CHAPTER 8

Research Recommendations

Discussions in the preceeding chapters have pointed out numerous areas of uncertainties in our understanding of the chain of events linking a major nuclear exchange to environmental consequences. These uncertainties affect the prediction of the magnitude, longevity and detailed nature of the effects. However, knowledge of the general characteristics of the potential short-term atmospheric response is based on fundamental principles which are less subject to uncertainty. Nevertheless, it is important to reduce the many uncertainties in order to more effectively portray the potential consequences of a nuclear war.

Some of the remaining uncertainties can never be resolved short of a nuclear war itself. Besides questions of how nuclear weapons might be used, there are questions of scale (city-sized fires, hemispheric-scale smoke palls) that cannot be addressed experimentally and, therefore, cannot be confirmed directly. However, there are many other uncertainties that can be substantially reduced through careful research. Such research could also prove useful in areas of atmospheric dynamics, physics, and chemistry that currently are not adequately understood. It is the purpose of this chapter to identify those areas where experimentation and analysis may prove to be illuminating.

The following research recommendations are the result of discussions among the authors of this volume and the participants of the SCOPE-ENUWAR Synthesis Workshop held at the University of Essex in June 1985. The recommendations are divided into several categories, essentially along the lines of the various technical areas discussed in the study. The final section is an exception, offering a few broad recommendations to the science community at large.

8.1 STRATEGIC DOCTRINE

The issue of the potentially severe, global-scale environmental effects of a nuclear war is relatively new. The strategic implications of this issue should be discussed with and factored into the thoughts and concepts of government and military planners. There should be ongoing discussions between the planners and the research scientists so that issues such as weapons
inventories, targeting strategies, and plausible expectations about the manner in which nuclear exchanges might develop can be treated using assumptions that are widely agreed upon.

It is recommended that:

- A wider range of plausible scenarios and associated conditions must be developed in order to serve as a basis for considering the sensitivity of atmospheric effects to issues such as weapons types and use, trends in weapons development, the proximity of targets and cities, and other factors.

8.2 ELECTROMAGNETIC PULSE

The International Union of Radio Scientists has begun to study the implications of the predicted electromagnetic pulse (EMP) on the operation of electrical and electronic equipment in a nuclear conflict. This important, but very uncertain, effect must be better understood if more robust international communication systems for crisis control are to be developed. Thus, it is recommended that:

- The impact of EMP generated by high-altitude nuclear detonations during an international crisis should be more accurately characterized. Implications for future systems designed to prevent the breakdown of international communications and safety mechanisms at critical facilities such as nuclear reactors should be investigated.

8.3 DUST

While dust has played only a secondary role in the most recent studies of the climatic effects of nuclear war, it is clear that the contribution of dust to the overall problem—in terms of atmospheric and radiological effects—could be significant. Although it would be quite difficult to reduce all of the uncertainties in estimates of the physical and optical properties of dust, some of them could be narrowed. With this in mind, the potential properties of dust raised by nuclear explosions at continental sites where detonations might occur should be more accurately defined.

In particular, the following efforts should be carried out:

- Studies of soil characteristics, including the size distribution and index of refraction of the soil dust;
- A reanalysis of archived nuclear test data for the amount and characteristics of the soil dust generated; and
- A careful determination of the organic contents of surface and subsurface soils that might contribute to the absorption of sunlight aloft or to the production of soot in the fireball.
8.4 FUEL LOADING

The research carried out thus far clearly indicates that estimates of fuel loadings in and adjacent to target areas are an important aspect of the total problem. While rough estimates of potential fuel loadings have been made from limited fuel surveys in cities, biomass assays in wildlands, and statistics on world production and consumption rates of flammable materials and fuels, the figures obtained so far are only preliminary. Moreover, little information has been developed on the geographical distributions of the fuels or their proximity to likely target zones. It also has become apparent that the storage of fossil fuels, either directly or indirectly in fossil fuel products, may dominate smoke and soot emission estimates, surpassing, for example, the importance of wood used in construction.

Therefore, specific information should be obtained with regard to:

- Inventories of fossil fuel storage;
- Combustible fuel burdens in urban areas (cities, suburbs, and industrial zones);
- Combustible fuel burdens in rural areas (forests, grasslands, and agricultural zones), particularly in areas that are in the vicinity of potential targets of nuclear weapons and;
- Inventories of the storage of dangerous and/or toxic chemicals in potential blast zones that could be spilled or dispersed in a nuclear exchange.

8.5 SMOKE PRODUCTION AND PROPERTIES

The production and properties of smoke from large fires are areas of great uncertainty and great importance. While the issue of scaling from small or moderate size fires to the massive fires expected in the advent of a nuclear war cannot be resolved at this time, there is clearly a great deal of research that can be done to resolve some of the related uncertainties in this area.

