Under-examined Aspects of the Potential Environmental Effects of Nuclear War

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Abstract

In addition to destroying the area near the explosions, a nuclear war would lead to injection of a wide range of substances into the environment, both as a result of the delivery systems and explosions themselves and as a consequence of the blast, fires, and resulting destruction and disruption. While addressing the many remaining uncertainties concerning the effects of smoke injections on climate is the major topic of present research, there are a number of other potential impacts that could have major consequences, but which are currently poorly understood and have not yet been carefully examined. These under-examined effects include perturbations to atmospheric chemistry, the effects of injections of dust and water (which could create ice particles), the consequences of emissions from the smoldering phase of the fires, resuspension of materials due to perturbed surface conditions, and a range of other potential consequences.

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INTRODUCTION

The direct effects of fire and blast from a nuclear war would clearly have catastrophic short-term consequences on the areas involved. An important question, however, is to what extent additional consequences (referred to as the indirect effects) would persist and extend beyond the immediate areas. Study of these potential physical and environmental consequences has tended to be responsive rather than prospective, with researchers reacting in a crisis-like mode to a succession of issues that have largely been identified by chance over the past several decades. The sequence of issues has included fallout in the 1950's, rainout in the 1960's, depletion of stratospheric ozone in the 1970's, and the climatic effects of smoke in the 1980's. The potential for further surprises seems to remain.

For each of these issues, the intensity of concern has varied significantly over the course of investigation, resulting in divergent public and private opinions about the relevance of the potential impact to policy considerations. Often, the first assessment has suggested that the matter would be of global concern. Such an analysis has, not surprisingly, tended to prompt an initial reaction of fear followed by calls for the abolition of nuclear weapons. As analyses have proceeded and account has been taken of the role of simplifying assumptions, the diminishing importance of the effects relative to the initial destruction and associated economic disruption has returned the focus of attention to the more traditional arguments calling for "stable" force structures and balanced deterrence. While this continued flaring of new issues regenerates public awareness of the horrors of nuclear war, it is not clear that the wide swings in the interpretations of the effects has served to promote stability and peace. Also, the airing of dramatic new issues from outside of the weapons laboratories has served to decrease the credibility of the laboratories.

One reason for the wide swings in the estimates of the potential environmental consequences has been the near absence of a formal effort to carry on a continuing examination of the indirect effects of a nuclear war. In its stead, the issue has been left to near accidental discoveries, followed by, with each new issue, a frenzied effort to rebuild and strengthen analysis capabilities and to return credibility to nuclear deterrence.

With the benefit of almost four years of intensive study of the latest issue, the opportunity exists to again scan the entire range of potential environmental impacts, to attempt to identify areas where uncertainties are significant, and to recommend research needed to better understand under-examined areas. Continuing pursuit of research into these issues will not guarantee that surprises do not again arise, but, especially if account is taken of the changing mix and characteristics of the nuclear stockpiles, the likelihood of surprises will be reduced (especially the prominence of poorly-researched ideas) and the capability for competent and more rapid evaluation of new ideas will be strengthened.

The next section provides an overview of the effects from a nuclear war that may induce indirect effects. This section is followed by a compilation of various aspects of these effects that may warrant further study.

SUMMARY OF EMISSIONS AND CHEMICAL PERTURBATIONS

A nuclear war would lead to emission of a wide range of substances and perturbation to the environment that could lead to further perturbation of the atmosphere/environment system. The list below categorizes these emissions by the source of the injection.

