GLOBAL EFFECTS OF NUCLEAR WAR
STUDY PROJECT;
1ST QUARTERLY REPORT;
January - March, 1984

LAWRENCE LIVERMORE LABORATORY

GLOBAL EFFECTS OF NUCLEAR WAR STUDY PROJECT

FIRST QUARTERLY REPORT
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Compiled and Written
by G. F. Bing
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An Equal Opportunity Employer University of California P O Box 808 Livermore, California 94550 Telephone (415) 422-1100 Twx 910-386-8339 UCLLL LVMR

Building 111, L-19, Ext. 2-4317
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Introduction

In November 1983, the Director of LLNL established a project to investigate certain potentially very significant global climatic effects of nuclear war, in particular those effects driven by the worldwide pall of smoke expected from the many fires that would be started. The prediction of climatic effects involves numerous uncertain factors and the LLNL project is aimed at narrowing the key uncertainties. The project, directed by Dr. Michael May, is supported from Laboratory resources and is expected to last at least two years. The present project was preceeded in 1983 by a smaller LLNL study of the newly predicted effects. That study concluded the effects could not be dismissed and deserved further research at LLNL.

This first quarterly report is comprised of: 1) A brief background account of earlier global effects research at LLNL and elsewhere; 2) Recent (1980-1983) developments and LLNL's role; 3) An outline of the current project tasks; and, 4) Brief summaries of the work underway at LLNL in the January to March 1984 period.

1. Worldwide Effects: 1945-1980

Perhaps a definition or two is in order at this point. The worldwide or global effects of nuclear war of particular interest and concern are those "collateral" physical effects of war that extend far beyond the target areas and that are known or conjectured to be harmful to people and other life. They include global fallout, stratospheric dust and NO_x injections and the possible climatic effects and ozone disruptions associated with them, and the current concern, smoke and its climatic impact. Other worldwide effects of explosions such as seismic, acoustic, and electromagentic signals are interesting but not harmful.

Even before Trinity people worried about possible unintended consequences of atomic explosions including those that might be global. One of Edward Teller's jobs at Los Alamos was to try to identify and evaluate such possibilities. In 1946 Konopinski, Marvin, and Teller published a secret report, since declassified, dealing with one possible catastrophe and entitled "Ignition of the Atmosphere with Nuclear Bombs." They analyzed the possibility that a large fission or fusion explosion would start a self-sustained fusion burn of all the atmospheric nitrogen. They concluded it could not happen, probably.

The Trinity event provided the first experience with radioactive fallout both close-in and at substantial distances. Evidence of fallout more than 1100 miles from the test site was found from fogged x-ray film packed in contaminated paper. The first Russian test in August 1949 took place near the Caspian Sea and was detected off Kamchatka 4500 miles away. The radioactivity was subsequently measured in North America and Europe. Radiation levels at distant points from such events were very low and did not appear to pose any public hazard. The Bravo shot in 1954, with a 15 megaton yield and the second U.S. thermonuclear test, did pose a health hazard and did lead to substantial public and official concern. The health hazard was to some Japanese fishermen who had ignored danger warnings and to the Rongelap Island residents who had not been evacuated because of a faulty fallout prediction. This was, of course, close-in fallout rather than global but these events did make "fallout" a public issue and concern.

Because of the 100 to 1000 fold increase of yield of thermonuclear explosions relative to fission tests the amount of radioactivity per test was proportionally increased. Some of that radioactivity was injected into the stratosphere where it remained for long periods, spreading over the entire globe. Eventually that material which had not already radioactively decayed was deposited on the surface as global fallout. Radiation rates from global fallout were low compared to natural radiation background levels and clearly posed only a small incremental health hazard to people around the world. However, there was substantial uncertainty among the professionals and the public about the somatic (primarily cancer) and the genetic effects of radiation. That uncertainty supported continued public concern. Though the fallout hazard from testing was small, the consequences of local, intermediate range and global fallout in a multi-megaton nuclear war could be significant for people away from the intended target areas.

In the mid-1950's the AEC substantially increased its support of research on fallout and on the biological effects of radiation. LLNL has had some modest involvement in this research over the years. It is interesting that even today, more than thirty years of research later, estimates by various experts of the consequences of worldwide fallout in a nuclear war can differ by more than a factor of ten.

