NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
Environmental Research Laboratories
Air Resources Laboratory
Atmospheric Turbulence and Diffusion Division (ATDD)
456 South Illinois Avenue
Oak Ridge, Tennessee

History

Atmospheric Turbulence and Diffusion Division

1948 - June 1992

by

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INDEX

Foreword

"...and I tell you, Bear Creek Valley someday will be filled with great buildings and factories, and they will help toward winning the greatest war that ever will be.

"And there will be a city on Black Oak Ridge. The center of authority will be on a spot which is middle way between Sevier Tadlock's farm and Joe Pyatt's place.

"A railroad spur will branch off the main L&N line and run down toward Robertsville, and then it will branch off toward Scarbro. It will serve the great city I saw in my vision.

"Big engines will dig ditches and thousands of people will be running to and fro. They will be building things, and there will be great noise and confusion and the earth will shake.

"I've seen it. It's coming."

John Hendrix (*circa* 1850-1915)[1]

With these words John Hendrix, known locally as the prophet of Oak Ridge, predicted around the turn of the century events that were to take place more than 40 years later. Whether folklore or genuine prophecy, for those who place credence in his words, the prophecy has been fulfilled.

Soon after World War II began, the United States government undertook the development of the world's first nuclear weapon. The project was placed under the direction of the U.S. Army Corps of Engineers; the goal was production of an atomic bomb in three years. For safety and security reasons, the work was carried out in three widely separated geographic locations. In 1942 a secluded valley in eastern Tennessee was selected as the site for the production of U-235; Hanford, Washington, was chosen as the site for production of plutonium, and a physics research laboratory in Los Alamos, New Mexico, was selected for the actual design and construction of bombs, using material from Oak Ridge and Hanford.

The valley in Tennessee encompassed the small communities of Wheat, Scarbro[2], and Robertsville, as well as several thousands of acres of farmland and forests in Roane and Anderson Counties. Beginning in the fall of 1942 the U.S. Government summarily evicted the residents of the entire area. Notices of eviction were curt, often with less than two weeks notice, and certainly without explanation. In a moment of bitterness one resident remarked that "the only difference when the Yankees came before, we could shoot at them."[3]

Code-named the "Manhattan Project" and known locally as the Clinton Engineer Works, Corps of Engineers personnel, big machinery, and thousands upon thousands of military and civilian workers arrived. The "center of authority," the project's headquarters, was located exactly where John Hendrix predicted, i.e., between Sevier Tadlock's farm and Joe Pyatt's place. The Y-12 electromagnetic uranium isotope separation facility was located in Bear Creek Valley; the K-25

gaseous diffusion plant and the X-10 chemical separation plant were located in separate valleys a few miles apart. A railroad line, houses, dormitories, roads, and great buildings were constructed, and a city, soon named Oak Ridge, was built upon the Black Oak Ridge. By the end of 1945, when the Manhattan Project accomplished its mission with the dropping of the first atomic bomb upon Hiroshima in August, well over $1.5 billion had been spent for Oak Ridge building and operations. As John Hendrix foretold, the city built upon Black Oak Ridge helped in ending the greatest war there had ever been.

The end of the war was the beginning of a new era for the city of Oak Ridge. Faced with the problems of dealing with nuclear power and the communities that were created in developing this new technology, in August 1946, the Congress of the United States passed the Atomic Energy Act, and subsequently established the Atomic Energy Commission (AEC). Charged with the control and development of nuclear power, the Commission assumed the responsibilities and obligations held by the Manhattan Engineer District in 1947.

The Oak Ridge Operations Office of the AEC was organized to take charge of the city and of the production facilities. Nuclear safety was an issue of paramount importance, and it was recognized that meteorology, which controlled transport and dispersion of radionuclides released into the atmosphere, clearly had an important role to play in the development of safety standards.

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[1]George O. Robinson, Jr., *The Oak Ridge Story*. Southern Publishers, Inc., Kingsport, TN, 1950. pp. 18-19.

[2]Original spelling, now frequently spelled "Scarboro."

[3]Charles W. Johnson, and Charles O. Jackson, *City Behind A Fence: Oak Ridge, Tennessee 1942-1946*. University of Tennessee Press, Knoxville, TN, 1986. p.45.

Introduction

The Atmospheric Turbulence and Diffusion Division (ATDD) of the Air Resources Laboratory, Environmental Research Laboratories, National Oceanic and Atmospheric Administration, is located at 456 South Illinois Avenue, Oak Ridge, Tennessee. The laboratory was begun in 1948 as a U. S. Weather Bureau (USWB) Research Station.

The ATDD conducts research on the structure of turbulence and the diffusion of materials in the lower atmosphere. The work is aimed at understanding the complex interactions of the atmosphere and the underlying surface, predicting dispersion and transfer to the environment of air pollutants, and estimating the atmospheric consequences of various modes of energy production. Theoretical development, analytical and numerical models, and laboratory and field experimental programs are used to advance the state of the art.

Climatological data continues to be collected, disseminated, and records maintained as part of the basic ongoing meteorological program. Since the organization began many programs have been added, some have changed substantially in nature, and some have been phased out. When the laboratory became jointly supported by the AEC and the USWB (later Environmental Science Services Administration (ESSA) and National Oceanic and Atmospheric Administration (NOAA)) in FY 1965, the scope of research was considerably broadened. With the advent of sophisticated automated data processing systems, and the subsequent explosion of computer technology, many of the research techniques have changed.

ATDD's main strength lies in the breadth and diversity of backgrounds of the research staff; at present it consists primarily of 12 NOAA and 7 Oak Ridge Associated Universities (ORAU) scientists, engineers, and computer specialists. Most have been trained in meteorology, physics, and fluid dynamics, with a few specializing in fields such as forestry and computer sciences. Nearly all have advanced degrees. Collective work experience is particularly strong in theoretical and numerical studies of turbulence and diffusion, development of local and regional-scale dispersion and air pollution models and advanced planetary boundary layer (PBL) models, flow and diffusion near buildings and hills, and air-surface exchange process modeling and experiments.

Considerable expertise has been developed in forest meteorology, in meteorological data collection and analysis related to air quality problems, and the deployment, operation, and maintenance of sophisticated instruments in the field. A focal point is the well-equipped forest meteorology site on Oak Ridge National Laboratory's (ORNL) Walker Branch Watershed, where a unique facility has evolved for the study of forest-atmosphere exchange processes and forest structure-micrometeorological interactions. ATDD's work on these topics is internationally known, as evidenced by frequent invitations to present papers or lectures at workshops, symposia, and universities in the U.S. and abroad. Most major countries have been visited, including Russia and China. A hallmark of ATDD research seems to be an ability to synthesize highly technical information into easily-used methods and models relevant to air pollution problems.

