GLOBAL EFFECTS OF NUCLEAR WAR
STUDY PROJECT;
2ND QUARTERLY REPORT;
April - June, 1984

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SECOND QUARTERLY REPORT
APRIL - JUNE, 1984

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Second Quarterly Report
April - June

Introduction

This is the second quarterly report of the LLNL Global Effects of Nuclear War Study Project and covers the period April through June 1984. The First quarterly report for January through March 1984 in addition to summarizing work in that period also provided a brief historical summary of global effects research at LLNL and elsewhere. It included an account of the recognition of "nuclear winter" effects in 1982 and 1983 and the development of the Laboratory's program of research in this area.

Section 1 of this report repeats an outline of research tasks on global effects from the first quarterly report. Section 2 summarizes the research activities on each of these tasks in the present quarter. Section 3 notes the participation of project members at several important national and international meetings. Section 4 is a listing of visitors who spoke on global effects topics.

1. The LLNL Program

The LLNL research program on the global effects of nuclear war is divided into six tasks which deal with everything from the assumptions about the size of the war to the ultimate climatic consequences. Although this division is convenient, it should not conceal the coupling between the several tasks and the necessity for continuous communication and cooperation between the study participants to take account of the interrelationship. The tasks, with brief notes about them, are:

Task 1. Nuclear War Scenarios and Target Characteristics.
Task Leader: Robert Perret

Develop a range of credible nuclear war scenarios as input to the other tasks. Characterize the fuel loading and fire potential of typical targets.

Task 2. Fire Ignition, Spread, and Plume Rise
Task Leader: Joyce Penner

Use available computer models of fire ignition and spread, modified and improved as necessary, and available observational data to estimate the size and intensity of urban and other fires and the amount of smoke generated. Develop plume models to calculate hot air convection and the injection of smoke into the troposphere. Identify key experiments.

Task 3. Microphysics and Chemistry of Injected Materials
Task Leader: Joyce Penner

Develop basis for estimating the fate of materials including dust, smoke aerosols, and other combustion products injected into the atmosphere. Evaluate scavenging processes that determine the lifetime of injectants.

Task 4. Optical Properties of Injectants
Task Leader: Fred Luther

Utilize available calculational tools for estimating the scattering and absorption properties of smoke aerosols. Modify and improve as necessary. Identify experimental measurements of optical properties required and propose experiments.

Task 5. Atmospheric Modeling
Task Leader: Mike MacCracken

Use available 1, 2, and 3 dimensional atmospheric models and acquire or develop additional ones to study transport and fate of smoke and other material injected into the atmosphere. Estimate the climatic changes from the presence of smoke. Models transitioning from the local plume calculations to the intermediate (mesoscale), and global scale are required.

Task 6. Biological Effects
Task Leader: Lynn Anspaugh

Based on the predicted global physical effects of nuclear war estimate the biological and ecological consequences. Identify areas of significant uncertainty and possible experimental programs to investigate them.

These task breakouts are used below to report on work in the second quarter of 1984.

2. Research Activities for April-June 1984

Research activities in each of the six task areas are summarized in this section.

Task 1. Nuclear War Scenarios and Target Characteristics.

As noted in the first report we are working in cooperation with the Defense Nuclear Agency in developing unclassified nuclear war scenarios. Our original contact at DNA, Col. Richard Walker, has been reassigned and his replacement is Capt. Richard Tripp, USN. DNA has at least one small contract with SAI to develop unclassified U.S. and Soviet target lists and the information from this work will be available to us. Major Wittler of DNA, and assigned to LLNL, is familiarizing himself with the "Arsenal Exchange Model" which will permit use of target data sets in evaluating various scenarios. In general, work on scenario development has moved slowly in this period.

The contract to study combustible loading of cities with Prof. Dave Simonett of U.C. Santa Barbara noted last quarter has now been signed and results should be forthcoming by about the end of the year. It is called the "Combustible Fuel Base Assessment." In addition to studying one or two American cities in detail to estimate how much burnable material they contain and how it is distributed, they will also study the combustible loading data from the "five cities" civil defense studies of some years ago to determine how useful that information is today and how much significant change there has been.

