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by

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Biographical Note

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ABSTRACT

Human society is threatened by two possible climatic catastrophes of human origin: a slow global scale warming due to increasing concentrations of infrared-absorbing gases, and a sudden but drastic surface cooling due to the smoke and dust which would be generated by a major nuclear war. The slower process is almost certainly taking place now and may be impossible to stop before the end of the twenty-first century. The more sudden catastrophe is at present purely a theoretical possibility, which could be avoided completely by more rational human behaviour. Both are very complex physical phenomena, the magnitude and time-scales of which are at present difficult to quantify accurately but which can only be coped with appropriately by resort to global cooperation on an unprecedented scale. This paper explores the nature and some of the policy implications of these phenomena.

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1. THE GREENHOUSE EFFECT

1.1. Present Status

The so-called greenhouse effect due to the absorption by various trace gases of outgoing heat radiation from the earth, has been anticipated in theory for more than 90 years, ever since the paper by Arrhenius (1896) "On the influence of carbonic acid in the air upon the temperature of the ground." There has, however, been controversy over the magnitude of the effect, for a given increase in infrared absorbing gases, largely because of uncertainty over various feedback processes, especially those involving varying cloud cover. Moreover, until very recently, the timescale for climatic change due to the greenhouse effect has been considered too long to be of immediate concern to those responsible for governmental and capital works planning.

In 1983 the U.S. National Research Council (NRC, 1983), in a major report on the problem, suggested that a doubling of atmospheric carbon dioxide, which was the only gas considered in detail, would lead to a global average surface warming of about 1.5 to 4.5 C by about the third quarter of the next century. It added that several other gases besides CO_2 appeared to be increasing, and that these could cause the warming to occur "significantly earlier". Coupled with the acknowledged uncertainties, this led the NRC to recommend further research, but no immediate action to plan for the global changes anticipated, nor to attempt to ameliorate or prevent them.

Perhaps the most worrying prediction made then was that over the next hundred years "it is likely that there would be a global sea-level rise of about 70 cm", and that eventually a global warming might lead to a disintegration of the West Antarctic ice sheet, with a resultant rise in global mean sea level by 5-7 metres. The latter was thought to be very speculative, and probably would occur only on a timescale of several hundreds of years.

The overall tone of the report was that the greenhouse effect could be serious, but there were several decades ahead in which to do further research, and to plan either to minimise the effects or to adjust to them.

Today, the picture has changed. Several new pieces of information have made the greenhouse effect seem more probable, more imminent, and far less amenable to moderation in the short term. These considerations include: (i) new evidence that greenhouse gases other than CO_2 are increasing rapidly (Dickenson and Cicerone, 1986), (ii) improved confidence in the climate models used to predict the climatic effects, (iii) observed climate changes consistent with the beginnings of a greenhouse warming (Pittock, 1983; Jones, 1986a and 1986b) and (iv) a clearer recognition of the role of thermal expansion of the oceans. This new information is presented in a number of reports including the 4-volume state-of-the-art report from the U.S. Department of Energy (DOE, 1985) and especially in a study sponsored by the World Meteorological Organization (WMO), the United Nations Environment Programme (UNEP) and the International Council of Scientific Unions (ICSU) which assesses the latest research. This study has been published as a volume in the SCOPE series (Bolin et al., 1986). A new sense of urgency was highlighted in the statement issued from the WMO/UNEP/ICSU conference which considered this volume in draft form at Villach in Austria during October 1985 (Villach, 1985).

The Villach statement asserts that "Many important economic and social decisions are being made today on long-term projects ... all based on the assumption that past climatic data, without modification, are a reliable guide to the future. This is no longer a good assumption ... It is a matter of urgency to refine estimates of future climate conditions to improve these decisions." It goes on to state that "If present trends continue, the combined concentrations of atmospheric CO_2 and other greenhouse gases would be radiatively equivalent to a doubling of CO_2 from pre-industrial levels possibly as early as the 2030's." This, it says, would lead to a global mean equilibrium surface temperature increase of between 1.5 and 4.5 C, and a sea level rise of between 20 and 140 centimeters, essentially due to the thermal expansion of the oceans.

