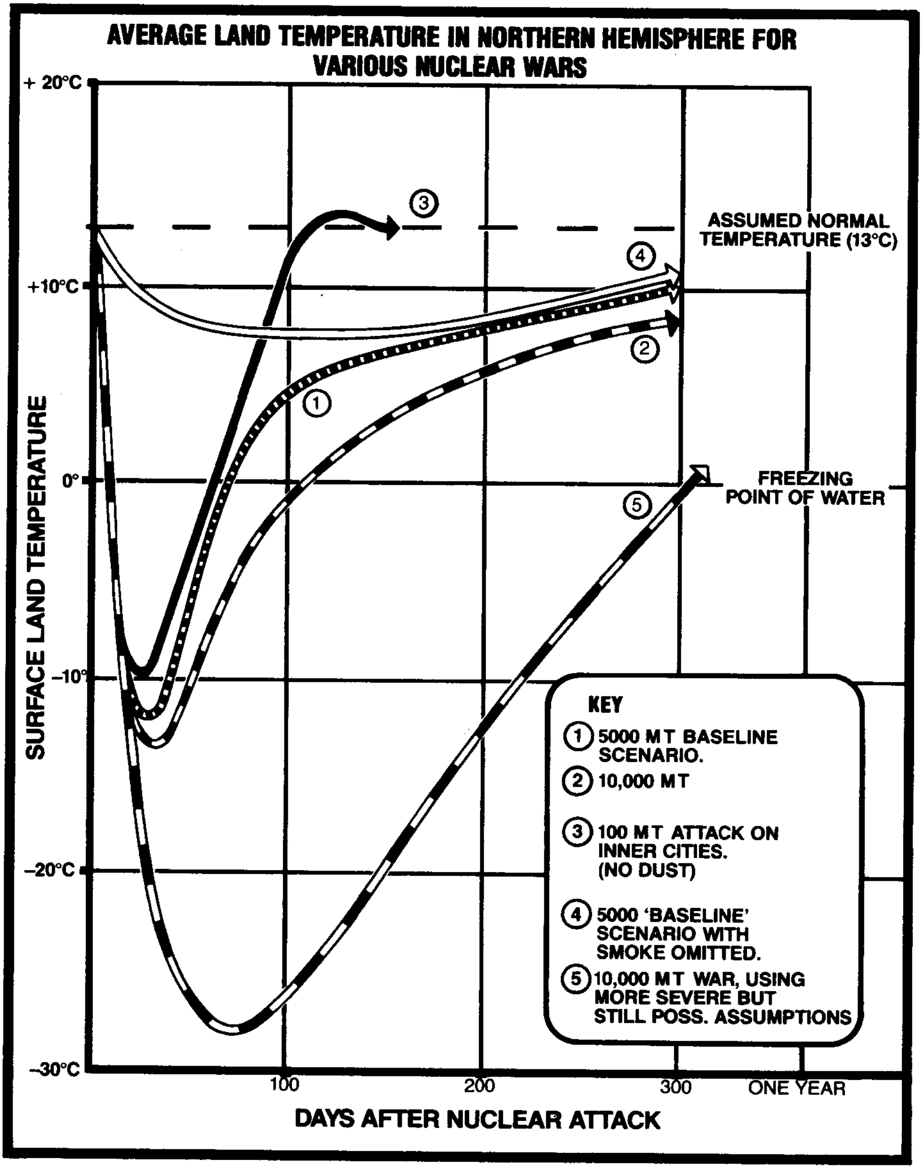

FIGURE 3 Average temperatures in continental interiors of the northern hemisphere.

Radioactive fallout

A nuclear explosion sends large quantities of radioactive debris into the atmosphere which falls to the ground sooner or later. Until recently, two kinds of fallout were considered: local and global. Local fallout consists of radioactive particles carried on relatively large dust particles that fall to the ground within a few hundred miles of the explosion in the first few days. Fine radioactive particles injected into the stratsophere take many months to fall to the ground, by which time they have dispersed over much of the globe; this constitutes global fallout. Because most of the radioactivity has decayed away by the time the global fallout reaches the ground, it does not cause short-term, acute, radiation doses, in sharp contrast to the local fallout.

The TTAPS group pointed out that lower yield warheads (i.e. less than 0.5 Mt) would inject a large amount of radioactive material into the troposphere, along with dust from groundbursts and most of the smoke from all sources other than urban firestorms. These tropospheric injections would spread quickly over large areas of the northern hemisphere, and be deposited on the ground after a few weeks, while their radioactivity was still relatively high. This would constitute what has been called 'intermediate time-scale fallout'.

In northern mid-latitudes, radiation doses from this source could amount to more than 50 rads (not counting any additional dose from ingested radioactive particles, which could be as much again), spread over a period of a month or two. Such radiation doses would not in themselves have acute effects or cause immediate fatalities. They would nevertheless be very dangerous, even to people who had not previously been exposed to sub-lethal radiation doses from local fallout, for they would seriously increase the risk of infection by damaging the immune system, as well as increasing the incidence of cancer, birth defects and genetic defects in people who managed to survive long enough for these effects to manifest themselves. For people in areas affected by local fallout who had already received sub-lethal radiation doses, the additional 50-100 rads could make the difference between survival and death.

What about Britain?

As already mentioned, the temperature reductions in islands and coastal regions would be less severe than in inland areas, due to the temperature stability of the oceans. Ideally, computer models would take the world's geography into account and make reliable predictions for each region. Soviet work and research carried out at the National Center for Atmospheric Research in Colorado do attempt such predictions. Unfortunately, the uncertainties are too great for us to regard the results obtained so far as more than first approximations.

A reasonable estimate appears to be that the average temperature in Britain would fall by 10-20°C after the baseline attack, although the reduction could be more severe. This average refers to the drop in temperature over a period of weeks. On a day-to-day basis, the temperature drop might vary from just a few degrees, with winds off the ocean, to as much as 40°C with winds blowing from the continental interior.

Light levels in Britain would be reduced just as much as elsewhere in the northern hemisphere. The contrast between the cold Eurasian and North American continents and the warmer oceans would be likely to generate strong winds and violent storms over the UK and the coastal areas of Europe. As the wind direction changed, the weather would change rapidly between snow and hail storms and extremely cold dry winds. As is well known to mountaineers, the effects of exposure to cold are greatly increased by wind.

BIOLOGICAL CONSEQUENCES

What are the probable effects of the nuclear winter on plants and animals on land and sea? How much of agriculture could survive?

Biologists discussing these questions at the Washington Conference expressed the view that any human survivors might be struggling against Stone Age conditions: 'hunters and gatherers with little to hunt and less to gather', as one speaker graphically put it.

Further study is needed before detailed predictions can be made, for some of the uncertainties in the conclusions of the physicists and meteorologists are of considerable importance in estimating the biological and ecological effects. Moreover, the effects of a nuclear war in spring or summer (in the northern hemisphere) would be significantly different from those of a war in the winter. The interactions of several stresses on biological systems and the varying adaptability of different species to these unprecedented conditions are also matters requiring careful investigation.

But these uncertainties do not affect the basic conclusion, which is clear and sombre. The main paper presented at Washington on behalf of a group of 20 biologists declared:

> It is clear that the ecosystem effects *alone* resulting from a large-scale thermonuclear war could be enough to destroy the current civilization in at least the Northern Hemisphere. Coupled with the direct casualties of over 1 billion people, the combined intermediate and long-term effects of nuclear war suggest that eventually there might be no human survivors in the Northern Hemisphere. Furthermore, the scenario described here is by no means the most severe that could be imagined with present world nuclear arsenals and those contemplated for the near future. In any large-scale nuclear exchange between the super-powers, global environmental changes sufficient to cause the extinction of a major fraction of the plant and animal species on the Earth are likely. In that event, the possibility of the extinction of *Homo sapiens* cannot be excluded.

Further work on the climatic and environmental consequences of nuclear war, and upon their biological impacts, might lead to lower (or higher) estimates of this possibility. However, a sober estimate by a group of distinguished biologists that it 'cannot be excluded' has to be taken seriously.

Plants

If sunlight is reduced to less than 5 per cent of normal, plants receive too little energy through photosynthesis to sustain themselves, and growth stops. If light levels are higher, but still below normal, growth is slowed and plant productivity is lower than usual. A 5,000-Mt war is estimated to reduce average light levels in the northern hemisphere to less than 5 per cent of normal for about 3 weeks, and to less than 50 per cent for almost four months. The consequences of more limited exchanges may be only slightly less serious. After a more severe (10,000 Mt) nuclear war, the light levels could be reduced to less than 1 per cent of normal for over a month and to less than 5 per cent for over two months. At 1 per cent of normal light, photosynthesis stops altogether and plants die.