Task 2. Fire Ignition, Spread, and Plume Rise

Tom Reitter and Sang-Wook Kang have used their fire ignition and spread code, adapted from a code developed at IITRI, to examine the influence of ambient wind speed, fuel loading, firebrand production, and atmospheric visibility (determining the distance to which the thermal pulse starts fires) on the course of fires. They have used an idealized uniform array of wooden buildings to characterize the urban setting. (Each building has a fuel density of 24 g/cm^2 and occupies 15% of the land area for an average fuel density of 3.6 g/cm^2, a reasonable value for suburban areas.) They assume a megaton burst igniting fires out to about 9 kilometers. In their model the initial fires build to a peak fuel consumption rate in about five hours, falling off abruptly as the initial fuel is consumed. Spreading fires continue at a lower rate determined by the ambient wind. The higher the winds the larger the area burned in a given time assuming the fuel is not exhausted. Fire intensity is directly proportional to fuel loading in this model. Fires spreads via firebrands and their production is treated parametrically; it does not appear to be a very sensitive parameter. Making a reasonable assumption about the energy per unit mass of fuel consumed, the code results provide an estimate of the power per unit area from the fire. Power rises to a peak in about 5 hours, with a maximum value of about 2.5 x 10^4 $watts/m^2$ extending over a total area of about 2 x $10^8 m^2$.

Kang and Reitter have obtained an old (1960's) estimate of fuel distribution for the city of San Jose and used the fire spread code to repeat estimates of others for the fires from a 5 MT burst over the city. They replicate the old results. San Jose has of course changed substantially since that time so the results serve only to test our version of the code. Work will continue on this code to improve and check the many parameters that enter into it. Dr. Arthur Takata, formerly of IITRI and a principal developer of the code, has consulted with LLNL on desirable improvements in the code.

Len Haselman has adapted and used his combustion codes TDC and COM3 to calculate the rise of hot convective plumes (carrying smoke) over fires of various intensities. TDC is a two-dimensional code while COM3 is three dimensional. COM3 gives results identical to TDC when run in a two-dimensional mode, and it is now used for all of Haselman's calculations. Thus far no three-dimensional calculations have been attempted. They will be very time consuming, requiring about an hour of CRAY time for an hour of real time.

The two-dimensional problems are either axisymmetric or Cartesian. The Cartesian problems can represent a line or slab fire of specified width and infinite length. With this representation it is possible to incorporate ambient winds perpendicular to the fire line. The axisymmetric or cylindrical calculations cannot incorporate ambient winds but may be a reasonable representation of the firestorm situation where symmetrically inflowing winds replace the rapidly rising hot air. Eventually a few three-dimensional calculations can explore the interplay of ambient and firestorm-generated winds as well as treat irregular fire area effects.

COM3 has been modified to incorporate water vapor effects. Water vapor can enter the convective plume either from the fire itself or from the humidity in the ambient atmosphere. As the moist air rises and cools, condensation releases latent heat and adds to the plume energy. Thus far only a few calculations with water vapor in the ambient atmosphere have been attempted. For a typical assumed humidity profile maximum plume rise can be increased by about 30% because of latent heat contributions. Thus far there have been calculations for fires of intensity 1.4×10^4 watts/m^2 to about 2.8×10^5 watts/m^2. (The Hamburg firestorm had an estimated intensity of 2.5×10^5 watts/m^2 over about 10 km^2. Forest fires can have intensities of 10^4 watts/m^2.) The fires extend to a radius of 5 km or, for slab problems, a width of 10 km. A fire of 2.8×10^5 watts/m^2 intensity sent smoke as high as 18 km by one hour while 1.4×10^4 watts/m^2 sent smoke to about 6 km (both without water vapor). A fire of intensity 8.8×10^4 watts/m^2 sent a plume to 11 km without and to 14 km with water vapor. Smoke plumes tend to spread out several kilometers below their top when the plume rises above the tropopause.

Further modifications and test problems are planned for COM3. Comparisons with plume calculations of others (there aren't many) show reasonable agreement. Eventually COM3 will provide information to estimate important microphysical processes in the plume including particle chemistry and coagulation and to evaluate scavenging effects. Plume calculations also provide information on how much smoke gets how high and is available to circulate around the globe.

Task 3. Microphysics and Chemistry

Joyce Penner and Bill Porch now have a functioning code to treat coagulation processes for arbitrary particle distributions. Brownian motion and particles sticking on impact are the essential mechanisms. Dilution effects, as occur in a rising and expanding parcel of air, can also be treated. An initial result of coagulation calculations for a smoke plume environment as predicted by Haselman's COM3 code is that small particles in the main smoke plume rapidly coagulate into larger particles, thereby significantly modifying the initial particle size distribution. The resultant extinction cross-section, however, is not greatly changed. It does appear that coagulation will, over a period of days, further increase average particle size and could decrease the aerosol absorption cross section by at least a factor of two. This effect has been neglected in the studies of the effect on global temperature change.