With regard to action, the Villach statement asserts that "While some warming of climate now appears inevitable due to past actions, the rate and degree of future warming could be profoundly affected by governmental policies on energy conservation, use of fossil fuels, and the emission of some greenhouse gases." It recommends that "Governments and regional inter-governmental organizations should take into account the results of this assessment (Villach 1985) in their policies on social and economic development, environmental programmes, and control of emissions of radiatively active gases."

1.2. Probable Consequences

To some it may seem extravagant to call the greenhouse effect a catastrophe, especially as it will undoubtedly have some beneficial effects. It is worthwhile, therefore, to look at some of the consequences which might be expected. A sea level rise, amounting on average to between 5 and 35 centimeters per decade, will have a number of deleterious effects in low-lying coastal regions. These include increased frequency of storm surge flooding and wave damage, decreasing gradients in coastal drainage systems with consequent increased freshwater flooding, coastal erosion, destruction of estuarine habitat and mangrove forests and damage to coral reefs. Salt water may infiltrate into many coastal aquifers presently used for irrigation and drinking water. Multi- billion dollar investments in marinas, ports and harbours, drainage systems, resorts and tourism will be put in jeopardy and flooding of coastal cities and agricultural land in river estuaries will occur in many parts of the world. Many industries sited in coastal areas, including not only salt extraction works but also fossil fuel and nuclear power stations using sea water for cooling, and those built close to port facilities, may need protection or eventual resiting. The capital expenditures this would require, plus loss of fertile agricultural lands, could have disastrous social and economic effects in the most vulnerable regions and countries.

Many coastal areas are not sufficiently well mapped to know how seriously they would be affected by a sea level rise of the order of one metre. However, areas significantly affected by rises in sea level of a few metres would include much of the east coast of the United States, the San Francisco Bay area, parts of the northern USSR, Denmark, the Netherlands, parts of West Africa, and the deltas of the Ganges, Amazon and Mekong rivers, as well as many major cities near sea level such as London, New York, Miami, Seoul, Beijing and many others (Henderson-Sellers & McGuffie, 1986).

The effects of climatic change may also be catastrophic, although the extent of the changes, and even their direction is still uncertain, and will vary from region to region. Other things being equal, higher temperatures will mean greater evaporation, but this could be counteracted to some degree by reduced average wind speeds as the north-south temperature gradient is reduced, except near the edge of the remaining polar snow and ice cover. The climatic zones, including rainfall belts, will in general move polewards, so that some regions, notably the present Mediterranean type climate zones, will probably get less rainfall. At higher latitudes, and at the poleward edges of the summer monsoon areas, rainfall may increase. Tropical cyclones, hurricanes, or typhoons (the same thing in different English dialects) will occur at higher latitudes, and may well increase in both frequency and intensity.

The impact of climatic change is very complex, since it involves not only the climate system (the atmosphere, oceans, cryosphere, biosphere and lithosphere,) but also human societal reactions and adjustments (Kates et al. 1985). For example, relatively small changes in evaporation or precipitation rates could have major impacts on agriculture, but this could be partially offset by changes in irrigation or breeding new plant varieties.

Give or take a bit of seepage, runoff is the difference between precipitation and evaporation, and often only a small fraction of either of these quantities. So even a small percentage change in either precipitation or evaporation can lead to a large percentage change in runoff. Areas with increased evaporation and static or decreased precipitation may experience drastic reductions in soil moisture and runoff. Other areas, where the precipitation increases more than the evaporation, may experience greatly increased soil moisture and runoff. Consequently agriculture may be greatly affected, with some areas benefitting while others may go into permanent drought conditions, or become waterlogged. In those areas subject to wetter conditions, increased flood frequencies would be expected.