1. Offensive systems
  - a. Rocket-exhaust products
  - b. Ablation of materials from reentry vehicles
2. Defensive systems (strategic defense)
  - a. Rocket-exhaust products
  - b. Dispersed components of systems
3. High-altitude nuclear explosions
  - a. Ionization
  - b. Nitrogen oxides (from ionization and thermal quenching)
  - c. Radionuclides (from device)
4. Surface and near-surface nuclear explosions
  - a. Radionuclides (from the device, activation of surface debris, and release of radionuclides from surface facilities)
  - b. Nitrogen oxides (from thermal quenching and surface fires)
  - c. Dust, debris, char and surface materials (lofting by mushroom cloud and fire plumes)
  - d. Carbonaceous aerosols and other particulate matter (as smoke from induced fires)
  - e. Water vapor (from surface, combustion, and lofting of boundary layer air)
  - f. Pyrotoxins (e.g., cyanide, etc. from combustion of organics)
  - g. Carbon dioxide (from combustion in fires)
  - h. Carbon monoxide (from combustion in fires)
  - i. Hydrocarbons (from combustion, release of products stored at surface)
  - j. Asbestos (freed by explosive force and lofted by mushroom cloud)
  - k. Chlorine, Bromine (lofted by explosions over sea water)
    - l. Condensation nuclei (created by fires)
  - m. Sulfur oxides (from combustion)
  - n. Pollen (from lofting by mushroom cloud and winds)
  - o. Pyrolyzed materials (created by nuclear flash)

- p. Toxic chemicals (from rupture of storage facilities)

The longer-term consequences from injection of some of these substances can induce environmental consequences that lead to further emissions.

5. Emissions from a perturbed environment

- a. Asbestos (freed by explosive force and redistributed by winds)
- b. Methane and hydrocarbons (from decay of killed organic matter)
- c. Particulate matter (lofted by winds and from delayed combustion of killed organic matter)
- d. Unoxidized sulfur (from decaying vegetation)

UNDEREXAMINED CONSEQUENCE CHAINS

Studies over the past several decades have examined the potential consequences of a number of these emissions. Volume I of the SCOPE report (Pittcock et al., 1986) provides the most recent estimates of the changes and effects for those substances that have been considered. The SCOPE review, is not, and does not claim to be, complete, and there remain many uncertainties in even those effects that have been considered. The uncertainties arise for several reasons: the characteristics of the full range of war scenarios are inadequately understood; the materials of which targets are composed is not complete; the amounts and types of emissions are poorly known and probably incomplete; the physical, chemical, and atmospheric processes which may be involved are incompletely or inaccurately represented; the delayed consequences of indirect effects are not thoroughly understood; and the combined effects of the various emissions have not yet been thoroughly analyzed.

It is not possible to resolve all of these uncertainties, especially in the fortunate absence of experimental results. Careful and continuing consideration of potential consequences may, however, be able to identify key issues and to reduce at least some of the uncertainties concerning effects that may be of major importance.

On the following pages, a number of issues concerning possible emissions, the roles of various processes, and potential effects are described; where possible, a proposed approach to researching of the issue is given.* The topics are subdivided by priorities:

- A. deserves attention in near future;
- B. merits longer-term consideration; and
- C. probably not important based on preliminary estimates.

The issues now recognized are summarized in the accompanying table. For our continuing research program, we expect to set priorities for future activities in consideration of this compilation.

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* The following G-Division scientists have suggested and contributed to some of these write-ups: M. Bradley, L. Edwards, S. Ghan, T. Harvey, J. Knox, C. Molenkamp, K. Peterson, W. Porch, C. Shapiro, K. Taylor, and D. Wuebbles.

We should note that our on-going research program is already looking at a number of important effects not listed here, including evolution of smoke particle size distributions, fraction of smoke particles nucleated, smoke particle removal, the effect of fog formation in limiting the initial temperature drop, and the effects on temperature and precipitation over periods from days to years.

A.1 : Coupled Chemical, Radiative, and Dynamical Effects from Nuclear War*

Brief Description : Chemical modeling studies have shown for some time that chemical interactions resulting from NO_x produced from nuclear explosions could have a significant impact on the levels of ozone in the troposphere and stratosphere. Likewise, climate modeling studies suggest that nuclear war could produce significant effects on the temperature distribution. However, the coupled impact of nuclear war on chemistry, radiative, and dynamical processes have not been adequately addressed in past studies. These coupled effects could either amplify or moderate the chemical or climatic consequences of the injections as calculated separately. It is, therefore, important to reexamine the combined and interactive effects of nuclear war on the ozone and temperature distributions. In addition, as a validation study, it is also appropriate to reexamine the effects of the past nuclear test series.