In the early 1970's another global effect of nuclear explosions was identified. About 5000 tons of oxides of nitrogen are produced for each megaton of yield. For large explosions, some of the NO_x is injected into the stratosphere and eventually spreads globally. There it catalyzes reactions that reduce the ozone density. In a nuclear war (with perhaps thousands of megatons exploded) ozone levels could decrease by more than 50 percent. As a consequence the ultraviolet light intensities at the surface would be much increased for more than a year with uncertain biological and ecological effects.

Because of concern about ozone and other effects, the Director of the Arms Control and Disarmament Agency in 1974, asked the National Academy of Sciences to analyze the "Long-Term Worldwide Effects of Multiple Nuclear-Weapons

Detonations" (the title of the Academy's 1975 report). The Academy study assumed a 10,000 megaton war with the injection of radioactivity, dust and NO_x into the atmosphere including the stratosphere. Global fallout and ozone depletion were estimated and the effects of fallout radiation and ultraviolet light on managed and natural ecosystems, on aquatic life and on people were estimated. Some estimates were also made of possible climatic effects of dust, NO_x and the ozone depletion. The final report concluded that the most significant and the only potentially catastrophic effects were those resulting from the ozone depletion. Substantial uncertainties remained and further research was recommended especially on ecological consequences.

Three LLNL scientists--Julius Chang, Mike MacCracken, and Florence Harrison--were important participants in the Academy study. Even before the Academy report, the Laboratory expanded work on worldwide effects with principal concentration on ozone problems. This effort, the "STRAW" program, continued at the few-FTE level until about two years ago. The Laboratory provided updated ozone calculations for the most recent Academy review of worldwide effects.

The 1975 Academy report was the first ever attempt to quantify all the then known or conjectured long-term global effects of nuclear war. It is still a valuable study and the point of departure for subsequent analyses.

A 1979 study by the Congressional Office of Technology Assessment entitled "The Effects of Nuclear War" did point out one new consideration for ozone depletion estimates. The 1975 Academy study had assumed weapon yields of one to twenty megatons thus assuring large injections to the stratosphere. The OTA report points out that far fewer high yield, greater than 1 Mt, explosions would occur because of the move toward lower yields for MIRV missiles. This would, in OTA's estimation, greatly reduce the stratospheric injection relative to the 1975 estimates.

2. Worldwide Effects: 1980-1983

In the late seventies and in 1980 and 1981 research activity on the global effects of nuclear war was low at LLNL and elsewhere and consisted mostly of tidying up ozone depletion calculations. There were a few new developments. In the 6 June 1980 Science, Alvarez et al. published their paper, "Extraterrestrial Cause for the Cretaceous-Tertiary Extinction" (what did the dinosaurs in?). They postulated that an asteroid impact put so much dust into the atmosphere that there was great darkness and no photosynthesis for long enough to explain the extinctions.

In June 1982, Pollack, Toon, Ackerman, and McKay of NASA Ames and Turco of RDA submitted a paper to Science (published in January 1983) describing their calculations of the temperature drop expected, 40°C over land, from the postulated dust cloud. These calculations were very similar to those they subsequently did for smoke effects from nuclear war. Another consequence of the Alvarez paper was the stimulation of the National Academy to revisit the questions of the effects of dust in the atmosphere following a nuclear war. The Academy, supported by DNA, planned a study of dust effects. This ultimately was expanded to include smoke effects.

In Sept. 1981, an article by John Gribbin in New Scientist quoted unpublished work of the Russian scientists Kondratyev and Nikolsky concerning the climatic impact of NO_2 injection into the stratosphere in a nuclear war. The Russians claimed that stratospheric NO_2 levels from nuclear testing, inferred from balloon and satellite measurements of radiation attenuation, had influenced the global temperature, decreasing it by about 0.5°C, and that scaling to the cumulative yield of a nuclear war suggested a global average temperature drop of 5 to 10°C for an extended time. Kondratyev and Nikolsky have never published the work that supports this prediction so that it is difficult to analyze its basis. Such a temperature drop would "---bring about disastrous consequences for man's economic activity" in their words.