The greenhouse effect is extremely complex, especially where the response of the biomass is concerned. Increased atmospheric carbon dioxide concentrations will in general increase the rate of photosynthesis in plants and decrease their need for water. This will in general be beneficial, as will warming at high latitudes since this will extend the growing season. However, the extent of the gain in productivity of plants due to the direct effects of increased CO_2 depends on the particular metabolism of the plant, so that some plants will gain a competitive advantage over others. Reduced water use by plants will also lead to greater soil moisture and increased runoff, improving conditions in some areas but adding to flood problems in others. Changing climates, especially increased humidity in some areas, will also lead to changes in the incidence of some insect pests, such as locusts, and of plant diseases, such as rust in wheat. There may also be changes in the incidence of some human diseases, eg. malaria and encephalitus, which are transmitted by mosquitoes.

The present system of nature reserves, which are often designed to preserve habitats of endangered species, will be threatened, along with genetic diversity, as the climatic conditions change. This suggests that such reserves may need to be enlarged to include presently more diverse climates, and that seeds of rare species may need to be collected and stored in order to ensure that genetic material is not lost.

1.3. Policy Implications

The social and political implications of such global climatic and other environmental changes will be enormous. They may show up within the next one or two decades in an increased incidence and severity of climatic extremes and "disasters" of the short-term localised kind -- floods, droughts, and coastal storm damage. Small changes in mean runoff will accumulate and may show up in the space of a decade or so in either reduced or overfull water storages used for irrigation or flood control. Within a matter of decades, such pressures may very well lead to inter-regional migrations, and to massive economic costs which will affect the viability of whole regions and countries. The existence of international boundaries will greatly exacerbate these problems by hindering migration and economic assistance.

The uneven impact of the changes on regional food production and economies may well lead to the economic decline of some countries and the rise of others, with corresponding shifts in international power and potential conflict.

There may well be growing pressure, especially from those more adversely affected, for concerted action to reduce the extent of the greenhouse effect and to modify or adjust to its consequences. This will involve debate about the regulation of fossil fuel usage, and efforts to increase the use of renewable energy sources and possibly nuclear energy, despite the latter's manifold problems. Pressure for control of and reduction in the use and manufacture of chlorofluorocarbons and some other non-CO_2 greenhouse gases will grow. Proposals to flood certain large areas which are presently below sea level, as a means of reducing or delaying the rise

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in sea level (Newman and Fairbridge, 1986), may also be seriously discussed. Such areas include the Quattara Depression in Egypt, the Dead Sea rift valley of Israel and Jordan, the Lake Eyre Basin in Australia, the Caspian Sea, and other areas in the United States, Argentina and Ethiopia. Such schemes could be coupled with hydroelectric power generation, but would be very expensive and could have serious environmental and human consequences.

Debate on these issues, especially on the control of fossil fuel usage, may be expected to become fierce. Conflict may develop between coastal and landlocked states. Developing countries, which desperately need greater energy production, and some of which have large coal reserves, may favour unrestricted fossil fuel usage, especially if they are also regional beneficiaries of decreasing aridity. On the other hand, developed countries, which may be able to limit growth in energy production via energy conservation, or which already rely extensively on alternative energy sources, may well strongly favour restricted fossil fuel usage, especially if they lie in areas likely to become more arid. Some high latitude countries, whose growing seasons are presently severely restricted by low temperatures, and/or where coastal navigation is restricted by sea ice, may well be in favour of allowing the greenhouse effect to continue unchecked.

Some precedent for international agreement on atmospheric pollution problems exists in the International Convention for the Protection of the Ozone Layer (for background, see Heimsoeth, 1983), which has now been signed by more than 30 countries including the USA and the USSR. Under this Convention a Protocol is currently being negotiated which will freeze production of some chlorofluorocarbons (CFCs) at 1986 levels and eventually lead to agreed reductions in amounts produced.