A feature unusual in a small laboratory is the ATDD wind tunnel facility, suitable for modest wind-building interaction studies and basic turbulence investigations, as well as for routine calibration purposes. A highly specialized and well-indexed library and journal collection have been developed, greatly facilitating literature searches; the Oak Ridge National Laboratory main library and the Y-12 engineering library are also close by. ATDD is linked by dial-up access to the extensive computer array at ORNL; there is also an extensive array of sophisticated automated data processing (ADP) equipment available in the lab. A well equipped shop permits most equipment

modification and repair work to be accomplished in-house, including design and construction of specialized electronic instruments..

Among the accomplishments since ATDD's inception in 1964 are the development of estimation procedures for effluent plume dispersion, buoyant plume rise, and plume behavior near obstacles such as buildings. Methods of determining effective plume diffusion parameters for various atmospheric and surface conditions, and easily-applied models of urban air pollution have been developed. Considerable effort has been spent on modeling cooling tower plumes, estimating the impact on the atmosphere of large energy and moisture releases, developing regional-scale numerical transport and diffusion models, and studying air parcel trajectories in complex terrain.

Basic research has included comparisons of Lagrangian (moving point) and Eulerian (fixed point) turbulence characteristics, and mathematical modeling of the planetary boundary layer (PBL) using state-of-the-art turbulence closure techniques. Forest meteorology research has provided one of the few available detailed data bases for radiative fluxes to, from, and within deciduous forest canopies. Many of the methods, ideas, and models developed at ATDD are in current use worldwide by air pollution modelers and regulatory agencies, including the U. S. Environmental Protection Agency (USEPA) and the Nuclear Regulatory Commission (NRC).

For the first 22 years or so, most ATDD funding was provided by the U.S. Department of Energy (DOE) and NOAA, or their respective predecessors, and they are still the source of basic support. However, beginning in the early 1970s, agency budget constraints and sharp inflation forced ATDD to seek a broader base of funding through a number of interagency and interlaboratory agreements. Support for joint research activities has been provided by ORNL, the U.S. Army Waterways Experiment Station and Army Research Office, Battelle-Pacific Northwest Labs (PNL), Los Alamos National Laboratory (LANL), USEPA, NRC, Tennessee Valley Authority (TVA), National Aeronautics and Space Administration (NASA), U. S. Air Force, U. S. Geological Survey (USGS), U.S. Forest Service, National Park Service, etc. Because of the complexities involved in multi-agency funding, no attempt has been made to provide specific financial data in this report.

Essentially all of the major accomplishments of this laboratory have been published in the open literature, in conference or symposia proceedings, as technical memoranda and technical reports, or occasionally as "in-house" reports. These are distributed to those persons or organizations who may have a special interest in a given report. A list of all publications produced since the laboratory began is attached as **Appendix A.**

A Monthly Activity Report provides current information on laboratory activities. An Annual Report is also produced. It contains an overview of accomplishments during the preceding year and a compilation of abstracts of all papers published during the calendar year. These reports are distributed to a selected list of supervisory and administrative personnel, sponsoring agencies, laboratories, and individuals who have a particular concern with the work of the ATDD.

Appendix B is a listing of both present and past ATDD personnel. To the extent possible, visiting scientists, students, part-time, and contractor personnel are included. The ATDD has operated under three directors: F. A. Gifford, 1955-1980; Bruce B. Hicks, 1981-1990; and currently, Rayford P. Hosker, Jr., who became the director in December 1990. Dr. S. R. Hanna served as interim director for several months in 1980 and 1981.

The laboratory is presently housed on a 4.5 acre tract in one of the oldest buildings in Oak Ridge. The main building, built in 1943 while construction was under way for the Y-12 and X-10 areas, was designed for temporary use as a field hospital to handle emergencies and minor injuries. The building was originally built on "mud sills," which were 2x12s propped up with 6x6 posts. The

present storage building was used for ambulance parking. In 1951 a concrete block foundation was installed, and in 1952 additional office space and an auditorium were added.

The facility has served many purposes over the years. It was used for awhile as the "Oak Ridge Department of Public Health," and in 1946 it was converted to use for the Oak Ridge Institute of Nuclear Studies (ORINS) as a teacher training center. ORINS used the building until 1964, when that organization became a part of the Oak Ridge Associated Universities. The building continued to be used for various training purposes, but was vacant for some time prior to undergoing extensive remodeling for use by the ATDD in 1972. Since its occupancy by ATDD it has undergone further remodeling and upgrading, particularly since the time in 1982 when beams supporting the floor on the outside wall of the library collapsed. The entire library collection was haphazardly arranged along the corridor floors for several weeks while repairs were under way. (Complaints of sore knees were not uncommon.) Additional space adjacent to the main building was provided in 1977 when a metal building for housing a "Fluid Dynamics Laboratory," was erected, and again in 1987 when a modular office unit was brought in to house the DOE Emergency Management program.

I. Establishment of Meteorology Program

Meteorological instruments installed at a site near the X-10 facility (now known as Oak Ridge National Laboratory) in 1943 marked the formal beginning of the Oak Ridge meteorology program. The U. S. Weather Bureau in Knoxville, Tennessee, provided meteorological services to the area. Several volunteer weather observers and other individuals maintained handwritten logs of weather conditions at various area locations.

In December 1947, the AEC requested the Weather Bureau to conduct a meteorological survey of the Oak Ridge area. The purposes of the survey were to provide detailed information regarding wind flow patterns over the Oak Ridge area, and to determine the relation of atmospheric conditions to the dispersion of radioactive contaminants. The program consisted of (1) measurements and observations of wind, turbulence, and related meteorological elements over a sufficient area and time to cover the normal range of conditions; (2) compilation and statistical reduction of the data to reveal the significant geographical, diurnal, and seasonal patterns of wind flow and diffusion; and (3) analysis of causes, effects, frequencies of occurrence, and formulas for extrapolation of these patterns. The resulting information was for application to the evaluation and planning of gaseous waste disposal facilities and air monitoring procedures, and for use in calculating the hazards associated with hypothetical accidental releases of contaminants under various conditions.

The work, supported by the AEC's Research and Medicine Division, (Dr. A. H. Holland, Director), began in 1948 under the direction of Dr. Joshua Z. Holland of the U.S. Weather Bureau. A staff of six was quickly assembled from throughout the United States. In addition to J. Z. Holland, the following arrived during the last half of 1948: Robert F. Myers, John C. Holland, Jack W. Tondee, Howard M. Day, and Edward W. Crume. Barlow H. Goad, a meteorological technician, and various clerical and technical staff were added in 1949 and 1950 respectively.

A network of micrometeorological stations was installed, and 24-hour observations started December 5, 1948. Extensive micrometeorological data gathering and analysis occupied the following two years, with the intensive observational phase of the survey being completed in the fall of 1950. The report of this work, USAEC ORO-99, "A Meteorological Survey of the Oak Ridge Area,"

published in 1953, is a classic of the micrometeorological literature. A monthly weather summary, first issued by the Weather Bureau Office in January 1951, is still being issued today.