Crops would suffer, especially if the nuclear winter occurred in spring or early summer. Some very simple experiments carried out recently by Dr Alan Longman, a biological scientist in Scotland, have shown that young or growing wheat plants are severely affected by just two weeks of dim light; after three weeks most of the six week old plants were dying or dead. Even if crops recover after light levels increase, their growth is likely to have been so delayed that there will be little or nothing to harvest.

A plant's response to cold varies according to the time of year, how suddenly the cold spell arrives and how long it lasts. Normally, plants have several weeks or months in which to harden themselves against the cold of winter. The nuclear winter would arrive suddenly, and its effects would therefore be much more serious. Oats, barley and rye would be very badly hit by temperatures of 0°C in late spring, even though they can be hardened to withstand lower than −10°C by late October. Temperate-zone trees may be injured even by transient frosts after they begin their active growth phase in spring. Even the Alpine Pine, which can withstand −50°C in winter, may be killed by a period at −5°C in summer. A 5,000 Mt war in summer is predicted to cause temperatures of between −5°C and −15°C in continental regions for several weeks. It would be two or three months before they rose above freezing point. Even in Britain, which might be protected to some extent by proximity to the ocean, intermittent but severe sub-freezing conditions could continue for weeks.

On a worldwide scale, temperature drops of only a few degrees could be catastrophic. Growing corn and soybean are very sensitive to temperatures of less than 10°C. A whole rice crop can be lost if the temperature falls below 13°C and rice is the staple diet of about half the world's population. By shortening the growing season, a small temperature reduction can reduce the harvest to almost nothing.

Tropical plants are particularly vulnerable to cold. They are geared to a continuous growing season and would have practically no resistance to even a mild nuclear winter. Tropical trees also depend on strong sunlight. If the tropical forests were destroyed, lack of seed supplies and erosion could make it impossible for them to regenerate, to judge from experience in large areas of the Amazon basin and South East Asia.

Taken together with radiation from local radioactive fallout, the intermediate time-scale fallout described previously would be very serious. Many varieties of pine trees are almost as vulnerable to radiation as are people, and much of the coniferous forest covering extensive areas of the northern hemisphere might be killed. Young barley and wheat plants are also relatively vulnerable to radiation.

Plants (and animals) would be injured by the poisonous pollutants released into the atmosphere by fires. The devastating effects of acid rain would be repeated on a vastly greater scale.

The increased level of ultraviolet radiation immediately following the nuclear winter would also have severe effects, harming plant leaves and reducing photosynthesis. It would reduce the yield of the plant and weaken its resistance to other hazards. It would be particularly destructive to the productivity of the minute organisms known as plankton that live in the surface layers of the oceans. These organisms are the basis of all animal life in the seas.

Each of these effects taken by itself would be serious; in combination they would be catastrophic. Plants weakened by radiation and pollution are less able to withstand cold. An increase in ultraviolet radiation makes it harder for plants to recover from the effects of reduced light.

Animals

For animals outside the tropics, winter is an annual hazard that requires much feeding and preparation. Even then it is often barely survived. A sudden nuclear winter would catch animals unprepared and would kill many of them. Those that survived would be in poor condition to face the following winter.

Many birds normally escape winter by migration to warmer regions. Birds would also be caught by surprise by a nuclear winter and many would die. Even if they did migrate, the tropics and probably large parts of the southern hemisphere would also be cold and dark. There would be nowhere for the birds to go.

If the nuclear war occurred at the beginning of the normal winter in the northern hemisphere, the nuclear winter there might be less catastrophic. For some animals and many plants the difference between winter and arctic winter (or worse) might not be as serious as the difference between summer and winter. Energy reserves would have been built up and, for some species of animals at least, the strongest individuals might survive. In the case of plants also, seeds can survive much harsher conditions than growing plants. Nevertheless, the effects of a much colder and longer-lasting winter would certainly be serious. The following spring would be much colder and darker than usual and the intermediate time-scale fallout and the ultraviolet light would be at least as damaging as if the war occurred at another season. The tropics would be just as seriously affected by a winter war, and its impact on the southern hemisphere would be greater.

Most higher animals are relatively vulnerable to radiation. Dogs, birds, cattle and sheep would, like people, be killed or seriously injured in tens or even hundreds of millions. Those that survived would have reduced resistance to infection and disease. They would have to eat contaminated food and drink contaminated water (if they could find it unfrozen). Insects, however, are less vulnerable to radiation and thus more likely to survive.

Ultraviolet light also reduces animal resistance to infection. It causes sunburn and can cause skin cancer. The eyes are particularly sensitive to it (which is why skiers and climbers wear snow glasses at high altitudes). Many animals and people might become blind through cataracts or corneal damage.

As with plants, the combination of all these hazards would be even more serious than the sum of their separate effects. For example, animals and people weakened by radiation are more vulnerable to cold.

All animals ultimately depend on plants to live. By killing plants or reducing their growth, the nuclear winter would spell death for millions of herbivores. Close grazing of already weakened plants by starving animals would kill even more plants, so that many plant and animal species would risk extinction. As herbivores died, carnivores would starve and die also.

The ecological history of the Earth is witness to the fact that even relatively mild changes in climate can have dramatic consequences. Ecological systems are often delicately balanced and relatively small population changes in some species can sometimes cause others to die out altogether. The biosphere may survive a nuclear winter, but in a radically different form.

The oceans

What about fish, plants and other creatures living in the seas and oceans? Because the thermal capacity of water is greater than that of soil or rock, and because the upper layers as they cool will mix readily with the slightly warmer water below, the ocean surface temperature is not expected to cool by more than a few degrees centigrade after a nuclear war.

Does this mean that the impact of a nuclear war on ocean life would be minimal? According to the studies undertaken so far, this would unfortunately not be so. Most ocean life ultimately depends on the solar energy photosynthesised by phytoplankton. By blocking out most of the sunlight, the cloud of smoke and dust would reduce photosynthesis and lead to a sharp decline in the phytoplankton population. The ocean food chains would be cut off at their base, and millions of fish and other animals would starve.

Plankton are also very sensitive to ultraviolet radiation. Even normal levels of ultraviolet light are known to depress their productivity significantly. Two or more years of increased ultraviolet radiation would thus have profound effects on the marine food chains.

Human survivors who looked to the sea as a source of food after a nuclear war would therefore be disappointed. Although it would take some time for the loss of plankton to lead to the large-scale starvation of fish, it would be hard to take advantage of this. As mentioned earlier, the temperature difference between the oceans and continents would cause strong gales in coastal regions and make fishing very difficult — even supposing that the fishermen could find fuel for their boats.

Outlook for humanity

It is not part of our argument that there would be no survivors, but any there were would face a grim struggle against unparalleled odds, for which they could have little or no preparation.

Human survivors would face a cold, dark, radioactive, smoggy world. In countries directly affected by nuclear explosions, medical services, food and water supplies, electricity and fuel supplies, transport and communication systems would have completely broken down. Cities and industries would be in ruins. Social structures would have disintegrated. Survivors would be suffering from shock and psychological trauma. They would be surrounded by masses of corpses and seriously injured people needing care. Without proper sanitation or water supplies and without medical care, diseases would flourish in a population weakened by radiation, exposure and malnutrition.

> Apart from the difficulties of keeping warm, finding unfrozen water, and avoiding radiation exposure and the choking smog, food would be the most urgent need. The war undoubtedly would have destroyed much food in storage as well as crops in the fields. Worldwide food production rarely is abundant enough to provide carry-over stocks that would last for more than two months under normal consumption patterns.
>
> Only grains are stored in large quantity, usually far from population centers. Thus any grain that escaped destruction would be largely inaccessible. Without agricultural production, even a heavily decimated population would face severe and continuing food shortages in a short time — although they would be alleviated somewhat in developed countries by the disappearance of livestock as competitors for grains.
>
> (From the Special Supplement to the *Bulletin of the Atomic Scientists,* April 1984, written by the biologist Anne Ehrlich.)

Many countries, both in areas likely to be directly affected by nuclear explosions and elsewhere, depend heavily upon food imports, mainly from North America. These would abruptly cease, causing almost immediate famine.

> . . . In the sub-tropics and tropics, people might turn in desperation to the remaining forest areas, try to convert them to subsistence agriculture, and thereby greatly accelerate the already disastrous current rate of tropical deforestation, compounding the destruction caused by the atmospheric disturbances.
>
> In the northern target regions, it is unlikely that more than a tiny fraction of the original population could survive the first few months after a nuclear war of appreciable scale. Even though atmospheric conditions might return more or less

> to normal in a few years, other aspects of the environment would be altered beyond recognition. Ecosystems would recover slowly, with entirely new structures, impoverished species compositions and a reduced capacity to support human life. Local climates would probably be novel and unpredictable. Pre-war cultural adaptations would be useless in such a changed, hostile, unstable world.
>
> . . . Small isolated human groups might persist for several generations in a strange, inhospitable environment in the Southern Hemisphere, their adaptive capacities sapped by inbreeding and burden of genetic defects from the postwar exposure to ionizing radiation and increased ultraviolet-B – a classic recipe for extinction. (ibid).