However, as the Deputy Director of the United Nations Environment Program noted at a 1986 meeting in Virginia "... while regulations of the emissions and use of CFCs are likely to be relatively easy, the price of regulating CO_2 emissions through energy controls may be too high a price to pay and the future lies in adaptation to rather than in prevention of climate change" (Golubuv, 1986).

Hence there is reason to believe that despite problems which may well reach disastrous proportions in many parts of the world, there may be serious international disagreement as to what to do about the greenhouse effect, and when.

It is salutary, therefore, to note that the magnitude of the equilibrium climatic change associated even with a mere equivalent doubling of CO_2, which is now expected as early as 2030, is roughly the same as that between the height of the last glaciation, some 20,000 years ago, and the present. Such a change is now virtually inevitable, given the huge inertia built in to the economic and industrial infrastructure, the long lifetime of some of the greenhouse gases, and the lags built in to the climate system due to the huge heat storage capacity of the oceans. Even without any increase in the present rate of use of fossil fuels and other greenhouse gases, their concentrations in the atmosphere will continue to increase rapidly. Moreover, the lag built in to the climate system by the large heat capacity of the oceans means that the climate would continue to change and the average sea level to rise for some decades even if the trace gas concentrations were suddenly held fixed at some present or future level.

With concerted international action it might be possible to slow down the present rate of increase of at least some of the greenhouse gases over the next several decades. This would reduce the eventual peak concentrations which will be reached some time in the next several hundred years, and reduce the rate of climatic and social change, so that adaptation may become easier. If such action is not taken, the level of greenhouse gases could much more than double, with even greater rises in sea level, and even more extreme climate changes. Destabilisation of the West Antarctic ice cap would likely follow, causing a further 5-7 metres rise in sea level. This could occur within a few hundred years. Such changes would place a major strain on future civilisation, especially since most means of countering such effects would involve further expenditures of energy.

It is therefore necessary that humankind take a global view of the problem and seek long-term global solutions, rather than any apparent national or regional advantage which may in any case turn out to be temporary as the situation continues to change and develop. Anyway, major climatic disasters in some countries would inevitably spill over to others through trade and other economic and political linkages.

In the long run, it is difficult to see how the greenhouse effect can be limited without a rapid decline in per capita energy use and a slowing down or reversal of the present rate of global population growth.

In summary, the greenhouse effect is almost certainly with us now, and will increase over the next century, with profound effects on humankind. Only concerted and drastic action on a global scale will keep it within tolerable limits, and the time to start planning is now.

2. THE NUCLEAR WINTER EFFECT

2.1. Present Status

The "nuclear winter" effect, or more properly, the possible climatic effect of a major nuclear war, was first suggested in the scientific literature by Crutzen and Birks in 1982. There is, however, a remarkably prescient description of possible nuclear winter-like conditions, in the poem Darkness, written by Lord Byron in 1816. It was also partly anticipated by the French novelist Robert Merle in Malevil, published in 1972. The possible climatic effects were spelt out more fully by Turco et al (1983).

The nuclear winter effect arises from smoke and dust generated by nuclear explosions. This material, if in sufficient quantity, absorbs or scatters the incoming sunlight, preventing much of the solar energy from reaching the earth's surface. Smoke, in particular, is highly absorbent of visible radiation, but relatively transparent to infrared or heat radiation given off by the earth. It thus has the opposite effect to infrared absorbing gases, leading to a cooling at the earth's surface. This is only so, however, if there is sufficient smoke, and/or if it is high enough above the surface, so that a stable layer of air can form beneath the layer of smoke which is absorbing the sunlight and becoming warmer in the process. Otherwise, vertical mixing can cause the warmed smoke- laden air to descend and actually cause a warming at the surface. If there is sufficient smoke in a vertical column to absorb roughly two thirds or more of the sunlight, cooling occurs at the surface. Cooling will also occur with much smaller amounts of smoke provided the smoke is in the stratosphere where it and the associated stratospheric heating cannot be mixed down to the surface.