With the completion of the meteorological survey, the original measurement program was converted to a small, continuing research effort during Fys 1953 and 1954 and expanded to add methods of calculating or estimating concentrations of atmospheric pollutants. Initially, only concentrations of radioactive pollutants near nuclear reactors were considered; however, distances of interest increased to regional and even global scales, with the classes of pollutants involved being broadened to include air pollutants of all kinds, including waste heat and moisture, and pollutant sources of all kinds, including tall power plant stacks, cities, highway traffic, cooling towers, and power parks.

The micrometeorological stations were replaced during 1954-55 with an automated weather information telemetering system (WITS), basically developed by R. F. Myers of the Oak Ridge USWB. It was the first extensive operational automatic weather recording network, and operated continually, monitoring local wind and weather patterns at each plant site and reactor area, from 1955 until the mid-1970s.

II. Mid- to late-50s

When Dr. Frank A. Gifford was appointed in 1955 as Meteorologist-in-Charge, the first two phases of the USWB project--the microclimatological survey and the development of practical diffusion formulae by J. Z. Holland, and the design and construction of the digital telemetering system--were complete. The third phase, initiated by Gifford, was the refinement of diffusion estimation techniques and research into basic knowledge of atmospheric turbulence and diffusion. This was the phase that laid the foundation for the eventual formation of the Atmospheric Turbulence and Diffusion Laboratory.

The provision of consultant and advisory services on meteorological and climatological concerns to ORO contractors (mainly the Union Carbide Corporation, AEC's principal contractor) was one of the fundamental features of the early program. Services were also frequently provided to the Advisory Committee on Reactor Safeguards (ACRS), a statutory committee to the AEC to provide independent analyses to the AEC's Commissioners on the safety aspects of nuclear power installations. The methods and philosophy established by ACRS were considered as standards for international use in connection with nuclear siting practices. In 1958 Dr. Gifford was appointed a member of the ACRS and continued serving in that capacity until his retirement in 1980.

While continuing to provide both routine and special meteorological and climatological data and forecasts, several special studies were initiated and completed during the late 50s. The USWB made climatological, engineering design, and reactor hazard studies for the Puerto Rico reactor. Environmental hazards estimates were made or revised in connection with the Oak Ridge Tower Shielding Facility, and the Molten Salt Breeder, Homogeneous, Graphite, and Oak Ridge Research Reactors.

Calculations of concentrations and dosages for various meteorological conditions and hypothetical nuclear incidents relative to the many potential sources of contamination in the Oak Ridge area were extended. In cooperation with Oak Ridge National Laboratory, meteorological instruments were designed and installed for a waste pits evaporation study.

The Oak Ridge USWB staff provided extensive assistance in editing and publishing one of the first specialized books on atmospheric dispersion, *Meteorology and Atomic Energy*. This publication demonstrated that the potential hazard from airborne radioactive materials and the use of meteorology to help minimize this hazard had assumed great importance, and it organized research findings and prediction methods in a practical manner.

A new and extended theory of atmospheric diffusion from fluctuating plumes was formulated and studied. Numerous other fundamental and applied diffusion research studies were completed, such as fallout in turbulent air, plume shape parameter nomograms, and turbulence spectral studies. Much of this early work emphasized analytical solutions, nomograms, and other simple practical tools, because digital computers and powerful calculators were not readily available.

A tentative meteorological population index was devised to compare relative hazards of reactor sites on surrounding populations. A rapid method of evaluating pollution reception from multiple sources was also devised. Comparison studies of a "running mean" method of investigating theoretical dispersion behavior were initiated.

A course in Reactor Safety Meteorology was taught by F. A. Gifford at the Oak Ridge School of Reactor Technology (ORSORT), from 1958 through 1962.

Walter M. Culkowski (meteorologist), and Duane H. Turner (meteorological technician) were added to the staff.

III. 1960-69

1. Establishment of ATDL

One of the major achievements of the 1960s was the establishment of the Atmospheric Turbulence and Diffusion Laboratory (ATDL). Dr. Gifford proposed the establishment of such a facility in 1964. In a letter to Dr. H. M. Roth, Director of the U.S. AEC Research and Development Division in Oak Ridge, Dr. Gifford outlined the reasons and the planned activities for such a program. He stated that "the methods now in use for the prediction of atmospheric diffusion are based on quite old and limited theoretical techniques. These have sufficed in the past as much because of large uncertainties in our knowledge of radioactive source strengths in the atmosphere as for any other reason. As our ability to specify the source strength improves, for example, through the AEC's reactor safety research program, need for improved fundamental understanding of atmospheric turbulence diffusion becomes more keenly felt."

Gifford's proposal called for joint funding by the AEC and the USWB to emphasize the fact that atmospheric turbulence research was important in a number of areas in addition to nuclear radiation safety, e.g., agriculture, aviation, and air pollution. The proposed funding reflected this broader basis of need, and provided a mechanism for obtaining added support from research funds available in these other areas. Fundamental studies were to be conducted in the field of atmospheric turbulence and diffusion, and were to be designed to clarify the basic physical mechanisms involved and to determine characteristic atmospheric patterns and parameter values.

The proposal stated that neither an experimental approach nor applications would be emphasized. The existing close liaison with other AEC meteorology groups was to be maintained, so that the impact of the work could immediately affect the entire program and vice versa. The

continuing micrometeorology program for Oak Ridge Operations (ORO) was to go ahead essentially unchanged within the new framework. The proposed expansion would all be in the area of basic turbulence research.

The proposal was accepted by the AEC, and the Atmospheric Turbulence and Diffusion Laboratory officially came into being in FY 1965. The U. S. Weather Bureau underwent a major reorganization in 1965, and the Environmental Science Services Administation (ESSA) was created. The ATDL became a part of this organization at that time and was granted the status of an independent research laboratory. The laboratory moved from the AEC Administration Building to Cheyenne Hall (a war-time dormitory converted to office space) in 1964, and remained there until required to move in 1970 to the then-new Federal Office Building.

In a November 8, 1965, letter to J. Z. Holland, Division of Biology and Medicine, USAEC, Washington, D. C., Gifford clarified original plans regarding the division of costs between ESSA and the AEC. He stated that the intended goal was for ESSA to reach parity of incremental **research** support, not of total program support. Drs. Gary A. Briggs and Steven R. Hanna were the first ATDL research scientists to be supported by ESSA under the new financial arrangement.

Another item pertinent to laboratory support was an arrangement by the AEC for the transfer of some portion of costs related to meteorological services to DOE's prime contractor,(originally Union Carbide Corporation, but taken over by Martin Marietta Energy Systems, Inc., during the 1980s). This policy was established in 1957, when the manager of Oak Ridge Operations authorized the transfer of 30% of the annual cost of the USWB operations to UCC, set forth the circumstances in which this might vary, and established reporting requirements. The percentage has greatly diminished, but the precedent thus established has continued. ,

2. Weather Information Telemetering System (WITS)

Climatological data gathering and analysis continued as one of the main projects during the 1960s. The original WITS was totally replaced with state-of-the-art equipment, and operated continually until finally phased out in the mid-70s when computerized programs made its operation and maintenance uneconomical. Improvements to the system during the 60s included development and installation of a wind statistics system, and the development and installation of a solar radiation integrator.

