Nuclear winter down under

Hiroshima 6 months after the bomb was dropped.

The chilling concept of a nuclear winter following widespread detonation of atomic weapons has become quite familiar.

Put simply, it is the idea that the explosion of nuclear warheads and the ensuing enormous fires would throw large amounts of dust and smoke into the atmosphere. This would reduce the heat and light from the sun, causing temperatures at the earth's surface to fall and the patterns of atmospheric circulation to change, so drastically altering the climate.

The idea was first proposed in 1982, since when much scientific work has been done. However, most of this relates to the Northern Hemisphere, which is, after all, the place where people expect the majority of the bombs to fall. How it could affect us in the south has started to engage the interest of Australian scientists.

Since Professor Paul Crutzen of the Max Planck Institute of Chemistry in Mainz, West Germany, and Professor John Birks of the Cooperative Institute for Research in Environmental Sciences in Boulder, Colorado, first put forward the nuclear winter idea in *Ambio*, the environmental journal of the Swedish Academy of Sciences, it has generated much support, some controversy, and a great deal of further scientific work.

Of course, the chief problem is that nobody knows how many bombs may be dropped, and where or when they may fall. Accordingly, experts have devised various scenarios of possible nuclear wars and used these as a basis for calculating the resulting atmospheric disturbance. Their calculations are possibly more realistic than the original war scenarios, as we have considerable knowledge of the atmosphere's behaviour gleaned from meteorology.

A nuclear conflagration would devastate the biosphere.

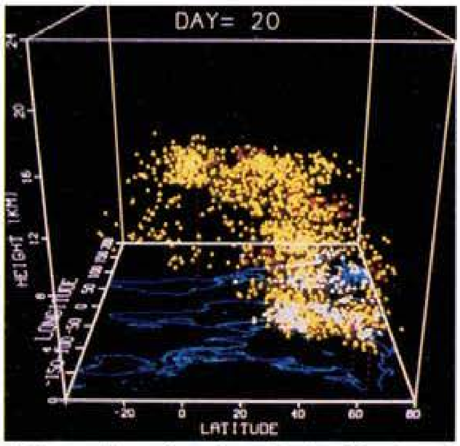
Before entering into these frightening studies we need to define our terms. The explosive capacity of a nuclear weapon is measured as the number of tonnes of ordinary TNT that would be necessary to give an equally destructive blast. The bomb dropped on Hiroshima in 1945 had an explosive yield of 15 +/−3 kilotonnes. Currently, the world contains a total nuclear arsenal of more than 12 000 megatonnes (Mt).

A simple calculation gives the horrifying result that the world's political and military leaders now have the potential to unleash nearly a million Hiroshimas; and remember that that fateful (but atomically speaking tiny) explosion destroyed 13 square kilometres of urbanised area, and tens of thousands of people died instantly.

The radiation that nuclear explosions produce and the subsequent fall-out play a relatively small part in the causes and consequences of a nuclear winter. Much more important are the injection of smoke and dust into the upper atmosphere and the subsequent effects on climate, agricultural productivity, and hence human food supplies. Other effects include the production of oxides of nitrogen, which could possibly destroy a significant part of the ozone shield that protects the earth from much of the sun's ultraviolet radiation. The effect of this reduction in our ozone would be offset by the smoke for as long as sufficient smoke persisted — probably about a year.

Recently, the Scientific Committee on Problems of the Environment (SCOPE) of the International Council of Scientific Unions published a two-volume report, with the collaboration of scientists the world over, on the environmental and biological effects of a nuclear war. Dr Barrie Pittock of the CSIRO Division of Atmospheric Research was one of the six authors of the volume on the physical and atmosphere effects.

The world's first hydrogen bomb, of 5 Mt, was exploded by the United States in 1952 at Eniwetok Atoll (11°N, 162°E), near Bikini in the Marshall Islands in the Pacific. The mushroom cloud rose to a height of 40 km.