There are great uncertainties as to the extent of the above-mentioned effects. These are due firstly to uncertainties as to the nature and scope of any nuclear war which may occur, and particularly the extent to which urban and industrial areas (which would generate most of the smoke) would be directly or incidentally targeted and burn. The amount of smoke generated per unit area burned, the proportion of soot in the smoke, and the precise optical properties of the smoke are also somewhat uncertain. The latest survey (Penner, 1986) suggests a range of possible smoke amounts between 24 and 270 million tonnes.

The height of injection of the smoke, and the proportion which is removed quickly by "black rain" in the smoke plume, are other variables difficult to quantify. Theory and observations suggest that mass fires with high fuel loadings can generate hot plumes powerful enough to put smoke into the upper troposphere or lower stratosphere, at heights in excess of 8-10 km. There were limited observations of black rain after the bombings of Hiroshima and Nagasaki, but no accurate estimates of the proportion of smoke washed out. Much depends on whether or not smoke is hydrophobic, i.e. on whether or not smoke particles repel water. If so, then only a small percentage of smoke would be removed by prompt washout, but if not, the percentage could be much higher. Most calculations have assumed prompt removal of one third to one half of the smoke, which is probably a generous allowance.

At low latitudes, or in the summer half of the year, large quantities of smoke would absorb large amounts of energy from the sunlight and would heat up, and rise in the atmosphere. Several computer models have shown that this effect would change the atmospheric circulation in such a way as to reverse the normal equator to mid-latitude flow in the upper troposphere of the northern hemisphere. Thus smoke put in at relatively low altitude in the mid-latitudes of the northern hemisphere can be transported upwards and southwards, some of it crossing the equator into the southern hemisphere at heights of between 10 and 20 km. (MacCracken and Walton, 1984; Malone et al., 1985; Stenchikov, 1985; and Thompson, 1985).

The extent of the cooling at the surface would depend not only on the amount and height of the smoke and dust, but also on the extent of the moderating influence of the oceans. Most computer models of climate used for calculating the effects are based on simplified representations of what happens in the atmosphere near the ground. These models average out the daytime and nighttime processes.

During the day under normal conditions sunlight heats the surface and causes convection to occur, which mixes air vertically between the surface and the lower troposphere. At night, especially inland under clear skies where infrared radiation can escape to space, the surface cools, causing convection to stop. This isolates the surface from the lower troposphere, allowing the ground to cool rapidly because the air above does not have to be cooled as well. Typically, the ground under clear skies in continental regions can cool by some 20 C in 12 hours.

Covey et al (1985) showed that in the climate model which they used to simulate nuclear winter conditions, even though the sun was effectively turned off for many days by the presence of the smoke layer, the model still had heat being mixed down to the continental land surface. The source of this heat was the oceans. Heat from the oceans was being transported inland by the winds and mixed down to the land surface. Covey et al. pointed out that this was due to the way the mixing processes near the ground were represented in the model, which was inappropriate to nuclear winter conditions. This, along with very rapid washout of smoke, due to its assumed low height of injection, is probably why the latest results from modelling by Thompson and Schneider (1986), reported with little documentation in Foreign Affairs, show much less cooling than one might expect from looking at the daily cycle of temperature. They attributed the reduced cooling to inclusion of washout and of the infrared effect of the smoke. The latter is also a function of the height of injection of the smoke.

Thompson and Schneider reported that their estimated coolings for the Northern Hemisphere in July led to conditions more like October than January, and therefore suggested that the term "nuclear autumn" was more appropriate than "nuclear winter". Such a more moderate average cooling would still lead to occasional frosts in July over much of the northern mid-latitude continents, and would have effects on agriculture which would be almost as disastrous as a full "nuclear winter".