Fred Luther has analyzed the limited information provided by Gribbin and an earlier paper by the Russians and concludes that the 5 to 10°C estimate is a factor of several too high, because they overestimated solar absorption by NO_2 and they assumed an equilibrium rather than transient temperature perturbation would result. On the other hand even a 1 or 2°C drop in global temperature of sufficient duration could have significant, if not catastrophic, biological effects comparable in magnitude but in the opposite direction to the predicted temperature rise from doubling atmospheric CO_2.

In 1981, the editors of Ambio, a journal published by the Swedish Academy of Sciences and generally dealing with environmental topics, decided to devote an entire issue to the consequences of a nuclear war. Prof. Paul Crutzen, Director of the Air Chemistry Division of the Max Planck Institute for Chemistry in Mainz, Germany, was asked to write a chapter reviewing what was known of the effects of bomb produced NO_x on ozone in the stratosphere and troposphere. John Birks of the University of Colorado, on sabbatical in Germany, joined Crutzen in the review.

Late in the course of this review which had to be submitted in February 1982 to Ambio for publication in June, Crutzen and Birks "discovered fire and smoke." Recognizing that the presence of large amounts of smoke might influence atmospheric chemistry by limiting photochemical reactions, they made some rough quantitative estimates of the extent of fires that would be started and the amount of smoke that would be injected into the atmosphere in a nuclear war. They concluded that forest and grass fires, urban and industrial fires, and burning of gas and oil-wells could generate more than 10^{14} grams of sooty smoke. This amount of smoke, when spread over wide areas, perhaps the northern hemisphere, would be sufficient to essentially cut off sunlight at the surface for some time. They also estimated that release of nitrogen as NO_x from the combustible material would more than equal the NO_x produced in the fireballs and possibly have important chemistry effects in the troposphere (e.g., increasing photochemical smog). Crutzen and Birks express their surprise that the possible effects of smoke from a nuclear war had been, for all practical purposes, overlooked in all earlier appraisals of the global effects of nuclear war.

The Ambio report was published in June 1982 and Crutzen and Birks' work soon became widely known. In fact, preprints of their article were circulated somewhat earlier and stimulated important additional research. Crutzen and

Birks did not explicitly estimate the climatic impact of the attenuation of sunlight by the atmospheric smoke though they anticipated the basic effects including a stable temperature distribution, reduced rainfall and less particle scavenging than in the normal atmosphere.

Turco, Toon, Ackerman, Pollack, and Sagan (they suggest the acronym TTAPS) undertook to analyze the climatic effects of the smoke using the same calculational tools they had used to study the asteroid-generated dust and, earlier, planetary atmospheres. They began their analysis in the spring of 1982 culminating in a lengthy draft report in March 1983. Their study addressed numerous other global effects, including fallout, ozone, and possible toxic combustion products, but their major contribution was to analyze systematically the sequence: war scenario, fire ignition, smoke production, injection, global spreading, and finally, the absorption of sunlight in the upper atmosphere and the resultant cooling of the earth.

TTAPS did their analysis for several war scenarios and with some variation of key parameters. At almost every step in their chain of analysis they were obliged to make assumptions about critical parameters and phenomena such as: how cities burn, how much smoke is produced, where does it go in the atmosphere, what are its optical properties and on and on. In addition, their calculations involved a one-dimensional climate model "tuned" to reproduce the global average climate of the normal atmosphere but almost certainly suspect for treating a highly perturbed situation. These limitations of their analysis should not detract from the credit they deserve. They do serve to suggest the many uncertainties still to be addressed in further research.

The draft TTAPS report was widely distributed and has influenced numerous other workers to get involved in global effects research and issues. The report provided the basis for an assessment of the biological consequences of nuclear war at an April meeting in Cambridge. On Oct. 31 and Nov. 1, 1983, a public meeting with presentations by Carl Sagan and Paul Ehrlich was held in Washington, D.C., to publicize the physical and biological consequences and to suggest the policy issues. The study of Turco, et al., and a companion article on biological effects by Paul Ehrlich and nineteen other authors were published in Science for 23 Dec. 1983. The TTAPS paper was given the short title, "Nuclear Winter" (quite different from the title of the draft report). Through these activities, the general public, the scientific community, and governments were well introduced to the problem.