Essential information on the quantity of smoke produced, its elemental carbon fraction, and its morphological and optical properties could be obtained from large-scale experimental fires. These might, for instance, be fires involving pools of liquid fuels such as oil or kerosene spread over areas of $10^2$ to $10^4$ m$^2$ or structural fires set for experimental purposes. Fires of even larger size in stands of forest could be helpful for understanding smoke production in large fires (as well as aiding studies of the plume dynamics for such fires). Obviously, very careful and critical planning will be required if useful scientific goals are to be achieved in such experimental situations. For example, redundant measurements and cross calibrations of instruments should be employed, as well as consistent in situ and ground-based observations.

In field environments of large-scale fires, measurements of the following quantities should receive the highest priority:
- Smoke production efficiencies and yields, especially in large and very hot fires;
- The composition of smoke, with particular emphasis on the fraction of elemental carbon;
- The morphology (shape) of the smoke particles, both initially and as a function of time;
- Size distributions and coagulation rates as a function of time;
- The radiative properties of smoke at visible, near infrared, and thermal infrared wavelengths, including variations with time (aging);
- Microphysical interactions of smoke with condensed water in convective plume situations.

A large body of laboratory data already exists on the formation and properties of smoke and soot. Nevertheless, most of the important properties associated with climatic and environmental effects are not well defined. Clearly, further interpretation of laboratory experiments should be made and new measurements should be carried out to refine our knowledge and fill some of the gaps in the data base.

Laboratory studies are needed on a number of properties of smoke, such as:
- Smoke and elemental carbon yields from different types of fuels under varying conditions of heating and ventilation;
- Particle agglomeration rates, size distributions, and morphology;
- Optical properties of fresh and aged smoke; and
- Nucleation properties of smoke particles from different sources.

In addition to the measurement programs on experimental and laboratory fires, several other avenues of research should be explored, including:
- Designing properly-scaled, experimental fires involving house-sized fuel arrays to obtain rough estimates of smoke production on this scale;
- Performing theoretical studies of the optical properties of soot agglomerates to check and to allow for extrapolation from laboratory results;
- Conducting analog scattering and absorption experiments using microwaves on inhomogeneous and agglomerated particles; and
- Considering the feasibility of measuring smoke characteristics at unplanned fires in cities and wildlands using mobile instrument packages.

### 8.6 FIRE AND FIRE PLUME MODELING

Since experimental studies of massive urban fires will not be possible, model studies must be carried out. Research should continue on:

- The development of large-scale fires in cities following nuclear detonations;
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- The sensitivity of fire growth and spread to fuel loadings and meteorological conditions; and
- The effect of adjacent fires on fire development.

Detailed models of cloud dynamics and microphysics are being developed to study natural convective systems in relation to observations. However, only preliminary assessments of large-scale fire processes have been carried out with these models. Modeling studies are needed especially to define the dynamics, microphysics, and smoke lofting by cloud systems evolving from fires as large as those expected to be ignited by nuclear detonations, because such very large fires are unattainable experimentally. Studies of natural convective systems would help provide an understanding of the fundamental processes which control fire plumes. Unfortunately, many of the basic microphysical processes in clouds are not well understood, and progress on detailed plume simulations will be limited accordingly.

Nevertheless, useful information could be obtained from model studies of:

- Fire plumes
  - in different weather environments,
  - with spatially and temporally varying heat sources, and
  - with interactive smoke microphysics;
- The formation of massive convective plumes and cumulonimbus storms over large fires;
- The interaction and merging of multiple plumes in close proximity;
- The microphysical processes of smoke scavenging and precipitation removal in large-scale, fire-induced storms.

As noted above, studies of experimental fires are important in order to determine the quantity of smoke produced and its optical properties. Experimental fire studies are equally important in the context of fire dynamics in order to validate plume models. Measurements that should be made are:

- Ambient meteorological conditions;
- The extent, intensity, and time history of the heat source;
- The height of the smoke injection and vertical extent of the plume;
- The frequency of occurrence and water content of capping clouds.

8.7 PLUME DISPERSION AND MESOSCALE EFFECTS

Mesoscale models that could be usefully applied to the unique meteorological situations that might occur after a nuclear war are currently under development as a result of public and scientific interest concerning improved
weather prediction, acid deposition, and warning of severe storms. The science of mesoscale modeling is, however, still in a formative stage. Extensive observations and model validation studies have not yet been carried out, although many interesting features of local and synoptic scale meteorological events could be studied in this manner.

Modeling of smoke cloud dispersion and scavenging on the mesoscale, leading to the global-scale, should be initiated and extended to treat:

- The evolution of extensive smoke-filled ice anvils downwind from large conflagrations;
- The interaction of smoke plumes with synoptic weather systems;
- The response of the boundary layer and lower troposphere to blanketing by thick smoke plumes that may be intermittent or patchy;
- The potential trapping of toxic air pollutants in stable cold layers near the ground.

### 8.8 CLIMATE MODELING

General circulation models have already been modified to a limited degree to investigate smoke cloud effects following a nuclear war. The resulting studies have revealed the possibilities of accelerated global spreading and stabilization of massive smoke clouds, the potential for self-lofting of the smoke as a result of solar heating and for sudden temperature drops of land surfaces under dense smoke patches, even to temperatures below freezing during the warm season. The GCM simulations should be refined and extended to provide further insight into the problem.