To fill in the details of this awesome picture, much more research is needed. Teams of scientists are already engaged in such studies. It is already clear that any forms of life able to survive and multiply in the aftermath of nuclear war must be tough, adaptable and relatively simple in their needs. Pests and weeds satisfy these requirements, as humans do not. As one biologist at the Washington Conference put it, the world would become 'a republic of insects and grasses'.

THE EVIDENCE ACCUMULATES

The scientific work on the nuclear winter contains much that is new and unexpected, and attempts quantitative estimates (even if still with a large range of uncertainty) where previously only informed guesses were possible. This work is, however, firmly rooted in earlier studies involving large numbers of distinguished scientists in many countries. This is one reason why even the unexpected conclusions have been broadly accepted as valid, following careful examination by those best qualified to judge.

The earlier studies included some on subjects that may seem far removed from nuclear war. One example is the analysis of the effects of a global dust storm on Mars. This happened in late 1971 and could be studied in detail because the US Mariner 9 spacecraft happened to be near Mars at the time. As the dust absorbed the incoming sunlight, the planet's surface cooled and the upper Martian atmosphere warmed up. After some months, the dust fell out of the atmosphere and the temperatures at both levels returned to normal. During this event, it was observed that the dust spread rapidly over the whole globe, showing that the normal wind system on the planet had been disrupted by the temperature changes. The analogy with the Earth is clear.

Other evidence derives from the study of volcanic eruptions. The largest ones, such as those of Krakatoa in 1883 and Tambora in

1815, inject millions of tons of dust into the atmosphere, on a scale comparable with that of a limited nuclear war. The resulting dust clouds are known to have encircled the globe and to have led to average temperature reductions of about 1°C— quite enough to affect climate and agriculture significantly. A permanent temperature reduction of 1°C would almost eliminate wheat growing in Canada, for instance. The difference between this cooling and the much greater cooling predicted in a nuclear winter is attributable to several factors:

— In a nuclear war there would be numerous explosions, probably distributed widely over at least the northern hemisphere.

— A large part of the resultant cloud would be soot, which has quite different characteristics from those of volcanic dust.

— Even the dust component of the nuclear cloud would differ in particle size and chemical composition from that produced by volcanoes.

Nevertheless, volcanic eruptions can have quite severe and unexpected effects on climate. Following the Tambora eruption in 1815, which took place south of the equator in Indonesia, the following summer in Europe was the coldest on record before or since, six inches of snow fell in New England in June, and there were world-wide crop failures. (See 'The year without a summer', *Scientific American*, June 1979.)

Early warnings

Although the nuclear winter itself was overlooked, earlier investigators of the probable effects of nuclear war were not unaware that there would be global and long-term consequences in addition to the immediate effects, from blast, fire and radiation, on the countries directly involved. The global effects most often referred to were:

— long-term radioactive fallout, causing cancer and genetic damage affecting later generations;

— depletion of the ozone layer, resulting in increased ultraviolet radiation;

— dust clouds and consequent cooling, by analogy with volcanic eruptions;

— extensive disruption of the complex networks of the civilised world (communications, transport, trade, finance and, above all, distribution of food, fuel and medicines), leading to large scale famine and disease and a breakdown of social order affecting hundreds of millions not directly involved in the war.

However, as the experts in the US office of Technology Assessment (OTA) stated in their report, *The Effects of Nuclear War* (1979), 'The effects of nuclear war that cannot be calculated are at least as important as those for which calculations are attempted'. This report is one of the clearest and most authoritative surveys of the expected effects of a nuclear war and was produced by the OTA, a US Government agency, at the request of the Senate Committee on Foreign Relations.

The first three global effects listed above were considered in detail in a report by the US National Academy of Sciences (*'Effects of Multiple Nuclear Explosions Worldwide'*, Washington D.C., 1975). It predicted temperature drops of only a few degrees, but this was because the authors considered only the effects of dust from volcanic eruptions, overlooked important differences between volcanic dust and that from nuclear explosions, and took no account of smoke. The report predicted increases in ultraviolet radiation similar to the results of more recent calculations. However, by adopting a war scenario in which warheads had yields of 1 Mt or more, the report overlooked the possibility of severe intermediate time-scale radioactive fallout from lower yield weapons.

Another authoritative report, commissioned in 1978 by the United Nations *(Nuclear Weapons: Report of the Secretary-General*, 1980) dealt at length with the short-term effects of nuclear explosions, but only briefly mentioned longer term environmental and biological effects such as radiation-induced cancers and mutations, partial destruction of the ozone layer and the cooling effects of dust clouds. The experts responsible for the report clearly had no inkling of the subsequent scientific findings underlying the nuclear winter prospect. But they nevertheless concluded: 'Never before has mankind been faced, as today, with the real danger of self-extinction'.

Ambio studies

A major step forward in these studies, and the starting point for much that followed, was the publication in June 1982 of a special issue of the international environmental journal *Ambio*, under the auspices of the Royal Swedish Academy of Sciences. A nuclear war 'scenario' was selected by a group of experts to emphasise the environmental effects of a major nuclear exchange. This did not purport to describe the most probable nuclear war. It involved 14,747 warheads with a total yield of 5,742 Mt, i.e. less than 50 per cent of the combined Soviet and American nuclear arsenal then in existence. It was thus well within the bounds of possibility. The editors commissioned world experts to contribute detailed estimates of the global effects of this nuclear war in different fields, physical, atmospheric, biological, medical, economic, psychological, etc. The whole study was subsequently republished as *Nuclear War: The Aftermath* by Pergamon Press in 1982.

The first suggestion of the nuclear winter possibility came in a significant chapter on Atmospheric Effects, written by Paul J. Crutzen (Director of the Air Chemistry Division of the Max Planck Institute for Chemistry in Mainz, Germany) and John Birks (Associate Professor and Fellow of the Cooperative Institute for Research in Environmental Science at the University of Colorado, USA). This chapter emphasised in particular the production of long-lasting worldwide photochemical smog as a result of forest, urban and industrial fires throughout the northern hemisphere, and the resulting increase of up to 5 times in the normal concentration of ozone in the lower atmosphere, which would severely reduce the productivity of crops.

> It appears highly unlikely that agricultural crop yields would be sufficient to feed more than a small part of the remaining population, so many of the survivors of the initial effects of the nuclear war would probably die of starvation during the first post-war years.

The authors also calculated that hundreds of millions of tons of particulate matter (dust, smoke and soot) would rise up into the atmosphere and darken the sky of the entire northern hemisphere for weeks or months after a major nuclear war, thereby bringing agriculture to a complete halt even in countries not involved in the war. They suggested that there would be profound climatic consequences.

Crutzen and Birks did not have time in their study to estimate:

1 the detailed atmospheric behaviour, in relation to particle coagulation and sunlight obscuration, that might be expected;

2 the temperature reduction over large parts of the Earth's land surface, resulting from the prolonged cut-off in solar radiation;

3 the health effects of the fire-produced pollutants, which would be added to the direct effects on agriculture and food production.

However, they estimated that from forest fires alone, 'the average sunlight penetration to the ground will be reduced by a factor of between 2 and 150 at noontime in the summer over most of the Northern Hemisphere'.

The range of uncertainty indicated was a clear pointer to the need for further intensive research on this subject by atmospheric physicists and meteorologists, and was one of the stimuli for the Washington Conference.

The Washington Conference

The Conference on The World After Nuclear War — held in Washington D.C. on October 31 and November 1, 1983 — attracted over 500 participants, mostly from the USA, but with some also from the USSR, UK, Canada, the Federal German Republic and a dozen other countries. It was sponsored by over 30 scientific and environmental bodies, including the International Union for Conservation of Nature and Natural Resources and the International Union of Biological Sciences.

The Conference had been almost two years in preparation, and resulted from the coming together of three distinct strands of enquiry:

- atmospheric physicists and others who had been inspired by the work of Crutzen and Birks to investigate the effects of dust and smoke, using physical and computer models of the Earth's atmospheric circulation;
- a group of biologists and ecologists who were trying to alert their colleagues and the public to the often overlooked biological impacts of nuclear war;
- a group of environmentalists and executives of charitable and research foundations who were similarly seeking to present nuclear war as the ultimate, and possibly terminal, threat to the environment.