3. Planetary boundary layer studies

Theoretical models of the planetary boundary layer were developed, and efforts got under way to establish hydrodynamical models for the transfer of heat, momentum, and moisture between flow aloft and the earth's surface. These models dealt with such complex problems as turbulent shear flow and the diabatic behavior of the atmosphere. Complete and successful formulations could have significantly improved the ability to forecast weather by numerical techniques, improved the ability to predict the dispersion of pollutants, and provided a sound basis for evaluating the impact of technology on the environment.

4. Plume dispersion studies

Pioneering analyses of plume behavior from stacks were extended to include effects of buildings and the influence of radioactivity. A technique for analysis of photographs of smoke plumes to determine atmospheric diffusion coefficients was developed. The results of that project have been used internationally in practical application in air pollution problems. Theoretical studies on turbulent heat flux and boundary layer structure were initiated.

An early pulsed-laser meteorological probe was assembled for smoke plume geometry studies. Smoke plume studies were conducted at Idaho Falls and at Oak Ridge, together with concurrent measurements of mean winds, temperatures, and wind fluctuations, in order to establish basic turbulence parameters, chiefly the eddy energy dissipation rate. Plume rise studies were extended by considering some of the details of the entrainment process and by utilizing the latest turbulence data from the planetary boundary layer to derive an expression for buoyant plume rise at large distances downwind in neutral conditions. The basic hardware of a fumigation fluid modeling facility was assembled.

Plume Rise, a comprehensive comparison of alternative plume-rise formulas with available data, by Gary A. Briggs, was published in the AEC Critical Review Series, and became a major source of information for modeling tall stack plume rise in the growing air pollution community.

5. Turbulence and diffusion

A similarity theory of diffusion in the surface layer of the atmosphere was developed. Work was started on numerical computation of turbulent flow with the help of mathematicians from Union Carbide's Central Data Processing facility. Revised deposition and concentration estimates, and a revision to climatological norms were published. A computer program to simulate diffusion in conditions of varying terrain, wind shear, etc., was completed. Plume rise studies were extended, including the effects of inversions. The work of two foreign scientists, Dr. Werner Klug and Dr. F. B. Smith, on basic atmospheric diffusion theory and modeling, and on boundary layer flux problems was of inestimable value to the early success of the ATDL in these fields. Dr. Klug, with the Darmstadt Technische Hochschule in Germany, spent six months with the ATDL in 1966, and Dr. Smith, with the U.K. Meteorological Office, spent one year with the laboratory beginning in the fall of 1966.

Meteorology and Atomic Energy, 1968 was published by the AEC. F. A. Gifford wrote Chapter 3, "An Outline of Theories of Diffusion in the Lower Layers of the Atmosphere." This 445-page book was a complete revision of the original *Meteorology and Atomic Energy*, and provided both wider and deeper coverage of more topics, reflecting the large amount of work done in this field in the intervening years. It became a standard reference for many years.

A thorough study of published models of wind spirals and turbulence in the boundary layer of the atmosphere was conducted. Large helical roll-vortices in the boundary layer and the part played by these vortices in the formation of longitudinal sand dunes were studied.

6. Ecology program

With the entrance on duty of Boyd A. Hutchison in June 1968, an ecology-meteorology program got under way. A study of wind and turbulence in a pine plantation was started as the first phase of a comprehensive study of the changes in wind resulting as air moved from an open field into and over a pine plantation. A study of the spatial distribution of solar radiation within a tulip poplar forest was also initiated.

7. Nuclear Safety Information Center (NSIC)

At the request of the AEC, ORNL established the Nuclear Safety Information Center (NSIC). Its purpose was to serve as a focal point for the collection, storage, evaluation, and dissemination of nuclear safety information. The ATDL agreed to serve as the meteorological expert to the NSIC, and allocated one-half man-year for this purpose. W. F. Hilsmeier served in this capacity from early

1963 until his transfer to Boulder, CO in 1966. The task was then taken over by S. D. Swisher until NSIC was reorganized around 1975, and ATDL's role was significantly diminished.

8. Education and training

F. A. Gifford taught a graduate course in Air Pollution Meteorology at Vanderbilt University, in the Department of Environmental and Water Resources Engineering. Drs. Gifford, Briggs, and Hanna presented numerous lectures and lecture series on the subject of air pollution at various other institutions, including Yale and Syracuse Universities.

9. Personnel

Dr. F. A. Gifford was awarded, in 1963, the Department of Commerce Gold Medal "for major contributions to science and administration, for extremely significant research and outstanding leadership in the study of turbulent diffusion in the atmosphere, and for highly distinguished authorship in the field of meteorology."

Drs. Warren B. Johnson, Gary A. Briggs and Steven R. Hanna, and William F. Hilsmeier, Ruth A. Green, Billie J. Crowe, Searle D. Swisher, and Boyd A. Hutchison joined the staff. Hilsmeier transferred to the Environmental Research Laboratories (ERL) in Boulder, Colorado in September 1966, and Dr. Johnson left for a position with Stanford Research Institute in 1967.

IV. 1970-79

In 1970 the Environmental Science Services Administration was reorganized and the National Oceanic and Atmospheric Administration (NOAA) was formed, with ATDL becoming a part of that organization. In the mid-1970s the Atomic Energy Commission also underwent reorganization and the Energy Research and Development Administration (ERDA) was created. This was a rather short-lived organization; it was replaced in about two years by the Department of Energy (DOE).

The ATDL's basic research objectives remained unchanged: to develop and test mathematical models adequate to characterize momentum, energy and material exchange processes in the planetary boundary layer with particular emphasis on the problems of atmospheric diffusion and transport of heat and other waste products of mankind's energy generation activities, and on air-earth interactions. Research activities jointly supported by AEC and NOAA included (a) atmospheric diffusion studies, (b) planetary boundary layer studies; (c) numerical studies of turbulent flow; and (d) turbulent heat flux and momentum transfer studies.

In the NOAA/AEC-ERDA-DOE annual Interagency Agreements, the ATDL's tasks and responsibilities were generally defined as:

- the maintenance of adequate meteorological records for the Oak Ridge area for planning, design, and research;

- furnishing specific meteorological data, summaries, and normals as required in connection with evaluation of air contamination incidents, airborne radioactive contamination studies, waste disposal studies, regional studies, ecological studies, solar energy studies, design of facilities, and analysis of construction progress, flood hazard studies, and fire weather forecasts;

- liaison with disaster planning officials with respect to meteorological influences on airborne disposal of chemical, radiological, or bacteriological agents;

- research, consultation, preparation of technical reports, instruction and collaboration with scientists and engineers in the plants, laboratories, participating universities, other AEC/ERDA/DOE installations, and government agencies on problems of nuclear safety, waste disposal, air and thermal pollution, and environmental effects of energy production.