A three-dimensional graph showing the results of computer modelling of the distribution of smoke 20 days after a major nuclear war in the Northern Hemisphere. The simulation started with 150 million tonnes of smoke, and each dot represents 5000 tonnes. This study was conducted by the Lawrence Livermore National Laboratory, California.

Since 1982, he and Divisional colleagues Mr Ian Galbally and Dr Peter Manins have been studying the problem from a Southern Hemisphere viewpoint (see *Ecos* 39). At the end of 1985 the Division received an International Year of Peace grant of $140 000 from the Department of Foreign Affairs to further the studies on a nuclear winter 'down under'.

A southern perspective

The scenario discussed in *Ambio* suggested that only 3% of all the megatonnes dropped in a hypothetical nuclear war would fall in the Southern Hemisphere. *Ambio* also considered that the destructive capacity available in the world would not be fully used: some missiles would not function, some forces and weapons would be destroyed early in the conflict, and some capacity would probably be kept in reserve. The study came up with a figure of 5742 Mt (of an estimated total of 12 000 Mt) being detonated. The Southern Hemisphere share of this would amount to 173 Mt; some consider this an over-estimate.

According to the calculations of Mr Galbally and his overseas colleagues, this would produce some 10 million tonnes of smoke — certainly more than your average bushfire, but not sufficient for significant cooling in the Southern Hemisphere. Would our Hemisphere therefore escape unscathed?

It appears not. The major environmental consequences for us would arise from the transport of smoke and dust from the Northern Hemisphere and the modification of global patterns of atmospheric circulation caused by the changes there.

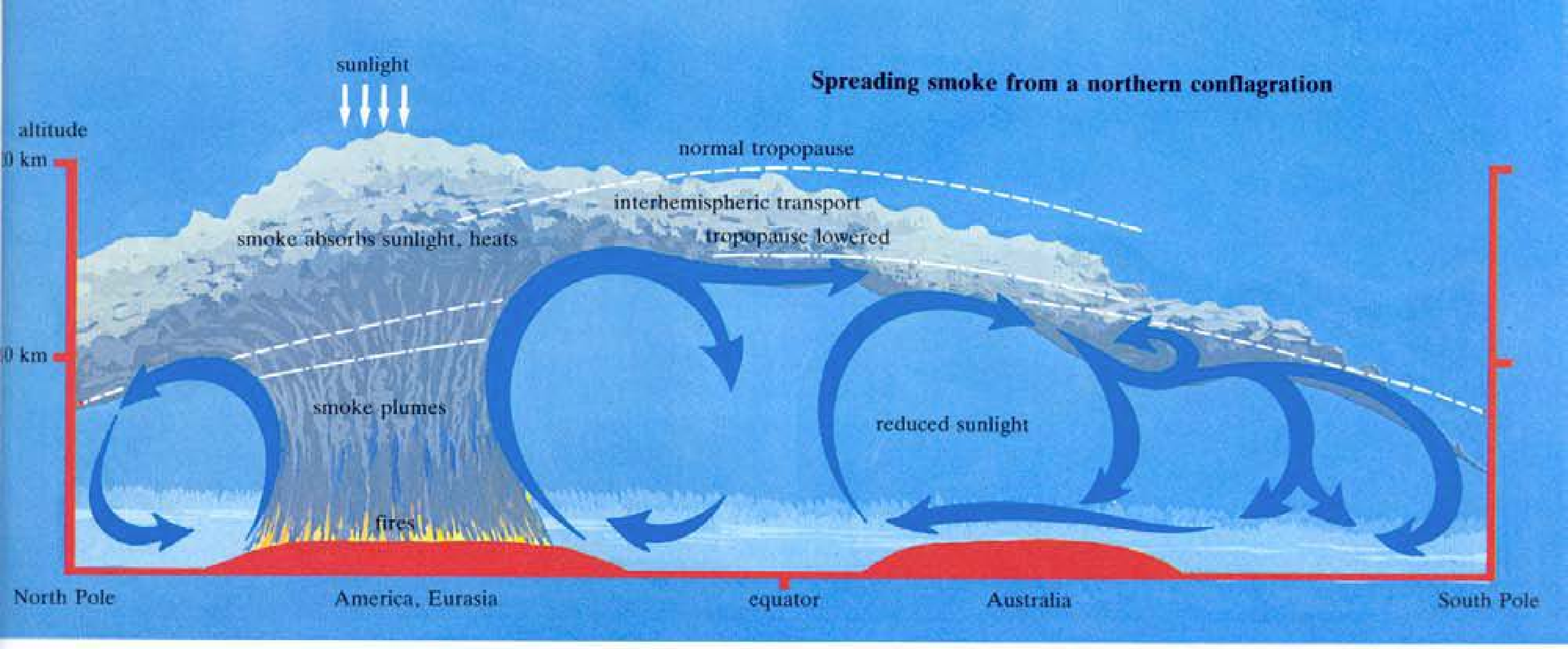
The SCOPE report considers that if the war took place in the northern spring or summer, then solar heating of the resulting smoke layer would drive it higher and give rise to an abnormally rapid circulation that would transport smoke and dust southwards. This would occur at altitudes of about 10–20 km, and the smoke could reach Australian latitudes in a matter of weeks.