Proposed Approach : The effects of nitrogen oxide injections and ozone reduction were included in the initial 2-D climate simulations by MacCracken (1983), but in a highly parameterized way. Analysis of the coupled effects was also very limited. The new 2-D chemistry-climate model being developed by G-Division's CO₂/trace gases program provides the opportunity for a much more thorough investigation. Ultimately, at least a simplified set of the chemistry could also be incorporated in the 3-D, coupled CCM/GRANTOUR model.

A.2 : The Role of Ice Processes in Smoke Plumes*

Brief Description : Ice processes play an important part in the dynamics and the precipitation processes of natural convective clouds. Ice processes may also be expected to be important in deep moist convection forced by the fires ignited by a nuclear exchange. The latent heat of fusion will cause more vigorous updrafts in the upper portions of the clouds, resulting in higher plumes. The many possible interactions of ice hydrometeors with other ice hydrometeors, with liquid hydrometeors, and with smoke particles could have a major effect on the amount of smoke that survives passage through the cloudy plumes. Some ice processes will increase the amount of smoke scavenged from the plumes; others will increase the amount of smoke released into the atmosphere.

Proposed Approach : The only feasible way to determine the net effect of the ice processes on scavenging is to include an ice parameterization in the smoke plume model. The specific ice processes that need to be parameterized in the model have not yet been determined, but it is clear that riming and the Bergeron-Findeisen process must be included. We also need to modify our warm-rain parameterization to account for overseeding. A review of the ice physics parameterizations which are currently being used in modeling natural clouds would be the initial step, followed by selection of an appropriate mechanism. Preliminary

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* For a more complete description, see the proposed program plan for FY-88.

Table: Under-examined Issues

A. Deserves Attention in Near Future

- A.1 Coupled Chemical, Radiative, and Dynamical Effects from Nuclear War
- A.2 The Role of Ice Processes in Smoke Plumes
- A.3 Electrical Scavenging Mechanisms
- A.4 Combining of Collection Kernels
- A.5 Cloud Processing of Smoke Aerosol
- A.6 Mesoscale Lofting of Smoke
- A.7 Stratospheric Dust
- A.8 Dispersal of Radioisotopes from Military Nuclear Facilities
- A.9 Merging of Smoke Plumes and Effects of Dust

B. Merits Longer – term Consideration

- B.1 Redistribution of Deposited Radioisotopes
- B.2 Emissions from Smoldering or Delayed Fires
- B.3 Absorbing Aerosol Heat Transfer Microphysics and Self-Lofting
- B.4 Limits of Smoke Lofting
- B.5 Injection of Water
- B.6 Injection of Chlorine and Bromine from Sea Water
- B.7 Tropospheric Dust
- B.8 Formation of "Acid" Rain from Fire-Ball and Fire By-Products
- B.9 Scavenging of Smoke by Existing Precipitation Systems
- B.10 The Effect of SDI Systems on the Environment

C. Probably Not Important

- C.1 Dispersal of Materials from Destroyed Warheads
- C.2 Miscellaneous (see below)

efforts by other groups indicate that the choice of mechanism can have a very large effect on the results, suggesting that a range of sensitivity studies will be needed.

A.3 : Electrical Scavenging Mechanisms

Brief Description : Current models of smoke plumes consider scavenging by condensation nucleation and Brownian diffusion and may soon be incorporating scavenging by phoretic effects, and hydrodynamic capture. Electrical scavenging mechanisms are an important omission, in part because they are the least understood process. Some preliminary measurements indicate that some of the aerosols may be charged, and it seems plausible that such intense plumes could create electric fields. Electrical scavenging may, therefore, be a very important scavenging mechanism.

Proposed Approach : Following review of experiments, measurements, and model simulations to establish that the presence of electric charges and fields may be present, data from past experiments at LLNL would be used to develop collection kernels that could be implemented and tested in our microphysics model. To use this capability, the ability to predict electrical fields would need to be added to our smoke-plume model.

A.4 : Combining of Collection Kernels

Brief Description : It is now assumed that the squares of the collection kernels for different scavenging processes can simply be added together, neglecting interaction effects. This simplification could lead to significant errors, especially for particle sizes where different processes have comparable effects.

Proposed Approach : Develop a numerical model to simulate particle-droplet interactions that can be used to investigate the interactive effects of different processes for various flow and concentration conditions.