In the Spring of 1982 the National Academy of Sciences on behalf of the Defense Nuclear Agency planned a reassessment of the long-term consequences of nuclear war. Concern about dust issues stimulated by the asteroid impact and dinosaur extinction theory seems to have been a principal reason for the proposed study. Only when Crutzen and Birks' work on fire and smoke became known, also in the Spring of 1982, was that topic added to the list of effects to be evaluated. In early 1983, the National Research Council of the Academy did establish a Committee on the Atmospheric Effects of Nuclear Explosions under the chairmanship of George Carrier of Harvard. That Committee more or less independently (Birks, Toon, and Turco are members) reviewed the global effects, particularly those of smoke, and produced a draft report in Dec. 1983. The draft was somewhat controversial and the eventual form and release date of the report are uncertain.

Other significant activities on global effects in 1983 include: an international conference in August at Erice in Sicily with a public session devoted to the topic (and with major LLNL contributions); a special session at the December meeting in San Francisco of the American Geophysical Union devoted to papers on global effects (also with Livermore contributions); a decision by the International Council of Scientific Unions to have its Scientific Committee on Problems of the Environment convene a series of technical meetings on the consequences of nuclear war to include climatic effects. (A first meeting was held in Stockholm in November. Additional meetings will occur in New Delhi, London, Leningrad, and Paris in 1984.) In addition, individuals and small groups of scientists at various institutions including the National Center for Atmospheric Research, NASA Ames, Los Alamos, and Livermore have started to work on the key global effects problem areas which have the greatest uncertainties.

It is interesting to sketch LLNL's developing interest in and research commitment to global climatic effects. During 1982 and 1983, a Long-Range Planning Committee (L-RPC) established by the Director of LLNL was considering possible new technical programs for the Laboratory. One topic proposed for research was climatic modeling particularly addressed to the CO_2 problem. In February, 1982, Mike MacCracken gave a talk on CO_2 to the L-RPC and more or less as a footnote expressed his opinion that if the Laboratory wanted to be more involved in atmospheric modeling, then analysis of the atmospheric and climatic effects of nuclear war might be a more appropriate path, considering our experience and present expertise, than CO_2 research. At that point in time, no one at LLNL appears to have been familiar with Crutzen and Birks' observations. MacCracken did mention the claims of Kondratyev and Nikolsky of the climatic impact of large injections of NO_x.

In July, 1982, at Bill Shuler's request, Joe Knox gave a briefing to a number of people on the "World Wide Effects of Nuclear War." Knox discussed ozone depletion and the effects of increased UV, climatic effects of NO_x and of dust, fallout radiation doses, and the Ambio article of Crutzen and Birks. For many of the listeners this was the first they had heard of the smoke problem. Knox provided copies of the Ambio article, The Atmosphere after a Nuclear War: Twilight at Noon. He briefly noted the smoke production Crutzen and Birks estimated and the possible consequences including extreme light attenuation. He also pointed out some important matters neglected or discussed only slightly by them having to do with scavenging (washing out) the smoke particles. He suggested the predictions of Crutzen and Birks deserved further analysis at LLNL.

Shortly after Knox's talk, Bruce Tarter was charged by John Anderson with further reviewing for the Physics Department the technical issues of the worldwide effects of nuclear war and of proposing a range of possible research programs for the Laboratory. In November 1982 he circulated a memorandum summarizing the issues and proposing three research options. He also briefed the L-RPC on his findings. In addition to the long standing problems of global fallout, dust loading, and ozone depletion, the fire and smoke observations of Crutzen and Birks were highlighted. At this time the full climatic impact of large amounts of smoke, very large temperature drops over continental areas ("nuclear winter"), was not recognized at the Laboratory.

Tarter's three research options, A, B, and C, were as follows. Option A was a continuation of about the existing level of effort on global effects related problems, about $0.5 million/year, with some redirection of effort to newer problems. Option B would increase the effort to about $1.0 million per year for several years and substantially expand the Laboratory's assessment capability by acquiring three dimensional global climate models and other tools. Option C was an even larger commitment to a long-term program in climate research and environmental effects at the several million per year level for five to ten years. There was a general reaction by the L-RPC and others that Option B was the desirable and attainable program level.