The research staff was augmented with the entrance on duty in 1971 of Dr. R.P. Hosker, Jr., and of Carmen J. Nappo. Dr. Detlef R. Matt was assigned to the lab for several months under funding from the International Biological Program (IBP); he then became a permanent NOAA staff member in 1974, and continued his work in the forest-meteorology program. Dr. K. Shankar Rao joined the research staff in 1976.

In 1974 ERDA entered into an agreement with Oak Ridge Associated Universities (ORAU) on behalf of ATDL whereby "computer, engineering, and library services" would be provided by ORAU. This enabled permanent ORAU staff assignments to the ATDL and opened the way for close collaboration with ORAU in scientific, administrative, and technical work. A computer specialist, Howell Snodgrass, was employed in 1977 as the first ORAU full-time employee assigned to ATDL.

ATDL established programs through both ORAU and NOAA for the employment of postdoctoral, graduate, undergraduate, Junior fellowship, and high-school vocational education (VOE) students for the lab. These programs have been invaluable as a means of extending research activities, providing training opportunities, and obtaining assistance for scientific and administrative staff.

Major accomplishments of ATDL during the 1970s were the development of the ATDL simple urban dispersion model; the acquisition of a building, wind tunnel, and related equipment for an applied fluid dynamics laboratory; conducting a major complex terrain field experiment, the Eastern Tennessee Trajectory Experiment (ETTEX); and the beginning of an active role in a new DOE program, Atmospheric Studies in Complex Terrain (ASCOT). The ecology-meteorology program became the forest-meteorology program and was broadened in scope.

Ecology, air pollution, oil embargoes, and the energy shortage of the early 1970s aroused national interest in regional-scale environmental impacts of energy generation facilities. As the size of power plants and industrial facilities grew, the potential atmospheric effects of the waste heat and moisture released became of increasing concern. Although ATDL had been addressing these issues for some time, research activities became more strongly oriented toward solving the problems of a lack of suitable computer models and adequate observations for testing the models.

1. Model development

Among the many air quality models developed were the ATDL urban diffusion model, the ORNL-ATDL Unified Transport Model (UTM), the Tennessee Valley Assessment Model (TVAM), and the Tennessee Valley Prediction Model (TVPM). The urban diffusion model and the UTM were extensively tested against field data and placed into use. The TVAM and the TVPM were applied to the data generated during the 1974 ETTEX program. A Regional Trajectory and Diffusion-Deposition Model (RETADD) was completed in collaboration with ORNL personnel.

A Lagrangian statistical diffusion model, suitable for application to diffusion over complex terrain or seashores, was also developed. An experiment at NOAA's Wave Propagation Laboratory

in Boulder, CO was used to provide information on the link between Lagrangian and Eulerian turbulence, so that the model could be operated using Eulerian tower data.

A number of other models were developed, including computer coding and testing of computational schemes. A steady-state one-dimensional model was developed and used to study the structure of the convective PBL. The evolution and structure of an idealized nocturnal boundary layer were simulated using a second-order closure model. Two types of diurnally varying PBL models, both based on higher-order turbulence closure schemes with different levels of sophistication, were formulated, and a simple turbulent kinetic energy closure model of the nocturnal boundary layer was also developed. This model compared favorably with the Brost-Wyngaard model. A radiation model and code were also developed.

2. Turbulence and diffusion studies

The vertical diffusion data from the Project "Prairie Grass" experiment were analyzed using the latest concepts in planetary boundary layer similarity theory; in particular, the vertical dispersion parameter σ_z was studied for its dependence on mixing layer depth, convective velocity, Monin-Obukhov length, and bulk Richardson number. Vertical soundings of temperature and wind speed at Washington National and Dulles International Airports were analyzed to determine the differences between urban and rural boundary layers.

During the mid-70s the U.S. Environmental Protection Agency developed and carried out in St. Louis a major program called the Regional Air Pollution Study (RAPS). An important product of RAPS was the data set from the Regional Air Monitoring System (RAMS). These data were at that time considered the most extensive urban meteorological and air pollution data ever collected. ATDL acquired the complete hourly data from 1976 and performed initial analyses of the correlations between meteorological parameters and pollutant concentrations. Data from these analyses have been extensively utilized in many of the ATDL computer models.

Theoretical studies were made of asymptotic equations for diffusion coefficients, and comparisons were made with available field measurements. A review of turbulent diffusion typing schemes was completed by F. A. Gifford and published in *Nuclear Safety*.

The physical concepts concerning wind direction shear in a forest were outlined and calculations made of the effects of this shear on diffusion. Mean humidity and temperature profiles collected on the pine plantation's forest tower were used to estimate the effect of Bowen ratio on atmospheric stability. Similar estimates were made with the Project Prairie Grass data.

A Monte Carlo diffusion technique which accounted for the fluctuations in lagged velocity cross products was developed in FY 1976.

3. Dispersion studies

In the summer of 1974, the Eastern Tennessee Trajectory Experiment (ETTEX) was conducted by the ATDL with support from the ARL Field Research Office in Idaho Falls and ARL headquarters staff. The purpose of ETTEX was to measure certain aspects of mesoscale transport and diffusion over complex terrain. The results of the experiment were analyzed over the next two years and were then published as a NOAA technical memorandum in 1978. A separate experiment to investigate convective fumigation from tall stacks was carried out concurrently near TVA's Bull Run steam plant, near Oak Ridge.

A new empirical procedure was developed to estimate the size of the wake downwind of buildings, and to estimate the concentration of contaminants close to buildings. It has special application to the case of nuclear power plants. A study was also made of effluent transport and diffusion over water, largely because of the interest in off-shore nuclear power plants. Dr. Hosker made a comparison of estimation procedures for over-water plume dispersion.

4. Forest meteorology

From its inception in 1968, instrumentation priority was given to ecological-meteorological studies in support of the International Biological Program at the Oak Ridge Walker Branch forestry site. With the completion of installation of the planned original instrumentation in 1978, this facility was recognized as a unique and invaluable national scientific resource. Instruments and data acquisition systems were and are regularly upgraded to maintain the forestry site as a state-of-the-art research facility. Periodic observations of space and time distributions of wind speeds within the forest were made, and the space and time distributions of incoming and outgoing fluxes of solar, photosynthetically-active, all-wave, and long-wave radiation within and above the fully leafed forest were determined. A paper describing a technique for photographic assessment of deciduous forest radiation regimes was published. Estimates were made of the relative efficiencies of forests and grassland as scavengers of dry deposition. Field collection of data required for a study of energy partitioning above and within a tulip poplar forest was completed.

In 1976 a research quality solar monitoring station was put into operation at the forest meteorology site. Solar radiation had been measured continuously in Oak Ridge since 1949 as part of the old USWB network. Although the earlier network was disbanded, solar radiation data collection has continued in Oak Ridge to the present.