The three groups pooled their efforts and secured a wide range of sponsorship and financial backing. To ensure that the scientific content of the conference was well prepared, two preliminary meetings were held in April 1983 in Cambridge, Massachusetts, with the participation of over 70 distinguished physical scientists and biologists. A draft of the TTAPS study was presented first to the physical scientists, who had many questions about details but very little quarrel with the general conclusions. The biologists then examined the consensus results of the physicists. They too had many questions about details but essentially no disagreement on the impact on biological systems, agriculture and human life of climatic changes on the scale of the TTAPS predictions.

In the following months, the TTAPS paper was refined in the light of comments, while 20 of the biologists prepared a paper on the long-term biological consequences of the atmospheric and other effects forecast by TTAPS. Both papers were presented at the Washington Conference and subsequently published in *Science* (23 December 1983).

Preliminary results were also presented in Washington of several independent studies, notably those of groups working at the US National Center for Atmospheric Research in Colorado, the Soviet Academy of Sciences in Moscow, and the Lawrence Livermore Laboratory in California. Their results were in substantial agreement with the TTAPS conclusions and were incorporated in the findings.

A highlight of the Conference was the participation of Soviet scientists, both in person and through a two-way televised link-up by satellite of a lengthy discussion between the leading speakers in Washington and a similar group in Moscow. This demonstrated a remarkable convergence of views, not only on the scientific findings but also on their policy implications.

The SCOPE enquiry

In parallel with these developments, an international study had been initiated through the International Council of Scientific Unions (ICSU). The ICSU General Assembly in September 1982 voiced the need for an unemotional, non-political authoritative and readily understandable statement of the environmental effects of nuclear war. The request was passed on to ICSU's Scientific Committee on Problems of the Environment (SCOPE), which decided in June 1983 to launch a two-year project with a view to reporting at the next general SCOPE meeting in September 1985.

The direction of the project on Environmental Consequences of Nuclear War (ENUWAR) is in the hands of an international steering group with members from the USA, USSR, UK, France, India, Japan and Sweden. Many of the scientists involved in the Washington Conference are participating in this work. All the threads of the enquiry will be brought together at a two-week session in June 1985 at the ENUWAR headquarters at the University of Essex. It is not expected that ENUWAR will publish any findings until its report is presented to SCOPE, but thereafter its conclusions will be disseminated actively through the National Academies and individual Scientific Unions. It is also intended to supplement the full scientific report by a shorter 'popular' version for the general public.

Range of uncertainty

Study of the nuclear winter is a relatively new research area, though it is based on years of research concerning the nature of the climatic system. At present, a range of possibilities — some relatively certain, others based on guesswork, intuition or speculation — are being investigated. Given the implications of this research, it is critically important that no line of study is ignored solely on the grounds that it is based on assumptions that are less than certain. The neglect of the nuclear winter danger for so many years was, in part, due to a reluctance on the part of scientists to consider atmospheric consequences in other than a cursory fashion.

The analysis of the climatic effects of nuclear war is made more difficult by the lack of experimental evidence. Scientists need to conform theoretical results with hard data, but cannot experiment with a full-scale nuclear war (or even a 'small' one)! There is, however, some experimental evidence, from the attacks on Hiroshima and Nagasaki in 1945 and from the hundreds of atmospheric tests carried out in the two following decades. We have indirect evidence, as already mentioned, from Mars and from volcanic eruptions.

As computers grow rapidly more powerful, we are reaching out towards accurate climatic modelling on both a regional and a global scale. In the biological field, we have a wealth of data on the effects of climatic variation on living things and we can reproduce the physical conditions of a nuclear winter in the laboratory without undue difficulty.

The conclusions presented at Washington have been examined and assessed by numerous groups of scientists well qualified to check the evidence and the assumptions. The discussions have continued subsequently on an ever wider scale, and many other papers have been published. Most agree that the basic conclusions are well founded, in spite of the uncertainties that remain. The people involved in these studies are not alarmists but serious investigators. Where they have to make assumptions they tend to be conservative rather than to exaggerate. They are very conscious of the uncertainties involved in their calculations and they are meticulous in their examination of the sensitivity of their results to these uncertainties.

The main areas of uncertainty may be listed as follows:

Attack scenarios We cannot know exactly what weapons would be used in a nuclear war, how many would be exploded or where.

But the nuclear winter predictions are unexpectedly insensitive to changes in the scenario. TTAPS have shown that scenarios involving more than about 2,000 warheads and a mix of military and urban-industrial targets are all likely to create sufficient smoke and dust to cause severe effects. The 100-Mt attack on cities, implausible though it may be, is an indication that even quite a 'small' nuclear war might trigger a nuclear winter.

On the other hand, it is possible that a highly unlikely but conceivable scenario, in which only the ICBM silos (totalling about 2,500 in the USA and the USSR) were attacked with very accurate low-yield warheads, would generate insufficient dust and smoke to trigger a nuclear winter.

Dust and smoke Exactly how much sunlight is shut off from the Earth, and for how long, would depend on factors such as the characteristics of the particles in the cloud, the quantities of dust and smoke, the height of injection, the atmospheric circulation and the rates of coagulation or rainout of the particles. There are many uncertainties here, but there is also some reason to suppose that errors are more likely to cancel each other out than all to operate in the same direction.

Temperature reduction Until more complete atmospheric modelling is possible, this is an area of considerable uncertainty, as was clearly stated in the TTAPS paper. For that reason, we have adopted the authors' own suggestion, to reduce their estimated temperature drops by one-third.

Biological effects If the physical effects — darkness, cold, nuclear and ultraviolet radiation — are as stated, there is little room for doubt that the most serious biological consequences will follow. Much research remains to be done to elucidate these effects in detail, both singly and in combination. One major uncertainty, which relates only to the temperate zones, arises from the different impact of darkness and cold at different seasons of the year. An error of 10°C in estimating temperature drop would be of little significance if it concerned the difference between average temperatures of −15°C and −25°C, but would be highly significant if it concerned the difference between +5°C and −5°C. The same applies, to a lesser degree, to the percentage of sunlight reaching the Earth's surface.

These areas of uncertainty are the subject of vigorous scientific debate at present, and it is likely that further research will clarify many of them before very long. Nevertheless, unless a major error has been made by a large number of the world's leading atmospheric scientists, the current conclusions are unlikely to be altered radically. The effects of the uncertainties seem insubstantial compared with the gross perturbation of the climatic systems that would certainly be caused by a major nuclear war.

Voices of dissent

Not surprisingly, the nuclear winter concept has not gone unchallenged. This is a new research area, so vigorous questioning and some differences of opinion are to be expected, and indeed welcomed. Some of the sharpest criticisms have been hasty, vague or ill-informed. These have been easily answered. Several detailed scientific points have been raised which have been accepted as broadly valid and then used to refine the calculations. As already indicated, there remain areas of genuine uncertainty. All that can be said of these is that the assumptions and models used by Crutzen, the TTAPS group, Ehrlich and their colleagues are reasonable and at least as good as any of the others that have been proposed. The debate continues in the scientific journals and will no doubt lead to a better understanding of the issues involved.

Some critics have seized upon minor errors or uncertainties as a basis for attacking the overall credibility of the nuclear winter findings. This is not a serious or justifiable approach. The main conclusions have been shown to be insensitive to many changes of assumption. For instance, doubts about the likely percentage of firestorms in urban areas are technically interesting, but the TTAPS work has already demonstrated that the nuclear winter effects are only slightly modified if firestorms are omitted altogether.

Similarly, C. Kearny, a retired American civil defence specialist, has made great play of the fact that TTAPS probably overestimated the area of fires that would be ignited by attacks on missile silos *. He points out that missile silos in the USA are mostly far from forests and that many silos would be double-targeted, thus reducing the total area affected. He also points out, again correctly, that the heat from surface bursts would typically ignite a smaller area than airbursts — a point which TTAPS apparently neglected. However, Kearny does not mention that sensitivity studies by the TTAPS group, together with work by Crutzen and his colleagues, have shown that the climatic results would not be seriously affected by a correction to the total area of forest fires taking Kearny's calculations fully into account.

Strident critics should check the significance of their criticisms before trying to use them to attack the whole concept of the

* *Practical Civil Defence*, Jan./Feb. 1984, p.14.

nuclear winter. Kearny, for instance, so overstates his case, as well as making a number of errors himself, that he can scarcely be regarded as a serious critic.

John Maddox, editor of the scientific journal *Nature* was quick to express scepticism of the nuclear winter concept. Some of his doubts seem to arise from an overhasty reading of the material. For instance, in his editorial on 12 January 1984, he implies that the TTAPS calculations are based only on the dust from nuclear explosions, whereas their paper in *Science* emphasises smoke as the most significant factor; a mere glance at some of the graphs makes this quite obvious.