In January 1983, Tarter's study was presented to the Director and Associate Directors at an L-RPC briefing. The L-RPC recommended that the Laboratory continue its existing effort, essentially Option A, and seek resources for Option B as soon as possible. Reactions were mixed and after some further discussion beyond the briefing it was decided that there should be a detailed and intensive short term review of critical physics issues before establishing a broader Laboratory program. Tarter was charged with developing the study outline and identifying participants.

The outline was prepared and agreed to and the study got underway in March under the directon of Tarter and Mike MacCracken. Resources were provided by the L-RPC, Physics, Nuclear Design and Military Applications. Altogether eighteen people from D, G, and T Divisions, participated in the study.

Early on, other groups around the country working on global problems were identified. This included the NASA Ames and RDA group of Turco, Toon, Ackerman, Pollack and Sagan mentioned earlier. Turco et al. circulated a draft report of their work in March 1983 and a copy was availble at LLNL in late April. The TTAPS report strongly influenced the work of the LLNL study group. Their predictions of very low light levels in the northern hemisphere causing long-lasting temperature drops of 40°C over continents had not been made previously.

Recognizing the many necessary assumptions and uncertainties in the work of Turco et al, the LLNL study effort now concentrated on independently assessing the NASA/RDA assumptions and results and, where possible, improving the calculations. The results of the LLNL review were summarized in an August 15, 1983 report "LLNL Study of the Global-Scale Physical Effects of a Nuclear Exchange: Preliminary Findings" (Internal Report UCIR 1523). The LLNL study qualitatively confirmed the conclusions of the NASA/RDA group and identified key assumptions and uncertainties and further work considered necessary.

Four members of the study group were invited to present papers on global effects at the Third International Conference on Nuclear War held in Erice, Sicily, August 19-23. Their papers, to be published in conference proceedings and available as UCRL preprints, give detailed results of some of the LLNL study effort. The papers were: Nuclear War: Preliminary Estimates of the Climatic Effects of a Nuclear War by Mike MacCracken; Global Scale Deposition of Radioactivity from a Large Scale Exchange by Joe Knox; Nuclear War: Short Term Chemical and Radiative Effects of Stratospheric Injections by Fred Luther; and Tropospheric Response to a Nuclear Exchange by Joyce Penner. These authors also presented invited papers on similar material at the December meeting in San Francisco of the American Geophysical Union. By the Fall of 1983, LLNL was a major participant in and contributor to research on the new problems of global effects.

In November 1983, LLNL management decided, based on the work and recommendations of the study group and the heightened government and public concern about the worldwide effects of nuclear war, to establish a continuing research program. At least initially the focus of the program is primarily on the fire-smoke-climate change problem since it is the most poorly known, and a potentially disastrous global effect of nuclear war.

3. The LLNL Program

The LLNL research program on the global effects of nuclear war has been 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 first quarter of 1984.

4. LLNL Work for January-March 1984.

This has been a period of expansion of the Laboratory effort on global effects, bringing people into the effort not previously involved, identifying and acquiring new calculational tools from outside LLNL, and gathering data on subjects like fire and smoke which are somewhat new to LLNL. Thus there is a certain amount of "getting organized" in the following summaries of work.

Task 1. Nuclear War Scenarios and Target Characteristics

Since mid-January Bob Perret has been working with Colonel Richard Walker, head of the Strategic Warfare Division in the Nuclear Assessment Directorate of DNA to develop several nuclear war scenarios as basic input to the global effects research. Their objective is to provide completely unclassified scenarios that still capture the essentials, from an effects perspective, of U.S. and Soviet capabilities and targeting doctrine. Major Richard Whittles, an Air Force officer with Field Command DNA, has been assigned to the Laboratory and will work in D Division with Perret. He has previously been assigned to the JSTPS in Omaha. He will spend about half-time working on the development of scenarios.

Perret has had discussions with Dave Simonett, Dean of the Graduate Division and a Professor of Geography at U.C. Santa Barbara, on work toward characterizing the fire potential of typical urban targets. Prof. Simonett has a remote sensing Laboratory and proposes to use his facilities to investigate the distribution of building types of several representative American cities using aerial photographs. From the data obtained, it should be possible to quantify the fire potential of cities better. Perret expects to arrange a small contract to accomplish this work this summer using student help.

In addition to the above activities Perret has drafted, in consultation with other LLNL task leaders, a proposal to DNA for additional support of LLNL research. Perret has been designated as the primary LLNL person responsible for discussing DNA contractual support of this work at LLNL.