Normally, the exchange of air between the two hemispheres takes about a year. We know this from monitoring the difference in carbon dioxide concentrations between the north, where most of the industrial emissions of the gas take place, and the south, where concentrations are seen to increase in step with the north but a year later. (For the same reason the small amount of the radioactivity released during the Chernobyl accident in the U.S.S.R. that reaches Australia is expected to take about a year to do so.)

Once the smoke had arrived in the Southern Hemisphere what would happen to it? Unfortunately, it would be too high in the atmosphere for rain to wash it down. It would therefore persist while more smoke drifted in from the north. Eventually, enough could accumulate to produce significant surface cooling. It would probably remain for 6–12 months, depending on the height to which it originally rose following detonation of the bombs. The smoke would eventually disperse by aggregating into larger particles, which would fall out, and by means of the slow exchange of gases between the stratosphere and the troposphere.

If the war occurred in our spring or summer (autumn or winter in the north), the smoke would move south only slowly owing to the lack of significant solar heating to drive it. How much would eventually be propelled southwards when the northern summer arrived remains very much open to conjecture.

A complex computer program for climate modelling, originally designed by CSIRO scientists Dr Bill Bourke and Dr Bryant McAvaney, of the former Australian Numerical Meteorology Research Centre in Melbourne (now with the Bureau of Meteorology Research Centre), has been applied to the nuclear winter idea by scientists at the Los Alamos National Laboratory, U.S.A. On the basis of its predictions, Dr Pittock concludes that an injection of 170 million tonnes of smoke (such as might follow a major nuclear war)



Spreading smoke from a northern conflagration

Smoke and dust injected into the troposphere (the bottom portion of the atmosphere) would be heated by the sun's radiation and rise into the stratosphere. At heights of about 15–20 km it would move south, bringing appreciable amounts over Australia. Research at CSIRO's Division of Atmospheric Research is, among other things, estimating the extent of the cooling this would produce. Incidentally, a rise in temperature in the lower stratosphere, caused by the smoke absorbing sunlight, and the fall in temperature below, caused by the shadow of the smoke, would lower the Northern Hemisphere tropopause — the boundary between stratosphere and troposphere.

occurring in the northern summer could reduce the strength of Australia's sunlight by 20% within a few weeks, and this reduction could possibly remain for as long as 1 year.

As well as affecting the temperature, with possible decreases of about 5°C, this atmospheric absorption would significantly shorten day length. The lower the sun sank in the sky, the greater the aborption would become, and the scientists predict that a winter's day at latitude 30° (approximately that of Sydney or Perth) would be reduced from 8·5 hours of light to about 6.