A.5 : Cloud - Processing of Smoke Aerosol

Brief Description : Our current nucleation scavenging parameterization simulates the incorporation of smoke particles into cloud droplets due to their activation as condensation nuclei. We also simulate the transfer of cloud drops (with smoke particles) to raindrops due to autoconversion and collection, and the subsequent deposition of smoke on the ground within the raindrops. The parameterization also simulates the resuspension of the smoke particles by evaporation of cloud droplets and of raindrops.

Currently, interstitial smoke particles that have undergone evaporative resuspension are not differentiated from smoke particles which have never been activated as condensation nuclei. However, these cloud-processed smoke particles will probably be physically different from unprocessed particles: they will very likely be larger and heavier (due to agglomeration) than the original particles, and will therefore have shorter atmospheric residence times due to their greater terminal velocities. Their optical characteristics may also be different. Ignoring particle alteration due to evaporative resuspension could result in an overestimate of the amount of smoke in the atmosphere.

Proposed Approach : The smoke plume model could be modified to keep track of cloud-processed interstitial smoke. It would be possible to discriminate between smoke that was resuspended by cloud droplet evaporation and smoke that was resuspended by raindrop

evaporation (these particles would probably be larger). It would also be possible to keep track of smoke particles that had been processed through the cloud more than once.

A.6 : Mesoscale Lofting of Smoke

Brief Description : Theoretical considerations suggest that the self-lofting mechanism is most effective on spatial scales not resolved by current GCMs. Thus, previous climate simulations of the global atmospheric response to a nuclear war may have underestimated the smoke lofting that would occur, or may have assumed an inappropriate vertical distribution of smoke as initial conditions. Further, mesoscale lofting may lead to large vertical velocities which enhance water condensation and precipitation.

Proposed Approach : To address the mesoscale lofting issue, Ghan's two-dimensional dynamical model could be coupled to a Lagrangian trace-species transport model (TRANZAM or a variant), our delta-Eddington solar radiation model, and the NCAR CCM longwave code. This model could be used to investigate the competition between lofting and removal and how much lofting would occur before the smoke spreads to synoptic scales. (Although a two-dimensional model may underestimate the rate of horizontal mixing, the time scale for such mixing could be determined from a three-dimensional model.) By varying the horizontal resolution of the model, the extent to which lofting is being improperly estimated could be determined.

A.7 : Stratospheric Dust

Brief Description : Explosions of several hundred kilotons or more could loft substantial amounts of submicron dust particles into the stratosphere and upper troposphere. These particles can induce significant scattering of solar radiation. In the absence of smoke, the dust particles could induce climatic effects similar to those following a very large volcanic eruption (e.g., reduced daytime temperature maxima, altered circulation patterns). In the presence of smoke, the dust can, in the first few days, add to the cooling, but the presence of the dust could also limit solar warming of the smoke, and thereby inhibit self-induced lofting.

Proposed Approach : Incorporate interactive dust into the CCM/GRANTOUR model and conduct sensitivity studies.

A.8 : Dispersal of Radioisotopes from Military Nuclear Facilities

Brief Description : Although the present inventory of military nuclear facilities is not large, the reactors contain substantial amounts of radioisotopes and are likely to be targeted. In addition, it has been suggested that SDI systems may be powered by a large number of small nuclear reactors. The effects of targeting of military facilities may thus be a significant contributor to the dose received from targeting of nuclear facilities.

Proposed Approach : An inventory of military nuclear facilities and their radioisotope loading would be prepared. Existing models could then be used to estimate potential dose commitments.

A.9 : Merging of Smoke Plumes and Effects of Dust

Brief Description : Smoke is initially emitted from individual fires, often in association with the lofting of substantial quantities of dust. After the initial buoyancy associated with the

heat of the fire is dissipated, the smoke will move as a plume in the mean atmospheric flow field. Some of the plumes from individual fires will be near to each other and will tend to merge. Because of their large optical depths, the plumes will generate perturbations to the normal flow fields, and these perturbations can affect the mixing of the plumes and their vertical distributions. The details of this mixing have not been examined in studies of the transition from the plume models, which give the initial plume vertical distribution, to the climate models. In lieu of such information, well mixed clouds of the scale of several hundred kilometers have been assumed.