Maddox has also justifiably complained that one of the main supporting papers prepared by the TTAPS team had not yet been published six months after the Washington Conference. However, the bulk of the detailed evidence was already being widely circulated in typescript months before the Conference and has been accessible to any serious investigator. Other relevant scientific papers have also been published or circulated.

The main point emphasised by Maddox is that the nuclear winter concept rests on a network of assumptions and estimates and thus cannot be regarded as scientifically proved. He argues that further studies are needed, with which everyone will agree. But he then goes on to counsel caution in presenting the provisional results 'so as not to alarm the public unnecessarily'.

Scientific caution is, of course, a good thing, but nuclear war is not just an interesting scientific problem. It is also a social and political problem — and a singularly urgent one. Decisions have continually to be made and it is important that an informed public should be able to exert an influence on them. To do so, the public must know that, according to the best scientific evidence currently available, nuclear war would probably trigger a climatic catastrophe. The risk of 'unnecessarily alarming the public' pales into insignificance beside the risk that the prolonged studies required to attain a degree of certainty that would convince every scientist may be overtaken by the holocaust itself.

As might be expected, the initial reaction of the Reagan administration to the Washington Conference findings was one of scepticism and suspicion that the whole thing was merely a veiled attack on the US government's programme of deploying an impressive range of new nuclear weapons systems with greatly increased first-strike capability. It is significant that, according to a report in *The Washington Post* (May 28, 1984), the administration has now launched a large-scale research programme to check the nuclear winter findings. It is expected to cost 'several million dollars a year for the three prime years of study, and would include not only massive calculations on supercomputers but also some experiments in which city-sized fires would be set to measure their intensity and ability to throw soot into the upper atmosphere'.

Evidently, if the nuclear winter findings were so obviously 'bogus' and 'dubious', as has been suggested by some overhasty critics, the Reagan administration would not be spending large sums on further large-scale research. They are clearly concerned that, if the Washington Conference findings are confirmed, 'major shifts in nuclear defense policy could result'.

WHAT IS TO BE DONE?

People have the right to know

Some 40 years ago, Albert Einstein said, 'The unleashed power of the atom has changed everything save our modes of thinking, and we thus drift towards unparalleled catastrophe'.

The authors of this pamphlet believe that the 'drift' (which many would now describe as a race) towards catastrophe can still be prevented, provided that 'modes of thinking' about nuclear weapons, nuclear deterrence and nuclear war are profoundly and quickly changed. This cannot happen while the people are kept in ignorance of the implications of current policies and actions.

All the world's governments concurred in the Final Document of the 1978 United Nations Special Session of the General Assembly on Disarmament. This described the world's nuclear predicament in forthright terms:

> Mankind today is confronted with an unprecedented threat of self-extinction arising from massive and competitive accumulation of the most destructive weapons ever produced . . . Removing the threat of a world war – a nuclear war – is the most acute and urgent task of the present day. Mankind is confronted by a choice: we must halt the arms race and proceed to disarmament or face annihilation . . .

The question whether we shall be able to 'halt the arms race and proceed to disarmament' before we have to 'face annihilation' has both technical and political aspects. The technical problems are soluble, given the political will. Even if only one-tenth of one per cent of the effort currently devoted to the arms race could be diverted to tackling the technical problems of the 'peace race', they could probably all be solved.

'Political will' is the key, and to be effective this requires a radical change in 'modes of thinking' in all the major countries. Whatever system of government prevails, a change of this kind cannot come about without widespread popular support. From the evidence of the past 40 years, government efforts to control 'the unleashed power of the atom' and to eliminate the danger of catastrophe have been singularly ineffective. The political will for survival will have to come from the people.

People not only have a *right* to know. We have a *duty*, to ourselves, our children and the millions of our fellow human beings — a duty to ask questions, to demand information, to insist that our representatives fulfil *their* responsibilities, a duty to learn, and then to act!

The 'Doomsday threshold'

Professor Carl Sagan, who co-authored both of the main scientific papers presented at the Washington Conference, has examined some of the policy implications of the new findings in an article on 'Nuclear war and climatic catastrophe: some policy implications' published in the Winter 1983-4 issue of the journal *Foreign Affairs*. The central point in his article is illustrated in Figure 4. It is the concept of a threshold for climatic catastrophe:

> Perhaps the most striking and unexpected consequence of our study is that even a comparatively small nuclear war can have devastating climatic consequences, provided cities are targeted . . . There is an indication of a very rough threshold at which severe climatic consequences are triggered – around a few hundred nuclear explosions over cities, for smoke generation, or around 2,000 to 3,000 high-yield surface bursts at, e.g. missile silos, for dust generation and ancillary fires. Fine particles can be injected into the atmosphere at increasing rates with only minor effects until these thresholds are crossed. Thereafter, the effects rapidly increase in severity.

Sagan regards the climatic threshold for smoke in the troposphere and for sub-micron fine dust in the stratosphere as about 100 million tons in each case.

The graph in Figure 4 (a simplified version of one in Sagan's paper) illustrates the concept of a climatic threshold in the region of 500 to 2,000 warheads. If fewer than 500 warheads are exploded, the climate is not at known risk. If more than 2,000 are exploded, a climatic catastrophe is to be expected. The greater the number above this threshold, the greater is the probability of catastrophe.

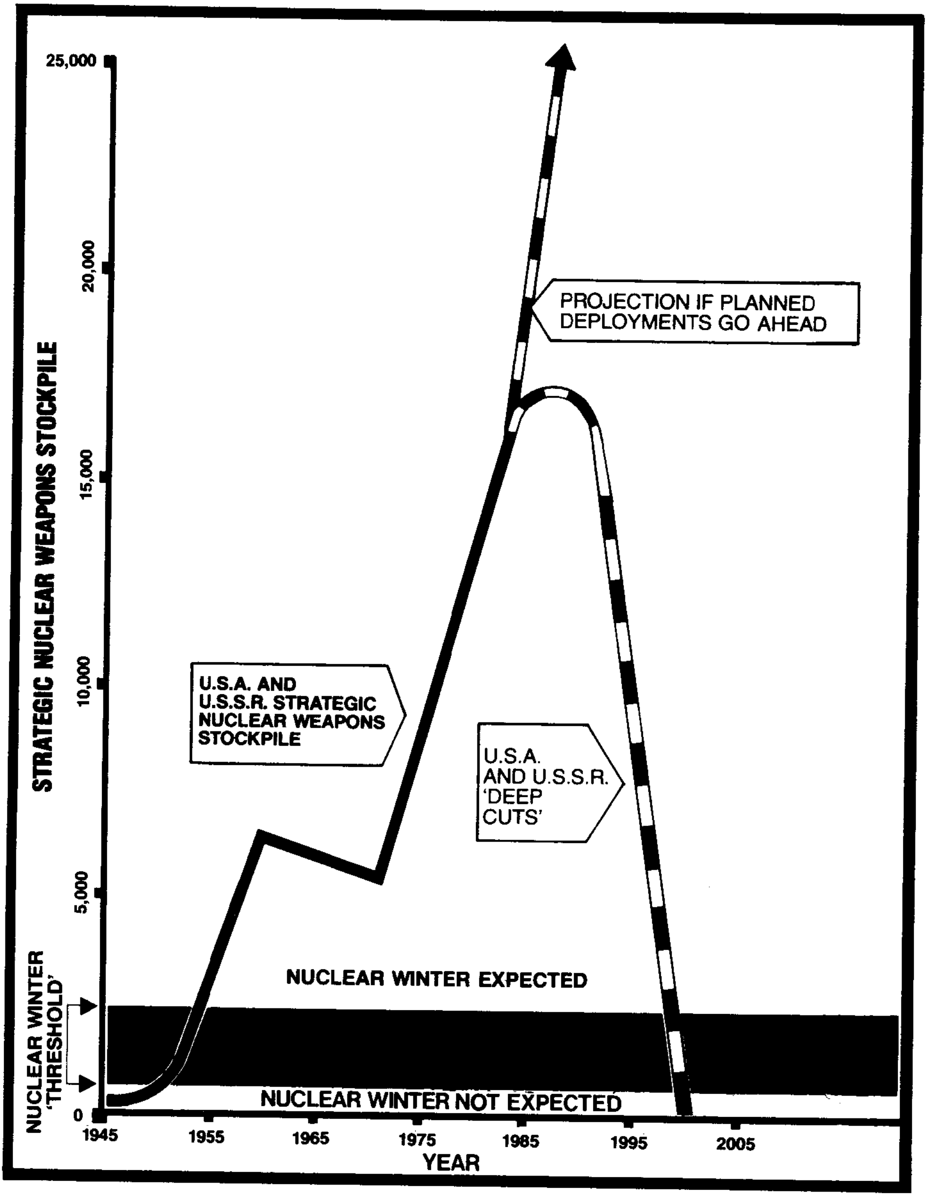

FIGURE 4 Strategic nuclear stockpiles and the threshold for climatic catastrophe.