As the oceans would retain their heat for longer than the land, the large oceanic areas in the Southern Hemisphere would tend to cushion us somewhat against the cooling effects of the smoke. However, subtle changes in ocean currents and surface temperatures over a longer term could result in severe changes in the pattern of rainfall.

For example, it's now considered quite likely that, owing to less heating of air over the continental land masses in the Northern Hemisphere, the monsoon rains there would be greatly reduced. The resulting crop failures would cause starvation for millions in the world's poorest countries.

Could something similar happen in Australia? Certainly the hydrological cycle (the continuous movement of water from the atmosphere to the earth and back) would decrease, because the sun provides the power that causes water to evaporate into the atmosphere. Less water in the atmosphere means less precipitation.

Types of smoke

Climatologists have used sophisticated computer models of the atmosphere's behaviour to predict the consequences of large-scale smoke injection. However, a computer is only as accurate as the information it is given, and the scientists face many uncertainties, not least of which is the mass of the smoke produced. They prefer to consider a certain mass of smoke (rather than a number of nuclear bombs) and feed this quantity into their computer simulations, as the megatonnage necessary to produce a given amount of smoke could vary considerably. It all depends what goes up when the bombs come down!

Cities contain far more fuel to produce smoke than rural areas. Storage sites for oil and petrol, important targets in any war, would burn to form vast amounts of smoke. Even if cities were not bombed deliberately, many militarily vital areas (command and communication facilities, ports and airports, industries and power stations) are located in or near them and, if these were bombed, the cities with their high fuel densities would almost certainly be consumed in the ensuing conflagration. Indeed, it is fires that are responsible for so much of the destruction that nuclear weapons cause. The Hiroshima bomb, laughably small by today's standards, destroyed every combustible object within 2 km of the centre of the explosion.

When we consider the smoke produced, another factor enters our calculations. It's a common observation that different types of fuel produce different types of smoke. For example, oil burns to give a very thick black smoke: being mainly carbon, it produces smoke that contains much soot — essentially unburnt carbon.

Soot has a very low reflectivity, or albedo, and thus strongly absorbs sunlight. A smoke with a high proportion of soot will absorb far more sunlight than an equal mass of smoke with only a small soot content. Also, even a thin layer of soot deposited on the earth's ice sheets could cause them to start melting (once the sunlight returned to the surface). This effect could be self-limiting, as the meltwater might carry the soot away.

Mathematical modelling by computers has shown that 100 million tonnes of smoke, produced in the northern spring or summer, could cause a nuclear winter. Mr Galbally and others have estimated that this would be produced from the burning of an urban area of 250 000 sq. km, and perhaps a similar area of forest, and that about 36% of the smoke, mainly from urban fires, would be in the form of pure elemental carbon (soot). Following such a smoke injection, temperatures inland in the Northern Hemisphere, even at latitudes as low as 30°N, could drop to below freezing after a few days.

Historical precedents

Could it be that the scientists are wrong? How can they be sure that their computer simulations would bear any relation to reality? In other words, where is the 'practical component' considered so essential to science?

Apart from studying controlled oil fires and bushfires, laboratory experimentation on the production of carbon by the burning of various industrial materials, and the historical reports of the explosions at Hiroshima and Nagasaki, scientists have also been able to obtain some data from the many nuclear test explosions that all four nuclear powers have carried out. But as well as this, some natural phenomena have themselves injected a sufficient quantity of particles into the atmosphere to change the climate.

For example, the volcano Tambora, on the Indonesian island of Sumbawa, was 4 km high until 7 April 1815, when the top kilometre blew off. The direct rain of rock and ashes killed about 12 000 people outright. The quantity of matter injected into the atmosphere, and its effects, exceeded anything else on record. (More recent volcanic eruptions such as El Chichon in 1982, although smaller in extent, have also had a noticeable effect on the atmosphere.) Even though the Tambora eruption occurred in the Southern Hemisphere (but close to the equator), the following summer in Europe and parts of North America was the coldest recorded before or since, and there were world-wide crop failures.