Whatever the precise degree of cooling, the models all suggest that temperature drops in excess of 15 C, and possibly as much as 30 C or more, would occur over large areas of the northern hemisphere continents after a major nuclear war fought in the northern summer. Coolings of 10-15 C could also occur in tropical regions, and the amount of smoke predicted to come overhead in the southern hemisphere might produce coolings in continental areas of about 5 C. A war in the northern winter, however, might produce far less effect, since the smoke would not be driven so high by absorption of sunlight and it would therefore be washed out faster. Probably little would reach the southern hemisphere.

The cooling at the surface and increased stability of the lower atmosphere induced by the smoke would be expected to lead to less convective activity and reduced rainfall. On the continental scale, we know that the summer monsoons in Asia and Africa are driven by heating in the continental interior, leading to ascending air and an inflow of moist air from the surrounding tropical oceans. Lowering of inland temperatures by the smoke would be expected to suppress this monsoon circulation, and thus stop the normal summer rains over large heavily populated regions. Such ideas have been borne out by computer models, notably in the results of MacCracken and Walton (1984) and Malone et al. (1985).

The early papers by Crutzen and Birks, and Turco et al., stimulated investigations leading to several major reports. Notable amongst these were the reports from the U.S. National Research Council (NRC, 1985), the Royal Society of Canada (1985), the Royal Society of New Zealand (1986), and the USSR Academy of Sciences (1985). The International Council of Scientific Unions (which is the non-governmental body to which most national academies of science are affiliated) commissioned a two-year study by the Scientific Committee on Problems of the Environment (SCOPE), which resulted in a two-volume technical report. Volume I, on the physical and atmospheric effects, was authored by Pittock et al (1986), while the second volume, on the ecological and agricultural effects, was written essentially by Harwell and Hutchinson (1985). All these reports have confirmed that severe climatic effects are, at the very least, a real possibility in the event of a nuclear war, but they have emphasised the uncertainties and range of possible consequences. The NRC and SCOPE reports in particular recommended further research, and some further research is going on, although not on a massive scale. None of these reports discussed the policy implications, although some individual authors, notably Sagan (1983), Thompson and Schneider (1986), Nye (1986) and Pittock (1987) have done so. The book by Pittock (1987) emphasises the implications for Australia and New Zealand.

2.2. Probable Consequences

Volume II of the SCOPE report (Harwell and Hutchinson, 1985), and the report from the USSR, go furthest in discussing the full range of possible environmental effects of a major nuclear war, and their human consequences. As the Soviet report tends to take an extreme worst case, I will concentrate on the SCOPE assessment (which in any case had the agreement of the Soviet participants).

The SCOPE study surveyed the sensitivity of crops and natural ecosystems to reductions in temperature and rainfall, and also considered other environmental stresses such as radioactive fallout, toxic chemicals from fires, and possible increases in ultraviolet radiation. The predicted climatic effects alone were considered sufficient to reduce food production in the northern hemisphere to nearly zero in the first growing season after a major war in the spring or early summer, and to substantially reduce productivity in the next growing season. Significant reductions in productivity were also considered possible in the southern hemisphere.

In addition, note was taken of the reduction in productivity to be expected in both targeted and non-targeted countries due to loss of energy subsidies such as fertiliser, other chemicals, and fuel for tractors, both from direct attacks and from cessation of trade. Loss of food imports would also have serious effects in some countries which do not normally produce enough food to feed their own populations, eg. Japan.

Combining these effects, the SCOPE study found, from a country by country survey, that the stored food available would only be enough to keep alive a small fraction of the world's population in the first year after a major nuclear war. Even this was based on optimistic assumptions, namely that the stored food would only be made available to people who could be fed for a whole year, that nobody would get more than 2000 kilocalories per day, and that the food would be perfectly distributed.