The US stockpile of strategic nuclear warheads crossed this threshold of 2,000 warheads and entered what Sagan calls the 'Doomsday Zone' back in 1954, followed by the Soviet Union in the 1960s. As Sagan points out:

> If the world arsenals are well below this rough threshold, no concatenation of computer malfunction, carelessness, unauthorised acts, communications failure, miscalculation and madness in high office could unleash the nuclear winter. When global arsenals are above the threshold, such a catastrophe is at least possible.

There are various possible ways by which the world — which means essentially the two superpowers in this context — can escape the shadow of Doomsday by reducing the global arsenals rapidly below the threshold, even if it cannot so rapidly eliminate nuclear weapons altogether.

None of the widely supported policies canvassed in recent years — 'Freeze' followed by phased reductions, 'Deep Cuts' or 'Build-down' — would reduce the arsenals rapidly enough to free the world from the risk of climatic catastrophe before the year 2000 at the earliest. Sagan argues, and we agree, that the world cannot afford to wait that long. More heroic measures are needed:

> No one contends it will be easy to reverse the nuclear arms race. It is required at least for the same reasons that were used to justify the arms race in the first place – the national security of the United States and the Soviet Union. It is necessarily an enterprise of great magnitude. John Stuart Mill said: "Against a great evil, a small remedy does not produce a small result. It produces no result at all."
>
> But, given the stakes, a prudent nuclear power should be willing to spend more every year to defuse the arms race and prevent nuclear war than it does on all military preparedness.

Reversing the nuclear arms race is needed to provide security for the USA and the USSR. It is just as vital for Britain. Can we perhaps give our fellow nuclear powers a lead towards prudence and increased security?

Defence and deterrence

Advocates of nuclear deterrence may welcome the Washington Conference findings as merely confirming its value. After all, they may say, nuclear war hasn't happened yet, and the newly perceived consequences only make it that much more unthinkable. Deterrence, on this view, should be stronger than ever.

Such a reaction is unacceptable to anyone who thinks the problem through. For one thing, what confidence can we have that the possibility of human extinction will really be understood in its full significance by *all* the military and political leaders in positions of responsibility in the states possessing nuclear weapons (or those striving to possess them)? This is a very risky proposition. They, and their scientific and military advisers, are thoroughly saturated in nuclear thinking and nuclear strategy. They have convinced themselves that nuclear weapons guarantee their security and we cannot afford to wait until this proposition is finally disproved.

The theory of deterrence makes no allowance, moreover, for mistakes or misunderstandings, for human or computer error — all of which are more likely to lead to disaster in times of crisis. In recent years there have been many US computing errors, as a result of which warnings of supposed Soviet attack have been flashed to command posts in different parts of the world. We may be certain that similar errors have been made by the less sophisticated Soviet computers. Human intervention and the need for confirmation have until now prevented disaster, but there can be no confidence that this will always happen in the future.

The deployment by both the USA and the USSR of missiles only a few minutes' flight from the most sensitive targets in the other's territory brings nearer the threat of 'launch on warning', which would entirely eliminate the possibility of human intervention.

It is asserted that nuclear deterrence 'has kept the peace in Europe for 38 years', with the implication that it can continue to do so for another 38 years, or even indefinitely. Advocates of defence policies based on nuclear deterrence seldom address the question of the *risk* involved. Risk assessment requires the evaluation of *two* factors: the chance of a disaster happening and the cost or damage that would result if it did. If the cost or damage is very high, the risk can be unacceptable even if the chance of disaster is small. How must the *risk* of nuclear war be assessed?

Opinions differ about the effectiveness and reliability of nuclear deterrence. However, its stability appears doubtful: whereas a few hundred nuclear warheads on each side would suffice for the purposes of mutual deterrence, the number is now some 50,000, and it is increasing. Nobody can claim that there is *no chance whatsoever* that accident, error, misjudgement, misperception of intent, unpremeditated escalation or madness in high places might trigger a nuclear exchange, and nobody can claim that there is *no chance whatsoever* of such an exchange escalating into a major nuclear war. It has long been understood that the human and material costs of nuclear war would be enormous. The nuclear winter findings now suggest that they may, for all practical purposes, be unlimited. So long as we are above the threshold, the risk is unacceptable, whatever the chances may be. A realistic appraisal of two inter-related developments — the destabilising effects of current and planned development of new nuclear weapons systems and the deterioration in East-West relations — leads to the judgement that the chances of nuclear war are already appreciable and are increasing.

Defence policies based on the possession and threatened use of nuclear weapons must now be regarded as far too risky to be acceptable.

Is a first strike suicidal — so we can all relax?

It has been suggested that the nuclear winter findings mean that even a fully effective first strike (i.e. one which disarms the other side completely so that there is no retaliation) would be suicidal for the attacker, because it would trigger a climatic catastrophe that would spare nobody.

It follows, according to this argument, that the military and political leaders of the USA, who are busy acquiring a range of nuclear weapons systems with greatly increased first-strike capability, will now think better of it and cancel these programmes, because they will realise that even if they can solve all the technical problems of missile accuracy and reliability and of antisubmarine warfare to make a first strike practicable, it's all to no avail anyway because it would trigger a nuclear winter. And, of course, it is hoped also that the same considerations will deter the Soviet side from adopting dangerous countermeasures, such as deploying similar weapons systems or adopting launch on warning policies. So, it is concluded, the world has moved back in effect to 'mutually assured destruction' and first-strike capacity is now 'self-deterring'. Furthermore, it is argued, a fully effective first strike is unlikely to be achievable anyway. The most 'survivable' nuclear weapons are the SLBMs (Submarine Launched Ballistic Missiles), which, being inherently less accurate, are likely to be targeted mainly on urban-industrial areas. A retaliatory second strike with these weapons will, therefore, trigger a nuclear winter even if the first strike does not. So, thanks to the nuclear winter discovery, peace campaigners can breathe a sigh of relief and relax a bit.

The argument is, unfortunately, fallacious. Even if we attribute to political leaders and military planners a far higher level of rationality than we have any historically founded right to expect, this sort of rationalisation could just as easily go the other way:

> The strategists of nuclear war-fighting and counterforce targeting could well be saying to themselves that it is by no means certain that a purely counterforce attack on missile

silos, major military airfields and key nuclear command centres (i.e. an attack on time-urgent targets only) would generate the fires and smoke needed to trigger the nuclear winter, especially if the attack occurred in a few years' time, using the highly accurate, relatively low-yield, warheads now being produced. The vast majority of missile silos and military airfields in the USA and the USSR are far enough away from cities that attacks on them will not start great urban conflagrations. Such fires are the most important factor in triggering a nuclear winter. Without them, the climatic changes may be very much less severe.

Furthermore, a counterforce attack on missile silos would involve groundbursts rather than airbursts, thus reducing the area in which fires would start still further. The use of penetrating warheads, such as those designed for Pershing II, would make it even less likely that the nuclear winter would be triggered by such an attack.

Finally, they could note with satisfaction that the very weapons they have been and are developing in order to have a first-strike capability are just what they should be developing to minimise the chances of triggering a nuclear winter.

These weapons are, however, extremely provocative, and their deployment may well be taken as demonstrating intent to make a climatically safe but disabling first strike. This is likely to provoke 'counter-deployments' of similar weapons, leading both sides into a more precarious 'hair-trigger' situation, with greatly increased pressures for considering a 'damage-limiting pre-emptive first strike'.

In a crisis, each side would have to weigh the balance between two options:

(a) devastation plus nuclear winter (if the other side strikes first), or (b) less devastation plus nuclear winter (if we strike first).

It would not be all that irrational to prefer option (b) to option (a).

On balance, it may be concluded that the impact of the nuclear winter findings on military-strategic thinking *(as distinct from the impact on the public and the peace movements)* is somewhat more likely to accentuate the current dangerous trends than to moderate them. Moreover, the new, more provocative and destabilising, though climatically less dangerous weapons will not replace all the existing less accurate, higher yield ones, but will be added to them. Since limited attacks on nuclear targets would almost certainly escalate to an all-out war in which many of these other warheads would be used, nuclear winter would still be expected. With *both* kinds of weapons in the stockpiles, the chances of war are greater and the consequences more disastrous. There are certainly no grounds for complacency.

It is only when we consider the possible impact of the nuclear-winter findings on the public and the peace movements that we can have grounds for hope. With our new understanding of the probable climatic and ecological consequences of nuclear war, we can clearly see that the nuclear arms race threatens *all* the Earth's people with disaster and possibly even with extinction. If this knowledge is vigorously and effectively communicated to peoples and governments, it can generate increased worldwide pressure to end the nuclear arms race.