Proposed Approach : The CSU mesoscale model would be modified to include the radiation package from the CCM in order to represent the effects of absorption of solar radiation by smoke on the local heating of the atmosphere. The merging of two or more interacting plumes could then be simulated in three dimensions, and the rate of plume mixing and the time needed for the smoke concentration to become reasonably uniform on the scale of a hundred km could be estimated. The simulation of dust injection would allow for inclusion of the effects caused by interaction between dust and smoke.

B.1 : Redistribution of Deposited Radioisotopes

Brief Description : For surface and near surface bursts, about half of the radioactivity is deposited locally, much of it quite close to the site of the explosion. Such materials could be redistributed by several mechanisms. For close-in fallout, fires induced by the explosion may induce large plumes having high winds that could resuspend surface particulate matter. Such induced circulations could redistribute local fallout, spreading it over wider regions than indicated by present fallout models. For radioisotopes deposited on snow, melting could carry it into rivers. Other redistribution mechanisms may exist.

Proposed Approach : The smoke-plume model could be used to treat lofting (and possible wet scavenging) of radioisotopes by the winds created by the fire plumes. Other potential redistribution mechanisms should be reviewed.

B.2 : Emissions from Smoldering or Delayed Fires

Brief Description : Major consideration has been given to emissions from the flaming phase of the fires, in all cases assuming unperturbed atmospheric conditions. There will also, however, be continuing emissions from the smoldering phase of fires (and emissions from delayed fires occurring with perturbed atmospheric stability), which introduce pollutants into the boundary layer and lower troposphere. These emissions, including, for example, carbon monoxide, could create significant concentrations especially in the presence of shallow inversions.

Proposed Approach : A survey of the literature and controlled experiments may provide necessary information on emissions. The Pielke mesoscale model could be used to determine the dispersal and mixing of emissions and whether concentrations reach health-levels or may induce other effects.

B.3 : Absorbing Aerosol Heat Transfer Microphysics and Self-Lofting

Brief Description : In hypothesizing self-lofting, the details of the physical interaction of sunlight and absorbing aerosols with and without absorbed water have been ignored. The

assumption is made that the heating of particles warms the air, which then moves up carrying the particles with it. This effect should be investigated more closely.

Proposed Approach : The detailed microphysics code should be modified to permit radiation absorption by wet particles (being done for GBL/SDI studies). Present work should be extended to consider the effect of evaporation from wet particles, to calculate the relative heat transfer mechanisms, and to compare initial wet and dry photophoretic downward forces with buoyant upward forces. This should include consideration of particle shape and conductivity parameterizations of aggregate soots as well as other volatile particle components besides water.

B.4 : Limits of Smoke Lofting

Brief Description : The absorption of solar radiation by sufficient loadings of smoke warms the air and carries the smoke particles upward. The various climate models used to date have carried the smoke up to the top of their vertical domains, typically 30-35 km. There are likely some limits because, once some smoke is lofted, it will warm the air and tend to prevent lofting of smoke below that level. While the stratosphere is stable, which would also help limit lofting, there have not yet been any calculations that indicate at what levels the rise may be limited. The level reached by the smoke is critical to determining the duration of any effects.

B.5 : Injection of Water

Brief Description : Explosions and fire plumes will both lift large amounts of water to the lower troposphere (and perhaps upper stratosphere). The water comes both from entrainment of boundary layer moisture and as a by-product of combustion. Based on smoke plume simulations, Tripoli and Penner have estimated that, by mass, 100 to 1000 times as much water vapor may be lofted as smoke. Much of it might be injected into the upper troposphere as ice particles. These ice particles (and condensed water) could significantly perturb the local radiative balance and, if such particles persist, affect the regional climate.

Proposed Approach : Incorporate ice particles into the radiative prescription in our meso-scale model and conduct diurnal calculations with varying amounts of smoke present. On the larger scale, water vapor injections can be added into the global climate model and the cloud and temperature perturbations estimated.

B.6 : Injection of Chlorine and Bromine from Sea Water

Brief Description : Surface and near surface explosions over ocean waters could loft large amounts of sea water, carrying therewith large amounts of chlorine and bromine into the atmosphere. If injected into the stratosphere, such compounds could catalyze ozone depletion. While this effect may be small in the presence of smoke-induced effects, the effect could be important in the event of exchanges that do not start major urban fires.