Task 2. Fire Ignition, Spread, and Plume Rise

Depending on weapon yield, atmospheric conditions, and the combustible character of the target, a megatonish nuclear explosion can be expected to ignite multiple fires to ten kilometers or more. The blast wave that arrives after the thermal pulse may quench some fires and will certainly break up the "kindling." There is very little experience with the course of fires ignited over such broad areas (Hiroshima, Nagasaki and a few WWII incendiary attacks are the data base), so that it is necessary to rely on computer models to estimate how large fires develop and spread.

Several such computer models were developed some years ago for Civil Defense studies. The best of them appears to be one developed by the Illinois Institute of Technology Research Institute, IITRI. The code had already been transferred to Livermore for a FEMA program but had not been utilized. The IITRI code has now been used successfully by Sang-Wook Kang and Tom Reitter, both of Nuclear Systems Safety Program, to run several test problems on fire ignition and spread. Kang and Reitter have been modifying and generally improving the code to make it more versatile. They are obtaining data on combustible structure distributions for several U.S. cities (from Civil Defense studies done some years ago) so they can do more realistic test calculations. Ultimately the fire ignition and spread code will be used, with input from Task 1 on scenarios and target characteristics, to estimate how typical urban targets would burn, how much fuel would be consumed and how rapidly. It should provide a basis for predicting how much smoke and other products would be produced in the immediate vicinity of the fire.

Air heated by an extended fire rises convectively carrying with it, in the plume, smoke and other entrained material such as ash and dust. Just where this particulate material is carried depends on the area of the fire and its intensity, the turbulence in the flow and the entrainment of unheated air, the conditions of temperature and humidity in the ambient atmosphere, and the local wind fields. In general, the larger and more intense the fire, the higher the plume (and smoke) will rise. The higher in the troposphere the smoke is injected, the more persistent it will be and the more effect it is expected to have on surface temperatures. Very intense fires, firestorms, may even inject material into the stratosphere. As with fire ignition and spread, relevant experience is limited and one must rely heavily on computer modeling of plume rise.

Len Haselman of B Division had developed a two-dimensional combustion code, called TDC, primarily for studies of flow in internal combustion engines. Fortunately TDC is of sufficient generality that, with modifications to include effects of water vapor condensation and microphysics, it should be able to be used to investigate plume rise phenomena. The code is two dimensional so it can treat line ("slab") or axially symmetric representations of fires.

Test problems run thus far by Haselman have given plausible results with plume height increasing with fire intensity. The output of the code includes the velocity fields of the flow and the mass distribution of tracer material, smoke. Haselman intends to do further test problems at different fire intensities, to include water vapor and condensation effects, to modify the turbulence model, and to utilize a three-dimensional version of the code, called COM3, which, though very expensive in computer time, will permit some investigation of the effect of asymmetry and wind shear on plume rise.

A number of elaborate computer models exist outside LLNL for studying cloud phenomena. Charles Molenkamp in G Division is exploring the availability and utility of such models for application to the fire plume problem. Cloud models necessarily incorporate water vapor, condensation and precipitation physics and may help in investigating questions about scavenging and rainout of smoke in fire plumes.

Steve Sutton, of Nuclear Systems Safety Program, is modifying another existing code, MINT, for possible application to plume rise calculations. MINT is a three-dimensional, compressible and implicit hydrodynamics code, developed outside the Laboratory, which has been used for calculating the flow of liquid fuels. By adding an energy input boundary condition to represent fires, it should be applicable to plume problems. Because the calculations are implicit, it is possible that the code may be faster for a given problem than explicit codes such as TDC. The necessary modifications are in progress.

Task 3 Microphysics and Chemistry

The simplest picture of the injection of smoke and other particulates into the atmosphere assumes the aerosols generated in and near the fire are chemically and physically inert, are carried to altitude in the convection plume and then spread by the winds and turbulent diffusion over broad areas. A more accurate picture takes account of the fact that numerous physical and chemical processes can take place that will strongly influence just how much smoke and other aerosols are actually injected into the atmosphere, what their properties are, and how long they persist.