One of the obstacles to a more rapid growth in public activity against nuclear weapons is that the realities of nuclear war and its aftermath are not understood. For a great many people, the direct effects of nuclear explosions are so far outside human experience as to be practically incomprehensible. Who ever saw a fireball brighter than a thousand suns? Radiation is invisible, mysterious and unreal. Even the blast effects of a nuclear explosion are so different from those of any other kind of explosion as to be beyond the grasp of our imagination. But to be cold, to be in the dark, to be without food or fuel — these things are more comprehensible. Knowledge of the realities of nuclear war does not automatically move people into action for nuclear disarmament, far from it. But so long as people are ignorant of these realities they are not likely to do anything at all.

The immorality of nuclear weapons — as weapons of mass and indiscriminate killing and as weapons with the unique property of killing and maiming the unborn — has long been of concern to humanists and religious people alike. The nuclear winter predictions must surely deepen that concern, for they mean that nuclear war can now be seen to threaten not merely a *proportion* of the unborn with premature death or deformity, but *all* the unborn with non-birth. Whatever may be the basis of our moral judgements, materialist or religious, it must surely be the utter limit of immorality to be gambling, in the name of 'defence' and 'nuclear deterrence', with the entire future, and therefore with the entire past, of mankind.

It seems, therefore, that the nuclear winter findings can, if they are properly used, lead to even wider sections of the community in every country becoming interested and involved in activity for nuclear disarmament.

Civil Defence

It is not seriously disputed that civil defence could do little to protect people in Britain against a major nuclear attack even if increased resources were allocated to it. The planners are sufficiently realistic to admit that their work would not significantly reduce the number of short-term deaths and injuries to be expected. Nor are plans being made to stockpile large quantities of food and fuel. This is only partly a matter of finance, as it is realised that many stores would be destroyed in an attack or would be inaccessible to those in need.

Home Office planning is on two levels. On the one hand, they envisage Britain being subjected to a purely conventional attack or to the marginal effects (e.g. fallout) of a limited nuclear war fought mainly in continental Europe. On the other hand, 'if the worst comes to the worst', their efforts would be concentrated on preserving administrative centres and selected personnel. The objective would be to re-establish a structure after the attack that would be capable of controlling the remaining survivors and resources, and then regenerating production and some form of society.

There is a certain logic to this policy but its value is often seriously overstated. First, only a small minority of the population would survive long enough to stand any chance of benefiting from it. Detailed computer calculations, published in *Doomsday: Britain After Nuclear Attack* (Basil Blackwell, 1983) show that a 220-Mt attack on Britain (less than half of the fraction of the Soviet arsenal assumed to be targeted on this country) would probably cause about 39 million deaths from the immediate effects of blast, heat and local radioactive fallout, with another 5 million people seriously injured. These figures take no account of casualties from fires, which would be widespread.

Second, it is unlikely that there would be sufficient human and material resources available after such an attack to keep more than a small fraction of those who escaped serious injury alive for any length of time. There would be little or no food, fuel, sanitation, electricity, uncontaminated water or medical help. Agriculture and industry would be at a standstill and likely to remain so. Administrators cannot create new resources, however well briefed they are.

Third, the surviving administrative centres would be in no position to coordinate even the few remaining resources. Lack of transport and communications would restrict their influence to the immediately surrounding areas, even assuming that their staff had the backing of whatever survivors there were of the armed forces and the police. It is perhaps more realistic to suppose that able-bodied survivors, whatever their training and 'paper' responsibilities, would devote most of their energies to securing their own survival or to locating and attempting to rescue their loved ones.

This is a desolate picture. The nuclear winter predictions reinforce each of these three points. Many people would die of cold. Lack of shelter would often be decisive, especially for those already injured or weakened by other hazards. The nuclear winter would lengthen the period during which such survivors would have no prospect of finding extra food, fuel or other help. The possibility of effective 'regeneration' would inevitably be reduced by the additional delay. The increased ultraviolet radiation and medium-term fallout that are predicted would be additional hazards.

Effects on agriculture would be equally disastrous. Civil defence planners have previously assumed, somewhat optimistically, that a sizeable proportion of the war-year's harvest could be saved. These hopes must now be dashed; the entire crop would almost certainly be lost. Only if the war happened in early winter would there be a chance of salvaging something. The lack of seed and livestock — added to the lack of machinery, fuel, fertilisers, pesticides and workforce — would keep agricultural production very low for years. There would, of course, be no possibility of food imports for an indefinite period. Problems of production would be compounded with problems of distribution, because of the disruption of transport.

The nuclear winter predictions strengthen the stand taken by the Nuclear-Free-Zone local authorities and many other groups and individuals. It is cruel and dishonest to pretend that people have much chance of surviving a nuclear war. It is wasteful to commit scarce resources to civil defence measures that could, at best, have only a marginal effect. Surely it is much more sensible and humane to direct these resources, as well as the time and energy of many devoted volunteers, towards helping to prevent a nuclear war from occurring?

From Pravda to Penthouse

The Washington Conference attracted considerable attention in the USA and the USSR, but there is no evidence as yet that it has produced a significant shift in official policy. The conviction that nuclear weapons are the essential means by which national security can be defended against a hostile power is deeply rooted in both countries and among their allies. Perhaps in some respects this conviction may have been slightly dented but it has not been radically weakened. It may indeed be unreasonable to expect such a transformation until some alternative strategy to ensure national security and world peace has gained greater credibility.

It must nevertheless be of some significance, in political as well as scientific terms, that the nuclear winter conclusions have been presented to the public through a wide variety of television programmes, press reports and full-scale articles in journals.

Soviet scientists were involved from the start in examining the results obtained by their American colleagues and in independent studies of their own. Their direct participation in the Washington Conference, both through personal attendance and through the satellite television link-up, has already been mentioned. It is not surprising, therefore, that widespread publicity was given to the conference by many organs of the Soviet media. The issues were treated at length, for example, in a special issue of the *Courier of the Academy of Sciences of the USSR* (circ. 4,500); in the magazine *In the World of Science* (the Russian-language edition of *Scientific American*, circ. 20,000), and in the well-known popular journals *International Life* and *Soviet Union.* In the general press, long articles appeared in *Moscow Pravda* (circ. 600,000), *Literary Gazette* circ. 3 million), *Soviet Russia* (circ. 4 million); and in the main Soviet newspaper, *Pravda* (circ. 10 million).

The Committee of Soviet Scientists for Peace, Against Nuclear War devoted its session in November 1983 in Tbilisi to a detailed discussion of the long-term global effects of nuclear war; this was extensively reported in *Izvestia* (circ. 7 million) and in the regional paper *Dawn of the East* (circ. 400,000). The work of American scientists in this field has been widely reported and the Committee has produced a television film 'Prevention', which features interviews with leading scientists from both countries.

In Britain, the coverage by the media has been much less extensive. Shortly after the Washington Conference, articles appeared in *The Guardian, The Listener, New Scientist, Sanity* and *Chemistry in Britain,* and there was a report on the Washington Conference in the Nature programme on BBC2. More recently, there have been scientific papers and editorial notes in *Nature,* shorter pieces in other journals, and feature articles in *Sanity, Practical Civil Defence* and *Penthouse.*

SANA's response

Immediately the information material became available from the Washington Conference, SANA reacted in three ways. First, summaries of the Conference's findings were made available to members and others in large numbers. Second, seminars were arranged, at national and local level, for study of the scientific papers and discussion of the conclusions. For example, a major meeting was held in Oxford on 14 January 1984, attended by more than 80 scientists from all over the country. Several groups of British scientists are now examining different aspects of the work in more detail, either independently or in association with the SCOPE enquiry.

SANA's third response to the new information has been to make it widely available in a variety of ways. SANA members cooperated in the conference on 'The Land and Defence', sponsored by the Defence Research Trust and *The British Farmer and Stockbreeder* (Oxford, 19 March 1984). A book is being written, for publication later in 1984, by a group coordinated by Professor Ian Percival of London University. SANA members made major contributions on the subject at the International Nuclear-Free-Zones Conference in Manchester (April 1984) and are in continual demand for talks, lectures, articles and interviews. At the request of the Parliamentary Committee of CND, a briefing document for Members of Parliament has been produced and briefing sessions for MPs held at the House of Commons. SANA members have assisted in television productions with technical advice and direct participation. SANA has itself produced its own video presentation on the scientific and policy implications of the nuclear winter. *

At the invitation of the Sheffield City Council, SANA has collaborated in organising a national Nuclear Winter Conference (9 June 1984), attended by over 300 people, most of whom were representing local authorities, trade unions, peace organisations or other bodies. Apart from presentation of the scientific and policy issues, this Conference provided an opportunity for discussion of the implications for civil defence and emergency planning, for practical campaigning and for the moral and ethical aspects of nuclear defence policies. SANA intends to develop this dialogue between scientists and public representatives through a series of similar conferences in other parts of the country.