The broad conclusion, therefore, was that something like three or four thousand million people would die of starvation, ie. some five to ten times the number who would die from the direct effects of the bombs. More people would die from mass starvation in India than from the direct effects in the United States and the Soviet Union put together.

2.3. Policy Implications

The policy implications of the nuclear winter scenarios are controversial. Policy makers in the United States and the Soviet Union have not admitted that there are any new implications beyond those posed by the direct effects of nuclear weapons, which are bad enough. However, several possible implications do come to mind.

One is that nuclear winter puts the non-combatant countries in the front line in a way that was not anticipated before, so that it increases the incentive for those countries to ensure that the danger of a nuclear war is reduced. In my view this may be the most important implication, as it could lead to a much more concerted move by the non-nuclear powers to exert a restraining influence on the superpowers. It will be interesting to see how this evolves in the political arena.

A second possible implication is that nuclear winter makes the large-scale use of nuclear weapons suicidal, in the sense that it would lead to the effective destruction of any society using the weapons, if not of every individual member of that society. This would mean that the use of nuclear weapons is even more irrational than it appeared to be earlier. This would further undermine the credibility of reliance on nuclear weapons as a deterrent. However, to admit that nuclear winter undermines the credibility of nuclear deterrence is in fact to further undermine the whole basis of superpower strategy, so it is most unlikely that either superpower would make such an admission, at least until some alternative form of deterrence was in place.

We have not heard what the Soviet authorities think of these arguments. However, the U.S. Department of Defense has issued a report to Congress (Weinberger, 1985) which discusses the implications of nuclear winter for U.S. strategy. The report emphasised the uncertainties as regards the nuclear winter effects, and said that it was therefore premature to allow policy to be influenced by such considerations. In any case, it was argued, the possible climatic effects of nuclear war only strengthen the three elements which are stated to be basic to U.S. defense policy: nuclear deterrence; the objective of arms control; and the Strategic Defense Initiative (commonly known as "Star Wars"). The report claimed that the Strategic Defense Initiative would prevent nuclear weapons from reaching their targets, thus minimising smoke production and hence the risk of nuclear winter.

Several of the claims in the U.S. report are controversial, but it is undeniable that the possibility of nuclear winter raises the stakes in the nuclear arms race and in a possible failure of deterrence still further.

The possibility of nuclear winter thus adds to the urgency of efforts to reduce the risk of nuclear war. Nuclear winter is therefore, at least in my view, a major new factor to be taken into account in relation to nuclear arms and strategic policy.

3. SOME COMMON ELEMENTS

3.1. The Need to Understand the Climate System

The greenhouse effect and nuclear winter have a number of things in common at a technical level. They both represent major disturbances or changes in the climate system, taking it far from the present quasi-equilibrium situation. The postulated atmospheric effects go far beyond our direct experience. This presents a number of conceptual dangers as we seek to extrapolate from the present climate, and to use models based on present conditions. Different processess and effects become important, and many of the empirical constants and approximations which we have built in to our models may lose their validity.

To cope with these problems will require resort to lateral thinking. We must try to anticipate the unexpected, and to use analogies and make connections which we would not otherwise make. This goes some way towards explaining why certain features of the greenhouse effect, such as the importance of gases other than CO_2, and of the thermal expansion of the oceans, have been appreciated only recently, and why it took nearly four decades for the importance of smoke generated by a nuclear war to be recognised.

The fact is that the climate system has gone through many dramatic changes during the long history of the Earth, yet we have only been able to observe in detail a very tiny sample of its fluctuations. If we are to fully appreciate what is possible within the climate system we will have to devote much more energy to reconstructing its past behaviour from the geological and fossil record, and use this new knowledge to test our theoretical understanding. We might also look to the other planetary atmospheres for examples of climate systems different from our own.