Task 3 deals with these important microphysical and chemical processes. They include: sedimentation of larger particles; coagulation mediated primarily by Brownian agitation; important chemical changes to the aerosols; condensation of water vapor, precipitation scavenging, etc. The goal of this research is to characterize the aerosols which are injected as to total quantity, size distribution, and chemical composition and to quantify the processes which eventually scavenge the aerosols from the atmosphere.

Chuck Molenkamp has done a review of key microphysical processes especially those at early times in the plume and given an "educational" talk to the global effects group on this topic.

Bill Porch of G Division has acquired a coagulation code developed about ten years ago by I. H. Blifford of NCAR, J. W. Burgermeir of the Univ. of Vermont and C. E. Junge of the Max Planck Institute of Chemistry. Their report entitled "Modification of Aerosol Size Distributions in the Troposphere" (NCAR-TN/STR-98, Aug. 1974) describes the code. This code only deals with "out-of-cloud" coagulation processes so water vapor condensation and raindrop impact effects are not included. Porch expects to use this code to develop scavenging parameters for incorporation into the GRANTOUR global particle transport model of Walton and MacCracken.

Peter Connell in G Division has a "smog" code which treats a one-dimensional vertical slice of the atmosphere and models the chemical processes which take place. He is incorporating the gaseous emissions expected from large fires to permit calculations of their attachment and influence, if any, on the smoke aerosols. Connell and Penner used this code earlier to look at the fire-driven tropospheric smog and ozone production predicted by Crutzen and Birks. They believe those predictions are too high (see UCRL 89956 by Penner) because of certain assumptions made.

Task 4. Optical Properties of Injectants

Once a given quantity of aerosols, smoke and dust is dispersed, it is the optical properties of the particles that will determine radiation budgets and in turn the climatic effects. The scattering and absorption properties of aerosols are determined by their chemical composition, the particle size distribution and to a degree by particle shape. The amount and character of injectants are to be estimated under Tasks 2 and 3. The goal of Task 4 is to calculate or measure the optical properties at visible and infrared wavelengths of representative injectants for incorporation in radiation calculations in atmospheric models. Thus far the LLNL effort on this task has been calculational.

Fred Luther of G Division has been the principal researcher and he has written four review papers on optical properties of small particles. In January, Edward Teller suggested the possibility of counter-measures to the smoke-produced nuclear winter. He conjectured that injection of infrared absorbing material in sufficient quantity above the smoke might give a greenhouse effect and modify the expected cooling. To explore this idea, Luther investigated possible materials with the required properties. He reported on this work in three internal reports: "Infrared Absorption by Small Particles" (UASG 84-3, Jan. 1984); "Particles with Strong IR Absorption," (UASG 84-4, Feb. 1984); and "Infrared Absorption by Metal Spheres of Arbitrary Size," (UASG 84-8, March 1984). Though these reports address a particular application, they are generally good reviews of theoretical optical properties of aerosols. A fourth paper concerned with optical properties in the visible has just been distributed. It is entitled "Effects of Particle Size and Index of Refraction on Solar Radiative Properties" (UASG 84-10, April 1984). All reports are available from Luther.

Task 5. Atmospheric Modeling

The initial estimates by Turco et al. of climatic effects from widespread smoke were based on calculations with a one-dimensional model of atmospheric behavior which, by its nature, could not capture many very significant aspects of global atmospheric processes. The limitations of the simple atmospheric model, together with numerous necessary assumptions on war scenarios, fire phenomena, smoke properties, smoke injection and spread, etc., etc., leave many open quantitative questions which are only addressable by more sophisticated calculations. The LLNL task in atmospheric modeling is to look at the open questions, using as good calculational tools as possible, our own and those obtainable elsewhere including one, two, and three dimensional climate models.

For the calculations of Turco, et al., the smoke generated from many discrete sources is assumed spread instantaneously over the hemisphere. Their one-dimensional climate calculations give temperature estimates for the entire hemisphere assuming either a land or ocean surface. There is no quantitative account of the interaction expected between the atmosphere over land and over water when the predicted large temperature gradients are present. The one-dimensional calculations do establish that the atmospheric perturbations from large amounts of smoke are probably large and thus, curiously, suggest that such calculations are inadequate to represent even the average behavior of the actual perturbed global climate. It is generally recognized that satisfactory analysis of these global climate effects requires fully three dimensional calculations.