* *A Change in the Weather*: A 24-minute video presented by Professor Mike Pentz and Dr Irene Ridge on the scientific background and policy implications of the nuclear winter, including a reading by Dame Peggy Ashcroft of Byron's poem 'Darkness', written in 1816, the 'year of the lost summer'. The video can be purchased (£30) or hired (£10) from SANA (see p.48).

At the time of publication (August 1984) SANA is organising, in association with the Nuclear-Free-Zones National Steering Committee and with five major local authorities (the Greater London Council, the West Midlands County Council, the South Yorkshire County Council, the Avon County Council and the Glasgow District Council), a speaking tour by Professor Paul Ehrlich, Dr Richard Turco and Dr Anne Ehrlich in November 1984, which will include briefing sessions for members and staff of the local authorities, public presentations, and lectures or seminars in eight major British universities.

CONCLUSION

Perhaps the most important problem we face as we try to assimilate the new knowledge of the global consequences of nuclear war is that of *uncertainty*, *probability* and *risk*.

The element of uncertainty in the nuclear winter predictions has been seized upon by some who say: 'These predictions are full of uncertainties — they are in any case purely theoretical; after all, none of this has been tested! Unfortunately, there can be only one conclusive experimental test, and the chances are that there will be nobody around to evaluate the results.

In *The Fate of the Earth* (Picador, 1982), which was written before anything was known of the nuclear winter, Jonathan Schell recognised that nuclear war could possibly mean human extinction, and that:

> . . . it is ultimately extinction itself that fixes the boundary to what we can know about extinction. No human being will ever be able to say with confidence, '*Now* I see how many megatons it takes for us to exterminate ourselves'. To the extent that this check stands in the way of investigation, our uncertainty is forced on us not so much by the limitations of our intellectual ability as by the irreducible fact that we have no platform for observation except our mortal frames. In these circumstances, which are rudiments of the human condition, toleration of uncertainty is the path of life, and the demand for certainty is the path toward death.

Those sceptics who persist in comforting (deceiving) themselves and others by dwelling upon the uncertainties in the nuclear winter predictions need to be reminded that what is known so far about the effects of nuclear explosions is a story of surprises, as Schell points out, 'starting with the surprise that the nucleus could be fissioned at all'. He goes on to list the further surprises:

> Perhaps the second big surprise was the extent of harmful fallout; this came to light in the 15-Mt test at Bikini in 1954, when, to the amazement of the designers of the test, fallout began to descend on Marshall Islanders and on American

> servicemen manning weather stations on atolls at supposedly safe distances from the explosion.
>
> The next surprise was the extent of the effects of the electro-magnetic pulse. Probably the most recent surprise has been the discovery, in the nineteen-seventies, of the peril to the ozone layer.
>
> Given the incomplete state of our knowledge of the Earth, it seems unjustified at this point to assume that further developments in a science will not bring forth further surprises.

The nuclear winter is one of the 'surprises' from the further developments in science that Schell foresaw. Doubtless there will be others. Future work will inevitably lead to revisions of the estimates made by the TTAPS group and by Ehrlich and his colleagues. Some of these revisions are likely to be in one direction and others in another direction, but they are unlikely to alter the main thrust of the conclusions, unless some important physical effect has been neglected up to now. This cannot be ruled out, if only because the impact of smoke and dust was overlooked for decades and was in the end discovered almost by accident. The chances are, however, that such an effect would take our environment further away from its present life-supporting conditions, rather than cancel out the effects already known.

However small the probability that nuclear war may bring about the extinction of *Homo sapiens*, Schell emphasises that:

> the mere risk of extinction has a significance that is categorically different from and immeasurably greater than, that of any other risk, and as we make our decisions we have to take that significance into account. Up to now, every risk has been contained within the frame of life; extinction would shatter the frame. It represents not the defeat of some purpose but an abyss in which all human purposes would be drowned for all time. We have no right to place the possibility of this limitless, eternal defeat on the same footing as risks that we run in the ordinary conduct of our affairs in our particular transient moment of human history. To employ a mathematical analogy, we can say that although the risk of extinction may be fractional, the stake is, humanly speaking, infinite, and a fraction of infinity is still infinity. In other words, once we learn that a holocaust might lead to extinction we have no right to gamble, because if we lose, the game will be over, and neither we nor anyone else will ever get another chance. Therefore, although scientifically speaking, there is all the difference in the world between the mere possibility that a holocaust will bring about extinction and the certainty of it, morally they are the same, and we have no choice but to address the issue of nuclear weapons as if we knew for a certainty that their use would put an end to our species.

It is with this assessment of the risk in mind that we should challenge afresh the concept of 'nuclear defence', which Lord Louis Mountbatten called a 'dangerous illusion', and question the assumption that nuclear weapons can have some military utility.

George Kennan, when receiving the Albert Einstein Peace Prize in 1981, said:

> To my mind, the nuclear bomb is the most useless weapon ever invented. It can be employed to no rational purpose. It is not even an effective defence against itself. It is only something with which, in a moment of petulance or panic, you commit such fearful acts of destruction as no sane person would ever wish to have upon his conscience.

He could have had no inkling of the nuclear winter at that time.

Towards the end of the 90-minute satellite television dialogue between American and Soviet scientists with which the Washington Conference concluded, much the same thought was expressed by the Soviet astronomer Yevgeny Velikhov, Vice-President of the Soviet Academy of Sciences:

> The only possible conclusion . . . is that nuclear devices are not and cannot be a weapon of war . . . or a tool of politics. Nuclear superiority is a delusion. Nuclear arms do not add 'muscle' to the military power of the state; they are not muscle, but a cancerous growth which threatens the very state; either we destroy that cancerous growth or it will destroy us.

This statement was greeted by prolonged applause from the 500 participants in Washington, in which the Soviet scientists in Moscow joined. It expressed what was in the minds of all. It demonstrated a remarkable convergence of views, not only on the scientific conclusions, but also, and most importantly, on their political implications.

To reach the understanding — with Mountbatten, Kennan, Velikhov and many others — that *nuclear weapons are useless*, is the first step along the road that may lead the world out of its nuclear predicament. It is also the first step towards responding to Einstein's challenge: by changing 'our modes of thinking' we may yet avoid the 'unparalleled catastrophe' he foresaw.

We conclude, with Carl Sagan that:

> 'Our talent, while imperfect, to foresee the future consequences of our present actions and to change our course appropriately is a hallmark of the human species, and one of the chief reasons for our success over the past million years. Our future depends entirely on how quickly and how broadly we can refine this talent. We should plan for and cherish our fragile world as we do our children and our grandchildren: there will be no other place for them to live. It is nowhere ordained that we must remain in bondage to nuclear weapons'.

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* * *

What is SANA ?

In its three years of existence, SANA has established a solid reputation as 'toolmakers' for the peace movement, advisors to Members of Parliament, Local Authorities, professional bodies and the media, and as critics of Government ineptitude and worse on such matters as civil defence, the Cruise missile and the illusions of nuclear 'defence' policies. This reputation has been based upon careful scientific research and assessment.

Scientists Against Nuclear Arms is an independent organisation of scientists, formed in 1981 in response to the acute dangers of the continued escalation of nuclear armaments and the consequent risk of nuclear war. The term 'scientists' includes natural and social scientists, engineers and technologists.

The primary purpose of SANA is to promote and co-ordinate the activities of scientists wishing to assist those working to halt and reverse the nuclear arms race. SANA does this through the provision of reliable factual information and well-informed speakers: through publications, contributions to the media and scientific journals; and through promoting awareness amongst members of the scientific community of their special responsibility towards achieving disarmament.

SANA is active, nationally and locally, in providing information to the various peace and disarmament organisations and to Members of Parliament, Church and Trade Union leaders, County and Borough Councillors and other individuals with influence on public policy, and also in informing the general public.

SANA's work as a national body rests on a firm foundation of local groups in many parts of the country, whose members contribute in innumerable ways to further the aims of the peace movement. This decentralised structure enables the organisation to function with a minimum of administrative overheads and almost entirely on a voluntary basis.

Although its title refers only to nuclear arms, SANA recognises that nuclear disarmament cannot be considered in isolation from other disarmament measures and that other weapons of mass or indiscriminate destruction, notably chemical and biological weapons, must not be overlooked.

Recognising both the international character of science and the necessity for international collaboration if disarmament is to be achieved, SANA maintains contact with individual scientists and groups in other countries having similar aims.

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