Les Edwards is developing a code that will treat coagulation and water interaction processes in a plume-scale environment.

Peter Connell continues to work with Penner on tropospheric chemistry calculations. John Birks of the University of Colorado has suggested that large quantities of smoke in the troposphere would act to substantially reduce the ambient hydroxyl ion concentration by absorption on the smoke surfaces. This in turn would greatly increase the lifetime of biologically derived sulfur containing species such as H_2S which are ordinarily controlled by interactions with OH. Connell's detailed calculations show that other products such as HO_2, O_3, and nitric acid compete with OH for surface absorption and limit the loss of OH radicals. The net effect is some increase in H_2S lifetime but nothing like the hundred-fold prediction of Birks.

Task 4. Optical Properties of Injectants

As noted briefly in the first quarterly report, Fred Luther has written a valuable tutorial paper on optical properties of particles entitled "Effects of Particle Size and Index of Refraction on Solar Radiative Properties." (Report UASG 84-10, April 1984, available from Luther.)

Radiative properties at solar wavelengths vary greatly depending on the particle size and index of refraction. The absorption efficiency is greater than the scattering efficiency for very small particles (radius less than about 0.1 micron), but this reverses for larger particles. The radius at which the reversal occurs depends on the index of refraction of the particles. The maximum values of the absorption and scattering cross sections per unit-volume are not easily calculated without detailed Mie-scattering calculations (we have this capability at LLNL). Since smoke consists of particles with a distribution of sizes, the net radiative properties of the smoke are a combination of the effects for the various sizes weighted according to the particle size distribution function. The radiative properties of a distribution of particle sizes can differ significantly from the properties of a particle with the mode radius.

Since the composition and particle size distribution of smoke used in assessment studies of the potential global effects of a large-scale nuclear exchange are highly uncertain and could evolve in time, it is important that we understand the processes affecting these quantities so that appropriate values of the index of refraction and size distribution can be determined.

Luther also distributed a short memorandum dated April 24, 1984, that supplements the paper above. It is entitled "Effect of Index of Refraction on the Radiative Properties of Spherical Particles."

Luther attended a June 25-29 conference on Obscuration and Aerosol Research sponsored by the Army Chemical R&D Command. Papers addressed particle formation and growth, plume dynamics, non-spherical particles, optical properties and particle-radiation interactions. Luther contacted a number of scientists that might be helpful in our microphysics and optical properties work. A trip report is available from Luther.

Bob Perret has been in touch with Drs. Tihomir Novakov and Hal Rosen of LBL to explore having them do two small studies for the global effects project. Rosen has proposed doing a "Literature Survey of the Optical Properties and Emission Factors for Soot Particles." The research would identify uncertainties in parameters, critically review experimental methods and recommend key experiments needed to reduce uncertainties. Novakov proposed to measure "Size Fractionation of Black and Organic particulate Carbon from Fires." The experiments would utilize existing equipment at LBL to measure soot particles outside the immediate flame region from bench scale fires. Both studies would utilize the knowledge, skills and experimental facilities of noted aerosol researchers.

Task 5. Atmospheric Modeling

For several years, the Laboratory has had a version of the Oregon State University General Circulation Model (OSU GCM) available for climate calculations. Initially it was used in CO_2 related studies. It is currently being used to advantage on global effects research.

The OSU GCM has a lengthy history beginning with the work of Mintz and Arakawa at UCLA in the early sixties. Lawrence Gates and Michael Schlesinger brought the model to Oregon when they left Rand to join the Department of Atmospheric Sciences at OSU in 1976. Gates, a consultant to LLNL, has worked with LLNL researchers on numerous modeling problems. The OSU GCM has horizontal zoning of 4^{o} of latitude by 5^{o} of longitude (about 440 km by 550 km at the equator). It has only two atmospheric levels for the troposphere compared to, for example, the nine levels in the NCAR GCM. However, the model has been well "tuned" over the years and gives a good representation of the global climate. Other than the limited vertical resolution, the model is of similar sophistication in its parameterizations to other major GCMs.

A new radiation package, developed primarily by Prof. Robert Cess of SUNY, Stony Brook, and a consultant to the Laboratory, has been incorporated into the model. The radiation treatment utilizes the delta-Eddington approximation for radiation transport and permits treatment of the optical effects of smoke, dust, and water vapor.