Perhaps the 'lost summer' of 1816 inspired Byron to write his gloomy poem 'Darkness' in June of that year. Many people have noticed that it gives an uncanny description of what a nuclear winter might be like:

> I had a dream, which was not all a dream.
> The bright sun was extinguish'd, and the stars
> Did wander darkling in the eternal space
> Rayless, and pathless, and the icy earth
> Swung blind and blackening in the moonless air;
> Morn came and went — and came, and brought no day,
> And men forgot their passions in the dread
> Of this their desolation; and all hearts
> Were chilled into a selfish prayer for light.

Australian studies

How are Dr Pittock, Mr Galbally, and Dr Manins hoping to increase our knowledge of possible nuclear winter effects in Australia? Their study falls into two parts. The first considers possible ways by which carbon particles may be directly and rapidly injected into the stratosphere by nuclear fireballs (following surface explosions), as opposed to rising in hot smoke plumes.

Mr Galbally, Dr Manins, and Mr Lon Ripari are collaborating with Professor Crutzen in using computer modelling to gain more information about the behaviour of carbon particles in a fireball. In particular, they would like to know how much of this carbon will survive unburnt, rise more quickly, and reach greater heights than particles in a plume from a large 'normal' fire. This is important, as it impinges on the calculations about the quantity of smoke that is likely to be transported to the Southern Hemisphere.

Within a nuclear fireball, much of the material present (including fuel, metals, concrete, and soil) is vaporised. The problem is that only a limited amount of oxygen is available in the fireball for combustion to take place, the amount depending on the size of the fireball. Within it, any carbon that remains unoxidised will form soot. Depending on the cooling characteristics of the fireball, this may later be converted to carbon dioxide or carbon monoxide, or remain in the atmosphere as soot.

Mr Galbally and collaborators Professor Paul Crutzen and Dr Henning Rodhe have calculated that, in the case of a 100-kt explosion at the earth's surface, a density of combustibles on the ground (called the fuel loading) of only 70 kg per sq. m would produce an excess of fuel over oxygen. Now, a full liquid-fuel storage tank 30 m high would have a fuel loading of more than 10 000 kg per sq. m. If even a small fraction of this amount is vaporised then it would far outweigh the volume of oxygen in the fireball resulting from the fuel tank's destruction. The fuel, such as oil, would be vaporised by the high temperatures but could not combust, and would therefore produce large quantities of thick black smoke.

(A recently considered factor in the sooty smoke arena is the observation that many American and Soviet missile ranges are located on coal-bearing strata, and so attacks on these weapons could possibly carry coal dust high into the stratosphere.)

The second part of the study will consist of detailed computer simulations of the climatic effects of the smoke transported into the Southern Hemisphere at high altitudes. This work will also take into account the behaviour of the 'boundary layer' — that part of the lower atmosphere most strongly influenced by the underlying surface. In particular, Dr Pittock wishes to study the behaviour of the boundary layer over land, because this determines the extent of the cooling that would occur there.

The ocean can moderate cooling of the land surface when the wind carries heat from the sea inland. However, a stable layer of air over land can prevent this, as frequently happens on cloudless nights as the land cools and a temperature inversion forms. The sun's heating of the land in the morning warms the air near the ground. The warm air then rises and overturns the stable inversion.

The reduction of sunlight following a large nuclear war would cause this common night-time inversion layer over land in the Southern Hemisphere to remain for longer. Temperatures would obviously fall, but by how much would depend on many factors, including latitude, season, wind speed, and even soil moisture. Computer models of climate used so far in nuclear winter studies have not had an exact representation of the boundary layer, and Dr Pittock considers that they might possibly have underestimated the extent of cooling. The calculations in the model should help to clarify this.

Dr Pittock is also hoping to model changes in the top 50–100 m of the Southern Hemisphere ocean. This layer is normally warmed in the summer, and remains distinct from the cooler water below. Winter storms disrupt it, but with increasing heating by the sun it starts to re-form in the spring. How would the reduction in sunlight of a nuclear winter affect this process, which is important in the transfer of heat inland?