A workshop entitled "Forest Meteorology - Research Needs for an Energy and Resource Limited Future" was organized with funding by DOE. The workshop was held in Ottawa, Ontario, in August 1978, in conjunction with the World Meteorological Organization's International Symposium on Forest Meteorology. A summary of the proceedings was prepared by Dr. Boyd A. Hutchison and published by DOE.

5. Atmospheric studies in complex terrain (ASCOT)

In 1978, ATDL began an active role in project development and problem definition in a new DOE-sponsored program, Atmospheric Studies in Complex Terrain (ASCOT), particularly with regard to work at the "Geysers" geothermal energy production site in northern California. This role included program planning, experimental design, analytical and numerical modeling, data analysis and field studies of the nighttime atmospheric flow in valley environments. In the early stages of ASCOT it was recognized that nocturnal valley circulations provided the highest potential for air pollution episodes. For this reason, the understanding and modeling of nighttime valley flows was selected as the first ASCOT objective. Within this context, ATDL elected to concentrate on the fundamental dynamics of such flows, which involved the drainage of cold air on slopes and in valleys.

The ATDL participated in several ASCOT field experiments, including the multi-laboratory Anderson Creek Valley field experiment conducted in July 1979, and a four-day experiment in conjunction with Los Alamos National Lab in October 1979, whose purpose was to examine the structure of a simple drainage flow during nighttime conditions. A laboratory apparatus for cold drainage flow simulation was constructed to study the transition from laminar to turbulent flow, the entrainment rate of ambient air, and the shape of velocity and temperature profiles through the drainage layer.

Relevant constant-height balloon trajectory experiments were carried out at the TVA Widow's Creek steam plant, near a terrain escarpment.

6. Meteorological effects of energy generation

A critical review of models of air pollution transport and diffusion in urban areas was made. A method for the comprehensive evaluation of air pollution forecast models was developed and applied to several urban air pollution models. A numerical study was made of the three-dimensional variation of winds, temperatures, and moisture over cities. A model of droplet deposition was developed and verified with observations taken by Pacific Northwest Laboratory cloud physics specialists.

Estimates of the meteorological effects of power parks were made. The heat release of proposed power parks was found to be about 100,000 MW, thus creating the possibility of the concentration of vorticity or the possibility of increased rainfall and thunderstorm development. A comprehensive state-of-the-art literature survey was completed of mathematical formulations of deep or shallow moist convection, and of numerical prediction models for cumulus cloud formation and growth for the study on Atmospheric Effects of Nuclear Energy Generation (AENEC). A steady-state 2-D shallow cloud model was also developed for the AENEC study. A cooperative program among ATDL, ORNL, and the National Center for Atmospheric Research (NCAR) on the effect of man's thermal additions on global climate changes was completed.

A symposium, "Cooling Tower Environment - 1974" was organized by ATDL in cooperation with the Maryland Power Plant Siting Program. The proceedings were published in a book of the same name. Several studies of cooling towers were made, among them a study of a precipitation anomaly due to the emission of water vapor from the K-25 cooling towers. In FY 1976 the ATDD received authority from ERDA to participate in an EPA-funded task entitled "Effect of Cooling Towers on Weather." The objectives of the project were to study the influence of cooling tower geometry on a plume and to develop and test numerical cloud growth models for single cooling tower plumes. Funds for a 30.5m x 9.1m x 4.5m high steel building to house a wind tunnel, a darkroom, and model storage space were provided by ERDA; EPA funds were used to purchase a low speed, open return-type wind tunnel and other equipment. By the end of 1978 the ATDL Applied Fluid Dynamics Laboratory began operation.

7. Effluent plume behavior

The first "Idaho Smoke and Tracer Experiment" (ISATEX) was carried out in FY 1978. Oil-fog smoke plumes were released while high-altitude photographs were taken of the smoke plumes by a U-2 aircraft. These data were interpreted in terms of quantitative dispersion coefficients using an earlier technique developed by Gifford for analysis of smoke plumes to determine atmospheric diffusion coefficients. Studies were also made of small smoke plumes. This methodology was applied to Martian deposition patterns to determine horizontal diffusion coefficients for Mars. Wind and temperature profile equipment were purchased and installed on a 50 ft. tower in a grassy field near Oak Ridge.

Physical modeling of buoyant plume rise and dispersion in very stable conditions was completed at the EPA Fluid Modeling Facility (FMF) in North Carolina. Laboratory studies of the lift-off of a buoyant plume initially entrained in a building wake were also carried out at the FMF.

A model for plume rise terminated by the action of convective turbulence was developed and presented at the American Meteorological Society's (AMS) Workshop on Meteorology and Environmental Assessment. The theory of plume rise was carried further to analyze the effect of

simultaneous atmospheric turbulence and stable stratification, and more practical estimates of the transition distance to atmospheric turbulence-dominated entrainment were developed. Simplified techniques for calculating diffusion from small emissions were worked out.

A fumigation modelling facility, started in 1969, was re-installed in 1973 in a building adjacent to ATDL's present quarters, and a pumping system and additional density profile flexibility were added.

8. Nuclear Safety Information Center

In 1972 the NSIC's role was expanded to include the effects of nuclear facilities on the atmosphere and the environment. The ATDL continued to support this expanded role, answering inquiries concerning the processes affecting diffusion and deposition of radioactive material released to the atmospheric environment near the earth's surface in connection with reactor operations, fuel processing plants, etc., and the global transport of radioactivity as the result of nuclear weapons tests. The center was reorganized in 1975, and ATDL's participation in the program was essentially ended. Practically all of the 1,000 or more meteorological abstracts then stored at NSIC were prepared by ATDL.

9. Climatological Data

A 22-year record of meteorological data collected by the Oak Ridge weather station was edited, calibrated, and stored on line on disk at the ORNL computer center for easy reference by ORNL and other researchers.

10. Education and Training

ATDL staff continued teaching over the next two years an Air Pollution Meteorology course begun at Vanderbilt University in April 1969. Eight students took the course for credit.

F. A. Gifford spent nearly six weeks in San Miguel, Provincia de Buenos Aires, Argentina, in 1971, presenting a series of lectures on air pollution meteorology at the Observatorio Nacional de Fisica Cosmica.

In 1973-74, F. A. Gifford presented a course on atmospheric diffusion to graduate students in Environmental Engineering at the University of Tennessee. Drs. Gifford, Hanna, and Briggs prepared and delivered a 30-hour course on the Meteorology of Environmental Impact Assessment at the ORNL Environmental School.

Boyd A. Hutchison taught a course "Toward an Environmental Ethic: Ecology and the Survival of Man" for an adult education class at Oak Ridge High School. Numerous talks were given to elementary and high school students on careers in meteorology, environmental pollution, etc.