Covey, Schneider, and Thompson [Nature, 308 21-25, (1984)] have used the NCAR GCM to investigate the three dimensional climatic effects of a heavy fixed smoke layer (optical depth τ = 3) over the northern hemisphere for July conditions. Gerry Potter, Cess and Gates have repeated this calculation with identical assumptions on the OSU GCM and obtained essentially the same results for surface temperatures and circulation patterns. They have also done the calculation incorporating the diurnal cycle. All other GCM calculations of nuclear winter have assumed a fixed average solar inclination. For τ = 3, calculations taking account of the diurnal cycle predict about 25% more solar radiation transmitted than calculations with a fixed sun. At smaller optical depth, the effect is even greater.

John Walton and Mike MacCracken are coupling the Grantour particle transport code to the OSU GCM in an interactive manner. This will permit injection of smoke in target areas and then following it as it is transported and scavenged by the calculated winds and precipitation--which are in turn strongly influenced by the radiative perturbation of the smoke. Initial results from this more realistic coupled interactive smoke model were reported at Erice in August and will be discussed next quarter.

The Community Climate Model (CCM) of NCAR is now resident at LLNL. Charles O'Connor, formerly of B-Division, has got the code running test cases, although it is not yet well adapted to the LLNL computer system, graphics, etc.

MacCracken has modified the one-dimensional radiation and convection code, ZRAD, to include Cess' solar radiation package and it is being tested. Bob Ellingson, a consultant from the University of Maryland, has run an IR reference case using his detailed long wave radiation model. Ellingson's results will be used to check and normalize as necessary the simpler IR treatment in ZRAD.

Task 6. Biological Effects

June 11 through 14 LLNL sponsored a workshop on research needed to assess the biological and ecological effects of climate change induced by dust and smoke from burning cities following a nuclear exchange. This workshop was set in motion in January by a suggestion by H. A. Mooney of Stanford University that the discussion in the ecological literature up to now has been rather primitive and filled with uncertainty, that it was time to move the discussion to a higher level, and that we should proceed by convening a workshop to discuss current knowledge, ecological modeling assessments, and recommendations for new research. To implement this suggestion, a group of experts was assembled in the areas of tropical forest ecology, temperate forest ecology, plant phenology, cold tolerance, plant reproduction, plant physiology, agronomic systems, biometeorology, physiological ecology, animal cold tolerance, paleobotany, systems ecology, plant physiology modeling, biophysical modeling of animals, community modeling, ecosystem modeling, risk assessment, theoretical ecology, environmental assessment, computer science, and large-scale modeling.

The workshop goals were to:

- decide what questions were pertinent to the problem of ecological effects of "nuclear winter"; to specify scientific issues that need to be resolved or what scientific questions can be answered; discuss what we would like to be able to predict about biological and ecological effects.

- outline what is already in existence in the literature that can be applied directly to the problem; discuss what is already known that is applicable if reinterpreted in this new context.

- develop and plan additional research to cover those areas in which our knowledge is weak or non existent; suggest the best approaches to design new research to examine ecological effects.

- suggest how our models may be improved and what experiments are necessary to verify new models; make recommendations on integrating modeling with the experimental program.

- prioritize the suggestions for additional research; identify the most important areas.

- determine how our knowledge and models could be used to assess impacts of climatic change and suggest what scientific assessments should be attempted.

The workshop was divided into two sessions: one devoted to experimental research (June 11-12) and one devoted to ecological modeling (June 13-14). Workshop speakers made formal presentations on their topic areas on the first day of each session. The second day of each session was devoted to working groups and writing recommendations.

Mike MacCracken addressed each of the workshop sessions giving an overview of the "Status of Atmospheric Calculations on Nuclear Winter." Much consideration was given to the fact that the atmospheric physics calculations are in a state of flux and that many of the parameters having to do with smoke production and lofting from burning cities are very uncertain. There was discussion of the fact that the climate inputs to biological studies and assessments are still uncertain. The research program must be designed to accommodate the uncertainty.

According to Jim Kercher, the principal organizer of the workshop for LLNL, "It seemed that the biologists spoke with a clear and unanimous voice that the climatic environments being discussed (low light and temperature regimes) are outside the range of research experience and that there are definite, necessary experiments needed to determine biological responses. The physiological response of organisms could be guessed at in generalities but their exact nature is currently unknown." A report on the workshop is in preparation and will be published as an LLNL document. It will be a general research plan making concrete recommendations for future research. The purpose of the document is to stimulate discussion within the scientific community and to make the framework of a research program available to the federal government for planning. The report will be available late this year.

3. Meetings

Laboratory personnel from the Global Effects Project have participated in a number of important national and international meetings on global effects research during this period.

The Defense Nuclear Agency held a meeting on Global Effects on April 19, 1984, to bring together research participants from around the country and help DNA develop an ongoing research program. Joe Knox, Joyce Penner, and Bob Perret attended and described LLNL's work.