The biological effects

So far we have concentrated on the mayhem that nuclear war would commit on our atmosphere and climate. However, a nuclear conflagration would also devastate the biosphere. The effects on living things might be direct, or might follow on secondarily from the climatic effects we have already noted.

Most of the primary effects of thermonuclear weapons have been known since the first explosions took place. We have since refined our knowledge of the long-term effects of radiation. But the realisation of the prospect of a nuclear winter is relatively recent, and we are therefore only just beginning to appreciate the enormity of the biological damage that would flow from it — damage far more terrible on a global scale than the direct destruction caused by a bomb.

A bomb on your city — the direct effects

Upon detonation, a nuclear weapon vaporises within one-millionth of a second, and heats a sphere of air around it to more than 300 000°C. (By comparison, the temperature at the sun's surface is a mere 7500°C.) The air expands and cools, and a shock wave forms and travels ahead. A bright pulse of light, which bleaches the retina of the eye, is also produced.

The intense heat of a nuclear fireball can readily ignite a fire at a distance. The thermal pulse of a 1-Mt fireball, for example, can light spontaneous fires over an area of 1000 sq. km — assuming a clear atmosphere and relatively dry materials, such as we often have in Australia. Some of these primary fires would be quickly blown out by the enormous winds generated by the explosive blast. However, these winds might have the effect of creating secondary fires further afield. Secondary fires would result from electrical short circuits and broken gas-lines. Strong winds from the blast, by breaking windows and doors, would tend as much to facilitate the spread of fire as to extinguish it.

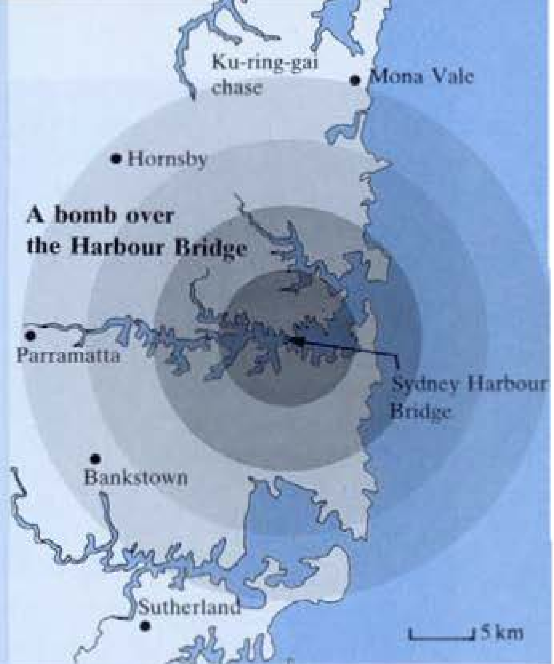
Organised fire-fighting could not exist; too many people would be injured, the streets blocked by rubble, water mains destroyed, and flammable fuel and chemicals spilt.

Most nuclear weapons aimed at large targets are designed to explode above the ground, as this increases the area of damage. The characteristics of the shock wave in the air, and thus the blast produced, depend on the height of these airbursts. A 1-Mt bomb exploded at a height of 1 km would give winds of 470 km per hour 5 km from the centre beneath the bomb. Even 10 km away the blast wind would be 110 km per hour, and windows at 20 km distant would still be shattered. Although the human body itself can withstand a relatively intense blast, flying debris and falling masonry would be major causes of injury for those who were far enough out to survive the initial explosion.

Radiation sickness would be a slower form of death for those unfortunate enough to survive the first day. The impact of a radiation dose depends on its rate of delivery: 450 rads at the body surface within a few days is the LD 50 — that is, the dose likely to kill half of a group of healthy adults. For a 1-Mt explosion, this dose would occur within 48 hours over an area of about 1000 sq. km. (By comparison, the Sydney metropolitan area — from Kuringai Chase in the north to Botany Bay in the south and to Parramatta in the west — comes to about 1200 sq. km; so a little over 1 Mt would be sufficient to kill — by blast, fire, or radiation — most of the population of more than three million in that area, unless they were in efficient fall-out shelters at a reasonable distance from the centre of the explosion.)