11. Other

ATDL sponsored a mesoscale modeling conference at Watts Bar Dam, Tennessee, in June 1971. A summary of the conference was published in the *Bulletin of the American Meteorological Society*. ATDL hosted the Ad Hoc Council on Regional Atmospheric Transport in October 1974. The Council was composed of scientists actively working in the field of atmospheric transport and diffusion. A workshop on transport and diffusion modeling using puffs and plumes was held at ATDL on January 26 and 27, 1977.

An ATDL program review was held September 24-25, 1970. Representatives from the AEC, ORNL, ESSA, and TVA attended. Observers came from Yale University, the University of California at Davis, Pacific Northwest Laboratory, and Argonne National Laboratory. A program review was also held in March 1977; reviewers were Dr. W.G.N. Slinn, Dr. Bruce A. Egan, Prof. Kenneth R. Knoerr, and Dr. John C. Wyngaard. Dr. D. S. Ballantine and Dr. Harry Moses of DBER and R. R. W. Jobach, NRC, as well as several people from ORNL and ERDA-ORO, attended the review.

F. A. Gifford participated in a number of study tours and reactor safety missions at the request of the IAEA, visiting Irkutsk in Russia, Thailand, Singapore, Brazil, and Argentina. He also attended the International Symposium on Stratified Flows, held in Novosobirsk, USSR, and in both 1974 and 1975 he visited Moscow, Leningrad, and other sites in Russia while participating in the 3rd and 4th meetings of the USA-USSR Work Group on Cooperation in the Field of Air Pollution Modeling, Instrumentation and Measurement Methodology.

V. 1980-89

"Air-surface interaction" is a succinct characterization of new major ATDD research programs in the 1980s. The 80s also brought a realization that the "turbulence" in the laboratory's name did not necessarily apply to the atmosphere alone. A new director, new staff members, the departure of other staff, new and expanded areas of research, numerous large field experiments, extensive participation in the National Acid Precipitation Assessment Program (NAPAP), assumption of a leading role in DOE's emergency management program, and continuation of the fundamental research and support activities placed heavy demands on both scientific and support staff.

In a 1981 program review, one of the reviewers commented that "There was a recognition that ATDL has been in a state of transition. In earlier times, the general characteristic of ATDL research was theoretical with concentration in boundary layer diffusion and the development of innovative models of boundary layer processes. ATDL came to be recognized as a world leader in planetary boundary layer research based largely on the work of Drs. Frank Gifford, Steven Hanna, and Gary Briggs."

While basic research activities continued as stated in the DOE/NOAA Interagency Agreement, several new programs were undertaken, and many activities were expanded upon under this basic structure. Two of the events that had a major impact on ATDD programs were the Acid Precipitation Act of 1980 (Title VII of the Energy Security Act, P.L. 96-294) which established an Interagency Task Force to develop and implement a comprehensive national program to increase understanding of the causes and effects of acid deposition, and the establishment by the DOE of an Emergency Response/Emergency Management Program. Some of the results of the activities undertaken under these and other programs are briefly reported below. Much of the work was accomplished through interagency and/or interlaboratory collaborative efforts.

Numerous personnel changes took place during this period, among them the retirement in 1980 of F. A. Gifford, the appointment of Dr. Steven R. Hanna as Acting Director for several months in 1980-81; the appoint of Bruce B. Hicks as director in January 1981, and the gradual departure or retirement of several senior scientists: Dr. Steven R. Hanna, Dr. Gary A. Briggs, Dr. Boyd A. Hutchison, and W. M. Culkowski. A number of new scientific staff members were added: Dr. Dennis D. Baldocchi, Dr. Tilden P. Meyers, Dr. Timothy L. Crawford, Dr. Ronald A. Dobosy, Dr. John Przybylowicz, William R. Pendergrass, Jerold A. Herwehe, David L. Auble, James D. Womack, Dr. Richard M. Eckman, and J. Randall White.

In a reorganization of the NOAA Air Resources Laboratory, the ATDL was changed to the ATDD (Atmospheric Turbulence and Diffusion Division) in late 1982. The Oak Ridge Department of Energy also underwent some reorganization and subsequent personnel changes which affected the ATDD.

1. National Acid Precipitation Assessment Program (NAPAP)

This large-scale extensive program, first funded by the Congress in 1980, was chaired jointly by the Environmental Protection Agency (EPA), National Oceanic and Atmospheric Administration (NOAA), and the Departments of Agriculture (USDA), Energy (DOE), Interior (DOI), and the Council on Environmental Quality (CEQ). Other federal agencies with an interest in acidic deposition research were also represented on the Task Force. The purpose of NAPAP was to develop and to progressively improve on the objective scientific information base for use by decision-makers in Congress, the administration, regulatory agencies, natural resource managers, private sector managers, environmental groups, and the public. The national program consisted of over 300 interrelated projects, funded by 12 federal agencies, in 10 major research categories: natural sources, man-made sources, atmospheric processes, deposition monitoring, aquatic effects, terrestrial effects, effects on materials and cultural resources, control technologies, assessments, and international activities. Hundreds of researchers in government, academia, and the private sector were involved in the national program.

ATDD began an active role in NAPAP in 1981, concentrating mainly on deposition monitoring research. In July 1986, B. B. Hicks was appointed chairman of the NAPAP Task Group II, **Atmospheric Chemistry,** jointly with J. L. Durham of the EPA Atmospheric Sciences Research Laboratory. A NAPAP Task Group II peer review was held in Knoxville, TN in March 1988. Overviews of specific projects as well as formal scientific presentations were given by ATDD staff. In a summary evaluation of a 1988 ATDD program review, it is stated: "The reviewers were impressed with ATDD's important contributions to NAPAP. In particular, Hicks' leadership of Task Group II and his tireless contributions to the Task Force have given ATDD national and international prominence in the acid rain research area." And in 1989 Hicks was awarded the NOAA Administrator's Award "for outstanding research in dry deposition monitoring in support of the U.S. national acid rain program." Hicks also served on the U.S./Canadian International Joint Commission, working on the studies related to the effects of acid rain.

ATDD was instrumental in organizing a specialists' workshop on dry deposition held at Harpers Ferry, West Virginia, in March 1986. It is probably worthy of note that ATDD made all arrangements for and funded the travel of several foreign scientists to the workshop with less than one week's notice. ATDD essentially prepared the proceedings document from this workshop, which was published as an official NAPAP document.

ATDD staff played a key role in producing the NAPAP State of Science and Technology (SOS/T) Reports Nos. 3, 5, and 20, with contributions to other reports as well. All of the Task Group II material in the 1988 NAPAP Annual Report was put together and edited by ATDD.

a. Dry deposition

Both wet and dry removal mechanisms control the fate of all airborne pollutants. The dry exchange of airborne trace gases and particles at the surface was identified as a major issue by the NAPAP. The ATDD designed and built an economical dry deposition monitoring network to provide data for inferring dry deposition fluxes. In 1982-83, a "CORE" network of three research sites was set up under joint DOE, NOAA, and EPA sponsorship. The CORE sites were the focal points for intensive studies of the processes involved in atmosphere-surface exchange of trace gases and

aerosols. These sites provided reference data, parameterizations of air-surface exchange, and the dry deposition velocities necessary to interpret data obtained at a more extensive network of routine air-concentration and meteorological monitoring stations operated under NOAA sponsorship. Although initiated as a contribution to NAPAP, the program proved to be relevant to air chemistry and to the prediction of changes in quality of the global atmosphere. Information regarding the development of this system and subsequent modifications has been well described in the literature published on this program.