George Keyworth, the President's Science Advisor, has asked Dr. Alan Hecht, Director of the National Climate Program Office (associated with NOAA in the Dept. of Commerce) to develop a National Plan of Nuclear Winter research. A first meeting was held in Washington May 7 and 8, 1984. Representatives from appropriate government agencies, from national laboratories and universities participated. Michael May attended as principal Department of Energy representative. He was accompanied by Mike MacCracken and by Bob Malone of Los Alamos. A first draft plan was circulated May 25 and LLNL has commented on it in detail. The goal is to have a national plan covering five years of research and utilizing the talents of all appropriate researchers. It is to be completed in September or October.

The Defense Science Board which advises the Secretary of Defense has established a small "task force" on Atmospheric Obscuration (nuclear winter) chaired by Prof. Hal Lewis. They had an initial meeting on May 1 and Mike MacCracken and Joe Knox made presentations.

On April 20, 1984, Mike May gave a talk on "Possible Climatic Effects of Nuclear War" to the California Seminar on International Security and Foreign Policy in Los Angeles.

The Scientific Committee on Problems of the Environment of the International Council of Scientific Unions (SCOPE/ICSU) has undertaken a review of the Environmental Consequences of Nuclear War (which finally gets reduced to one acronym, SCOPE-ENUWAR). As a practical matter SCOPE-ENUWAR has concentrated on information exchange meetings on global climatic effects.

They have convened meetings in Stockholm, New Delhi, London, and Leningrad. Representatives from LLNL have participated in the London and Leningrad meetings.

Sang-Wook Kang attended the London meeting. The workshop was devoted to discussions of fires from a nuclear exchange. It was held at the Royal Society on April 16 and 17, 1984. There were about twenty participants, three from the U.S. A number of useful papers were presented and key uncertainties in our knowledge of fire and smoke production were identified. Papers from the meeting are available from Kang.

Chuck Leith was invited to attend the May 13-18 SCOPE-ENUWAR workshop on "Climatic conseqences and their influence on the biosphere" in Leningrad. There were some 46 participants with 27 from the USSR and eight from the U.S. A number of interesting papers were presented of which the most significant was one by Prof. William Cotton of Colorado State University on "An exploratory simulation of the convective response to firestorms initiated by nuclear warfare." Copies of many of the papers presented are available from Chuck Leith.

SCOPE-ENUWAR plans to publish a book in 1985 based on information developed in this ongoing series of meetings. They aspire to keeping to the facts and not the politics. SCOPE-ENUWAR does not have resources to sponsor research but their expressions of concern on important research issues are apparently useful in generating national support for research especially in Europe.

From May 26 to June 15 Michael May visited in England and the Soviet Union and among other business had talks on global effects issues. At AWRE Aldermaston on May 30 he gave a talk on global effects of nuclear war. In Moscow, May met with E. Velikhov, Vice President of the Academy of Sciences. They discussed global effects, possible cooperative research and the August visit of LLNL scientists to Moscow prior to attending the Erice, Sicily conference. June 11-13, he attended the United Nations Regional Conference for the World Disarmament Campaign in Leningrad. May presented an invited paper to the Conference entitled "Brief Comments on Possible Climatic Effects of Large Scale Fires." Copies of his trip report and papers are available from his office.

4. <u>Visitors</u>

During this report period a number of specialists have been invited to LLNL to present talks on topics of importance to Global Effects research and to have extended informal discussions. The following is a list of the visitors and includes the subject of their seminar.

- o Steve Krueger of UCLA on April 23. "Turbulence Modeling and Plume Rise."

- Dr. Larry Radke of the University of Washington on April 25. "Aerosol Characteristics of Large Fires."

- Dr. Frank Murray of the Rand Corporation on April 26. "The Modeling of Wet Deposition of Aerosols with a Dynamic Cloud Model."

- Mr. Glen Rawson, Consultant on May 4. "Nuclear Dust."

- Desert Research Institute personnel on May 24-25. (John Hallet, Richard Pitter, Barry Gardiner, James Hudson, Fred Rogers, and Dennis Lamb) "Cloud Physics Problems in the Nuclear Winter Scenarios" (a series of presentations).

- Dr. Yen-Huei Lee of NCAR on June 1. "On the Structure and Maintenance of Standing Eddies in the NCAR Community Climate Model and the GLAS Climate Model."

- Steven J. Ghan of MIT on June 15. "Latent Heating and Quasi-Stationary Waves in the Atmosphere."