With regard to GCMs, the following research recommendations are offered:

- Improve the treatments and parameterizations of key physical processes, such as
  - solar and infrared radiation transfer in mixed environments, including smoke and water and ice clouds or low level fog,
  - smoke scavenging and removal by clouds and precipitation,
  - diurnal and boundary layer effects, particularly under conditions of strong static stability. Where necessary, more sophisticated parameterizations of heat transport and cloud/fog formation should be developed.
- Perform model intercomparisons to determine the importance of different physical representations and grid resolution in calculating responses.
- Investigate the sensitivity of the results to the season of smoke injections, and extend simulations to cover periods of a year or more.
- Perform simulations using higher resolution and nested mesoscale and cloud scale models.
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- Investigate the impact of patchiness of the smoke cloud on the radiative response of global climate models.
- Interpret in more detail the multi-dimensional climate and dynamics simulations that have already been carried out.
- Refine the treatment of stratospheric smoke in the models by including chemical and physical removal processes and interactive ozone photochemistry.

A broad base of information exists in meteorological and climatological records, astronomical data, satellite photographic archives, and the results of measurements made during atmospheric nuclear testing. A number of historical events have been uncovered that are relevant to the problem of climatic change induced by smoke and dust aerosols. Other examples may exist. Reasonable proposals to search archives and records (from World War II, for example) should be considered. Therefore,

- Historical data should continue to be reviewed for pertinent information on climatic perturbations, smoke cloud effects, and related physical phenomena.

Analyses of effects over periods of years to decades following a nuclear war have not yet been undertaken, although a number of speculations have appeared. This is an enormously complex problem, involving the forecasting of both physical and biological feedbacks for which analytical tools are poorly developed. Nevertheless, ideas should be pursued and estimates of effects obtained to see if critical factors have been omitted from existing studies, and to lay the groundwork for future studies when appropriate analytical tools become available.

Studies should be made of the long-term perturbations that are possible after a major nuclear exchange, including:

- Effects of climate feedback mechanisms such as ice-albedo coupling;
- Interactions between the oceans and the atmosphere over month to decadal time periods;
- The implications of massive chemical emissions during a war.

8.9 CHEMISTRY

Some of the earlier concerns about the indirect effects of nuclear weapons centered on the destruction of stratospheric ozone. Numerous studies of the effects on the ozone layer have been carried out, but none have included the possible addition of aerosol particles. Furthermore, the subject of tropospheric chemistry, especially near the surface following soon after the fires, has not been addressed in any detail. Therefore, a variety of studies need to be carried out, including:
• Estimate the emission of toxic gases during the burning of fossil-fuel derived products, such as plastic, and from large fires in general;
• Calculate the possible alterations to tropospheric chemistry (smog and acidic precipitation, for example) resulting from chemicals released by nuclear explosions and fires;
• Determine the response of organic and soot particles to ultraviolet irradiation; and
• Consider the interaction between sooty particles and reactive gases, particularly ozone.
• Simulate the concentrations of air pollutants and toxic materials that will build-up in confined river valleys, lowlands, and other sheltered areas as a result of smoldering fires.

8.10 RADIOACTIVITY

While considerable effort has been made to understand the effects of radioactivity and radioactive fallout, there are still important areas of uncertainty. Further research is recommended to:

• Calculate the local fallout in a manner that realistically treats overlap of radioactivity from adjacent surface bursts and includes the details of population distribution and land use patterns;
• Evaluate internal dose contributions in a post-nuclear war environment;
• Improve understanding of the radiological dose commitments associated with the potential targeting and damaging of civilian and military nuclear fuel cycle facilities;
• Extend the calculations of global fallout to include the stratospheric contribution in a smoke-perturbed atmosphere.

8.11 GENERAL RECOMMENDATIONS

The direct and indirect effects of a nuclear exchange are among the greatest problems facing the human race at this point in history. While the magnitude of the potential direct effects of a major nuclear exchange has been recognized since the first bombs were dropped on Hiroshima and Nagasaki, only recently have the major indirect effects come to be seen as comparably important on a global scale. Clearly, a great deal of research remains to be done. Furthermore, the study of indirect effects involves many scientific disciplines that must contribute and interact to bring together findings from scientists around the world. In addition, the findings must be expressed in a manner convincing to scientists, government, and the public around the world.

To provide continued improvement in the further understanding of this problem, we recommend that:
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- An international committee or coordinating body of scientists be established to follow the events, research, and progress on the problems of the global effects of nuclear war, and to report on a regular basis to governments and national and international scientific unions on the status of work and understanding. The committee could also, upon request, provide information to those seeking to pursue research on the problem.
- Interactions between physical scientists and biological scientists should be continued as a means to promoting interdisciplinary insights and discoveries; the discussions between scientists during this project have increased the appreciation of interconnections and interdependencies in the natural world and of common human interests among scientists. Ongoing international cooperation on interdisciplinary global environmental problems, as demonstrated by this study, can accelerate learning and broaden the base of science, and should be encouraged.