Our understanding of the greenhouse effect and of nuclear winter have both gained enormously from such lateral thinking. Past warm epochs, such as the so-called climatic optimum which occurred some 6,000 to 8,000 years before the present, may be valuable, if imperfect, analogues to the warmer Earth we can expect in the next several decades. Dust storms on Mars, and the seasonal and daily temperature cycles on Earth, are useful analogues of aspects of the nuclear winter. Analogies, of course, are never perfect, but they do help us to identify critical variables and mechanisms which we need to estimate, model and test.

As humankind continues to introduce new chemicals to the environment, as well as old ones in ever increasing quantities, it is perhaps pertinent also to ask what other, as yet unanticipated, climatic and other global hazards may be generated. The recent discovery of a rapidly growing "hole" in the ozone layer over the Antarctic in spring is a case in point. Its location and magnitude were totally unanticipated, and we still do not understand why it is happening. What else may be around the corner?

3.2. The Role of Uncertainties

In considering the policy implications of both the greenhouse and nuclear winter effects, uncertainties play a key role. In the case of the greenhouse effect, the theoretical possibility has been known for some 90 years, yet it is only since the Villach meeting in October 1985 that decisionmakers have begun to pay serious attention to the policy implications. As for nuclear winter, the decisionmakers in the one major nuclear power which makes its policy analyses more or less public are still saying that the uncertainties are such that it is too early to let it influence policy.

In both cases, at least some scientists have been accused of scare-mongering, sensationalism and irresponsibility in bringing the possibilities to the attention of the public. One of the problems is, of course, that careful scientific statements which pay due respect to the uncertainties may be regarded by many in the media as dull. They get sensationalised and "simplified" by the ommission of caveats, both because sensational stories sell better, and also because the media believes, rightly or wrongly, that the public would be too confused by typical scientific statements which play one factor off against another.

There also seems to be a marked lack of appreciation by scientists, decisionmakers, and the public in general, that all possible outcomes have probabilities attached to them, and also costs and benefits. We have to weigh the odds, and with them the potential costs and benefits of whichever course of action we choose.

In the case of the greenhouse effect, decisive choices were made decades ago as the growth of population and industry made a global warming inevitable.

Today our choice is whether to continue down the same path towards an ever more extreme climatic change, or whether to pull back, try to minimise the climatic effects, and to plan as best we may to cope with what cannot be stopped.

In the case of nuclear winter the die has not yet been cast, although decisions made in ignorance of the possible climatic effects over the past four decades have made disaster quite possible. Again, we must weigh the costs and benefits of the present and alternative courses of action against the probability of disaster. If indeed the theory is correct, and a major nuclear war would be suicidal for the superpowers, and genocidal for much of the rest of the human race, then we are faced with some difficult choices. Do we continue along the path of reliance on the use of force to settle international disputes, even though it is fraught with peril, or do we choose some other course?

4. CONCLUSION

The two potential climatic disasters we have considered here are both unprecedented in scale, unless we go back to the last glacial era some 10,000 years ago. A nuclear winter could spell the end of civilisation as we know it, while the greenhouse effect could cause fundamental changes to our way of life. An awareness of the imminence and magnitude of these potential catastrophes is very recent. We have still to come to grips with their implications.

The greenhouse effect throws into question the whole global trend towards increasing population, and industrialisation based on greater energy use. The nuclear winter effect throws into question the whole basis of international relations, which relies on the institution of war as the ultimate sanction and the arbiter of international disputes.

Both these problems arise because human population and the human capacity to modify the global environment have outstripped the capacity of that environment to absorb insult. In one sense they are indicators that the limits to growth have been reached, although in another sense, they may be merely indicators that growth must henceforth follow other, more intelligent and sophisticated paths. We are faced with an urgent need to understand our environment, and what it is capable of sustaining, better. We are also faced with an urgent need to know ourselves better, and of what we are capable. Can we evolve a planetary way of life which is compatible with the survival of spaceship Earth, or is the voyage doomed to a disastrous ending?

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