LLNL does not have in hand a completely satisfactory three dimensional climate model. To remedy this, the Community Climate Model or CCM developed at the National Center for Atmospheric Research, NCAR, is being transferred to Livermore and the necessary personnel to use it are being identified. In the meantime, a small contract with NCAR to obtain help with some desirable additions to the model and to provide for the transfer of these improvements is being arranged.

For any global climate calculation to evaluate smoke effects, it is necessary to determine or make assumptions about the smoke distribution with time. For one-dimensional calculations, smoke is assumed spread uniformly and then scavenged over time. With two and three dimensional climate models, it is possible to consider non-uniform distributions of smoke and how they evolve.

The GRANTOUR Code developed by John Walton and Michael MacCracken of G Division can be used to transport trace materials such as radioactive particles or smoke, based on the windfields determined in a separate climate model. (See UCID 19985. "Preliminary Report on the Global Transport Model GRANTOUR," Jan. 1984.) For the transport of radioactivity, the calculational sequence is straightforward: radioactivity is injected into the atmosphere at discrete points; it is transported by the windfields determined in a climate model; and the radioactivity is deposited on the surface through several mechanisms, including precipitation scavenging which are estimated from the climate calculations. The presence of the radioactivity does not influence the climate calculation in any way. GRANTOUR can thus realistically transport any material present in amounts small enough so that there would be no influence on climate.

In the case of large amounts of smoke, it can no longer be assumed that there is no climatic impact of the transported material. Now a realistic calculation should be interactive alternately transporting material, re-evaluating the climatic conditions and windfields, and then transporting and scavenging again.

GRANTOUR has been used in conjunction with the Oregon State University General Circulation Model (GCM), a three-dimensional climate model with two tropospheric layers which is running at LLNL. The initial version of GRANTOUR is effectively two dimensional using a single horizontal wind field obtained by averaging the windfields from the two tropospheric layers in the GCM. GRANTOUR has been used in its two-dimensional form to investigate the transport of radioactivity in the troposphere and also of smoke in a non-interactive calculation.

GRANTOUR is being modified to be three-dimensional so that it can now use the windfield data from both layers in the Oregon State model and wind sheer effects can be represented. Work is also in progress to permit using GRANTOUR interactively with the Oregon State GCM to transport smoke. When the NCAR Community Climate Model is available at LLNL, GRANTOUR will provide a means to incorporate smoke transport in the model in an interactive manner.

Gerald Potter in G Division is also working on improving the radiation prescription in the Oregon State model to make it more useful for global effects calculations. Fred Luther, in cooperation with Bob Cess, a consultant from Stony Brook, is working with a one-dimensional radiation transport code to develop improved solar radiation routines applicable to all of the available models.

MacCracken and Walton have been using the two-dimensional climate model, ZAM, for global effects calculations. ZAM's two-dimensions are latitude and altitude. Properties are averaged through 360^0 of longitude. A second code, TRANZAM, can transport several materials such as smoke or a gas like CO_2 in the same two-dimensional sense as ZAM. Now they have directly coupled TRANZAM and ZAM to permit interactive calculations. This model does not yet contain microphysics for the particles or gaseous materials. It will be able to permit calculations of the feedback effects of the particulates on radiation calculations.

Because of the necessary coarseness of the calculational grid in global climate models, it may be necessary to do intermediate or "mesoscale" calculations to make the transition from localized fire plumes to global scale. The Laboratory has no functioning mesoscale climate models. Chuck Molenkamp is exploring the availability of such models elsewhere. A particular model developed by Roger Pielke of Colorado State University some ten or more years ago appears to be available and possibly applicable to our needs. A version of the model has been used at LLNL for local scale calculations. It can be run in two or three dimensional versions.

Task 6. Biological Effects

At this time the Laboratory has no specific research underway on the biological and ecological consequences of a "nuclear winter." Lynn Anspaugh and James Kercher of the Environmental Sciences Division have made some rough appraisals of possible research needs and the effort entailed. In cooperation with Prof. Harold Mooney of Stanford, they are planning for two consecutive two-day workshops in June. They have invited a distinguished group of biologists, most of whom have accepted their invitation, to meet and develop a proposed program of biological research and ecological modeling that would address key uncertainties in this area. The workshop results could provide the basis of a national research effort.