Proposed Approach : Estimate injection amounts and introduce materials into the chemical-climate models that are being developed.

B.7 : Tropospheric Dust

Brief Description : Lofting of dust by surface and near-surface explosions could inject substantial amounts of material into the troposphere and, for explosions over several hundred kilotons, into the stratosphere. The NAS estimated that as much, or more, dust as smoke could be lofted into the atmosphere, although most of the particles would be of a size that they would be removed from the atmosphere within a few days. During this period, however, the potential exists for this material to contribute to the coagulation and removal of smoke particles.

B.8 : Formation of "Acid" Rain from Fireball and Fire By-Products.

Brief Description : Crutzen and Birks (1982) first estimated that if an appreciable fraction of fireball and fire-produced NO_x were deposited in rain, it would become highly acidic with average pH of less than 4. Areas receiving rainfall close to the fires would experience much more highly acidic rain than the average. It is not clear whether acid rain would be a global issue affecting both combatants and non-combatants alike.

Proposed Approach : Gas phase and aqueous phase chemistry would be added to the detailed warm-rain microphysics model and it would be applied using dynamics driven by Bradley's smoke/cloud model to evaluate the amount of nitric acid and sulfur which would be deposited locally. Results from GRANTOUR (with perhaps some chemistry added) could be interpreted in conjunction with the chemistry/microphysics model to estimate the amount of global deposition of acidic rain.

B.9 : Scavenging of Smoke by Existing Precipitation Systems

Brief Description : In the first few days following a major nuclear exchange, large quantities of smoke will be emitted into the lower troposphere by moderate and low intensity fires. Most of this smoke will escape early scavenging in the cloud or plume above the fire because the intensity of vertical motion is too small to induce precipitation. Some of this smoke will be transported into regions where there is natural precipitation since the normal weather patterns will persist for at least several days after a large scale nuclear exchange. Estimates of the amount of smoke removed during these encounters need to be made.

Proposed Approach : Climate models can be used to represent typical synoptic situations, and smoke can be injected into these models at appropriate times and places and transported through regions of precipitation. Refined techniques need to be developed to parameterize the rate of removal of smoke by precipitation based on the model defined precipitation characteristics and the vertical distribution of the smoke. Development of these techniques may involve simulations with other cloud and mesoscale models for the various types of precipitation.

B.10 : The Effect of SDI Systems on the Environment

Brief Description : The implementation of effective SDI systems could alter the environmental response to a nuclear war in several ways. First, lasers might be powered by nuclear reactors. These may become targets which could lead to large injections of radionuclides (see also B.1). Second, the debris from destroyed weapons might be dispersed and deposited locally, and/or globally creating a long-term radioactive hazard. Third, the amount of smoke emitted in a "conventional" nuclear war scenario could be significantly

decreased with successful application of SDI systems. Fourth, the amount of material left in space may create an unusable environment for future satellites, affects the environment on reentry (e.g., disperse radionuclides), or perturb radiative fluxes.

Proposed Approach : Our conventional assessment tools could be applied to each of these topics after review and initial estimates are made.

C.1 : Dispersal of Materials from Destroyed Warheads in the Atmosphere

Brief Description : The proposed SDI system would involve destruction of thousands of plutonium-containing weapons. There may also be large numbers of particles generated that could induce atmospheric perturbations.

Proposed Approach : A preliminary calculation suggests that there would be no significant health hazard from the dispersed plutonium, but this should be documented. An inventory of the amount of materials that could be left in the atmosphere by destroyed (and ablated) warheads should be made.

C.2 : Miscellaneous

Brief Description : A number of additional suggestions have not yet been written up:

- (1) Modification of large scale CCN levels could affect precipitation patterns.
- (2) Modification of surface characteristics (albedo, roughness, erosion, etc.) by direct effects and climate effects on ecosystems.
- (3) Oceanic oil slicks could alter evaporation and drag coefficients.
- (4) Release of toxics from rupture of storage facilities.
- (5) Alteration of aerosol particle climatology by increased surface trapping in inversions.