Radiation from long-term fall-out derives from long-lived radioactive isotopes as the short-lived isotopes decay. Two long-lived radionuclides produced in some quantity are strontium-90 and caesium-137. These both have half-lives of about 30 years.

Chronic radiation doses lead to an increase in cancer and birth defects, but possibly more importantly would severely reduce the effectiveness of the immune response. With the upsurge of normally controlled diseases following destruction of medical services and sanitation, and the large numbers of corpses, the body's inability to fight disease would be a serious cause of death for any survivors, according to a report recently published by the British Medical Association.



The blast of a 1-Mt bomb exploded over the Sydney Harbour Bridge would be sufficient to blow out windows in Mona Vale, 20 km distant.

Perhaps the last three lines of Byron's poem 'Darkness', quoted in the main text, provide the most eloquent description of the scene that might greet any survivors in a country directly involved in a nuclear war:

> The winds were wither'd in the stagnant air,
> And the clouds perish'd; Darkness had no need
> Of aid from them — She was the Universe.

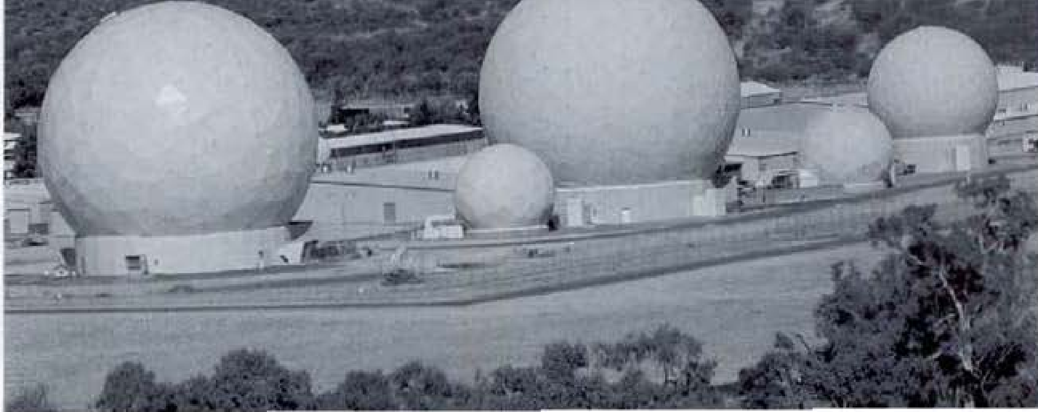
We have mentioned the possible failure of the northern monsoon rains. Added to this, almost complete crop failure in the Northern Hemisphere would result from the lack of light and the low temperatures. (A drop of only 3–5°C coming at the beginning of the growing season could destroy the North American and Soviet grain harvests.) The SCOPE report estimates that up to ten times more people would die from starvation due to the disruption of food supplies than from the direct effects of the weapons themselves. Australia, however, might not be catastrophically affected unless it — or other large areas of the Southern Hemisphere — were heavily bombed.

Whether Australia would be targeted, and to what extent, is unknown. The three United States–Australian joint communication facilities — at Pine Gap, North West Cape, and Nurrungar — have been mentioned as potential targets.

Average temperature reductions of a few degrees Celsius throughout Australia, following the transport of smoke southwards, may not be serious. The likely changes in rainfall patterns, the reduction in day length, and an increase in the number of frosts in the autumn, winter, and spring are the most serious threats to Australian agriculture.

According to the SCOPE report, most of the continent would probably experience less rainfall, although in some coastal areas rainfall might actually increase. The lower

The United States–Australian joint communications facility at Pine Gap, near Alice Springs — considered a possible nuclear target.



Smoke from an experimental fire burning oil. The intensely black smoke is typical of many urban and industrial fires, involving as they do large amounts of plastic, fabrics, bitumen, and the like.

average temperature could even boost production in some areas where heat stress is a problem, but would have a negative effect in temperate regions. Australian wheat yields are very weather-sensitive, but our pastoral agriculture is less so.

As part of an investigation into the sensitivity of Australian biological systems to possible climatic changes, Dr Pittock and Mr Henry Nix, of CSIRO's Division of Water and Land Resources in Canberra, ran a computer model. Like all models it had limitations, but it predicted a decrease in agricultural production of up to of 20% in the cooler regions of Australia due solely to a temperature drop of 5°C. In the model, temperature reductions had little effect north of 30 °S, but a 50% drop in precipitation produced a 50% drop in productivity in arid areas.

There is much uncertainty about the environmental perturbations that might occur in southern temperate regions. A lot would depend upon which season the nuclear war was fought in. Nevertheless, as we have a food surplus, the SCOPE report considers that, even with a reduction in agricultural production, Australia appears to be among the countries least vulnerable to post-war food shortages.

Looking again at the global scene, Mr Galbally and collaborators Professor Crutzen and Dr Christopher Brühl have pointed out that, immediately following the war, the atmosphere would carry many pollutants derived from the burning of industrial areas. Among these could be asbestos, which exists in large amounts in industrial and urban areas. Asbestos fibres, which even at a low concentration cause lung damage, are light enough to travel up with the smoke of the bombs' fires, to be deposited elsewhere.

Furthermore, cooling of the air below the smoke clouds would lead to what meteorologists term a 'temperature inversion'. This is a very stable situation of cold air below warmer air. Locally, it would trap many toxic emissions from the fires following a nuclear war. In much of the Northern Hemisphere the conditions would cause a freezing acid fog.

In addition, the SCOPE report poses the idea that fall-out of large amounts of dark dust could lead to a substantial reduction in photosynthesis in the upper layers of oceans and lakes. (Under normal conditions, animal plankton remove small mineral and organic particles from the surface waters, but after the period of darkness this process would be much disturbed.)

If the report is right, the productivity of the oceans — possibly a remaining food source for any human survivors near the coast — would crash to low levels, perhaps made even lower by the harmful chemical pollutants and radioactive material that would eventually find their way into the sea.

Fall-out of radioactivity after a major nuclear war would be not only locally intense, but global. Based on an exchange of 5000 Mt, similar to that in the *Ambio* scenario, scientists have calculated that in the Northern Hemisphere the long-lived radioactive *gamma*-ray dose from fall-out over a lifetime could average 10 rads, which is 100 times the 'normal' (although spatially variable) background.

Trident submarines carry 24 missiles each with between 8 and 10 independently targeted warheads of 100 kilotonnes. One fully loaded Trident sub therefore has the equivalent of about 1000–1600 Hiroshima-sized bombs.

In the Southern Hemisphere, we could expect five times our 'normal' dose — enough to increase the number of cancers. But added to this direct fall-out from the detonation of nuclear weapons is another possible source pointed out in the SCOPE report: nuclear installations.

According to Sir Frederick Warner of Essex University in the United Kingdom, who led the SCOPE team, the bombing of one-third of the world's nuclear power stations, along with 100 spent fuel storages and one fuel-reprocessing plant, would treble the long-term *gamma*-radiation fall-out after the nuclear war.

This list of biological effects could be longer; certainly the damage would not be confined to humans. In the Northern Hemisphere and tropics many species of animals and plants could well become extinct if a nuclear winter gripped the earth. Life itself would no doubt continue, but would human society?

The world's agricultural production, much of it relying on high technology, may already be stretched in its attempts to feed more than five billion of us; it is extremely sensitive to changes of climate, and would certainly not survive freezing temperatures and weeks of darkness during the normal growing season.

Our society also is fragile, relying on communication, transport, trade, and technology — much of which would be destroyed. It is no wonder that many researchers in the field of nuclear catastrophe believe that the living would envy the dead.

Roger Beckmann

More about the topic

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