In 1988, the ATDD entered into an agreement with EPA to conduct research to investigate and determine the uncertainties in extending site-specific dry deposition estimates to larger areas, and to investigate the uncertainties of site-specific deposition velocity and concentration measurements. Research was also conducted to investigate the feasibility of extending deposition velocity models to sites with complex vegetation patterns and rough terrain.

b. Instrument development

Setting up the NAPAP monitoring stations and CORE sites required the development of new instrumentation. In 1984 contracts were let with two universities to conduct research programs in collaboration with the ATDD. The University of Denver was funded to develop a new nitrogen dioxide sensor for use with the ATDD eddy correlation instrumentation. Carnegie-Mellon University was contracted to work on the development of improved surrogate surface methods for measuring surface fluxes of large particles. The ATDD designed and fabricated a computer-controlled 48-sample sequential rainfall sampler for use in wet deposition studies by Oak Ridge National Laboratory.

Under a 1986 interagency agreement with the National Park Service (NPS), a member of the Materials Effects Task Group of NAPAP, ATDD worked with scientists of the U.S. Geological Survey (USGS) in the design of a special, closed-loop, controlled environment chamber suitable for use with small quantities of radioactive tracers. ATDD also designed an aerodynamically correct sample holder for the exposure chamber.

c. Model development

ATDD worked closely with the EPA for many years on projects of mutual concern. Much of the work during the 1980s was related to the NAPAP program and to model development. One of the models developed was the Pollution Episodic Model (PEM), an urban-scale model capable of predicting short-term ground level concentrations and deposition fluxes of one or two gaseous or particulate reactive pollutants at multiple receptors. Work began on PEM in 1981 under an interagency agreement with the EPA; modifications, development of PEM-2, model evaluations, preparation of a User's Guide, etc., continued through 1985. There were several publications related to this model. Demand for one of them, *Plume Concentration Algorithms with Deposition, Sedimentation, and Chemical Transformation*, by K. S. Rao, (1983), was particularly heavy, and was cited by NTIS as one of their "best-sellers" during 1987.

2. Plume transport and dispersion

The Plume Transport and Dispersion program constitutes the foundation for research at the ATDD. It was designed to address specific problems confronting numerical modelers regarding the roles of changing atmospheric conditions and chemical reactions. Close interaction with all of the other components of the laboratory's research program is an integral part of the program, particularly for the ASCOT program.

Close relationships were maintained with all national laboratories involved in work on atmospheric dispersion, and with other government laboratories and universities. A working relationship was also established between ATDD and European scientists studying global-scale air chemistry. The ATDD made fundamental contributions in studies related to such matters as building-wake effects on dispersion, image analysis of smoke plumes to measure atmospheric dispersion parameters, and the study of the representativeness of meteorological observations and consequent model uncertainty. The ATDD played a leading role in developing many of the formulations currently popular in dispersion models.

a. Modeling

The theoretical development of a kinematic model that described the effects of variations in sampling time on dispersion measurements was completed in 1988. Also in 1988, the research-grade second-order closure convective PBL models developed at ATDD in 1977 for DOE's Meteorological Effects of Thermal Energy Releases (METER) program were revised and updated for other uses; documentation of the models was also developed.

A boundary-layer parameterization scheme based on the "well-mixed" hypothesis was developed in 1988 for the Global Model of Atmospheric Chemistry (GLOMAC) of the European EUROTRAC program. EUROTRAC funded environmental and atmospheric research in Europe, and supported modeling and deposition studies in the Bavarian Forest by ATDD staff.

b. Dispersion studies

A study of the probable environmental impact of fugitive coal dust emissions at the Ravenswood Power Plant, New York, was made for ORNL under the EPA Fuel Use Act Environmental Impact Study. In another project for ORNL, ATDD used remote sounding instruments and flow visualization techniques to assess the potential air quality impact of a coal gasifier facility proposed for a complex terrain site in Pikeville, KY.

A preliminary study related to the frequent occurrence of extremely dense fog along a section of an interstate highway, perhaps influenced by a nearby industrial source, was undertaken at the request of the Tennessee Department of Transportation. With DOE funding, a meteorological station was set up at a site on the I-75 right-of-way near the Hiwassee River, and recorded wind direction, temperature, and relative humidity for eight months (September 1980-April 1981). Unfortunately and tragically, the state canceled the project, and a recommended comprehensive study was never carried out. On December 11, 1990, 12 people died and more than 50 were injured when 83 vehicles were involved in chain-reaction accidents near this site in virtually impenetrable fog.

Three chapters in *Atmospheric Science and Power Production* (1982) were written by ATDD staff: "Flow and Diffusion Near Obstacles," by R. P. Hosker, Jr.; "Plume Rise and Buoyancy Effects," by Gary A. Briggs; and "Atmospheric Effects of Energy Generation," by Steven R. Hanna. This book, prepared under Department of Energy auspices, was the successor to *Meteorology and Atomic Energy, 1968*, and has been widely used.

A study was undertaken and a report was prepared for NRC on "Methods for estimating wake flow and effluent dispersion near simple block-like buildings," by R. P. Hosker (1981). An automatic desk-top computer-based video digitization system for photographic analysis of smoke plumes was designed and placed in operation in 1982.

A *Handbook on Atmospheric Diffusion*, by Hanna, Briggs, and Hosker, was published in 1982. This volume was a compact summary of the theory and practice of transport and dispersion modeling, and has been used by many institutions as an introductory college level text book in atmospheric transport. The Handbook was later translated by the Chinese government for use in that country.

In 1985 an extensive review was completed of the Gaussian plume model developed by K-25 scientists in Oak Ridge for assessment of possible effects following accidental release of UF_6 from uranium processing facilities. This work led to the development (1987-89) of a numerical model (TRIAD) designed to simulate the dispersion of gases that react quickly and exothermically with moisture in the atmosphere.

ATDD provided scientists and equipment for two field studies conducted in Brazil in April 1986 and February 1987, in collaboration with the Brazilian electric utility FURNAS at the ANGRA nuclear reactor site located in an unusually complex area. In 1973, F. A. Gifford had visited this site as a reactor safety consultant for the IAEA.

ATDD conducted a study for the NRC during 1985-86 to evaluate models available for simulating atmospheric transport and dispersion of pollutants on scales of tens to hundreds of kilometers; this included an evaluation of individual field experiments identified as useful for assessment of model performance on those scales.

A Workshop on Representativeness of Mesoscale Meteorological Observations was organized by ATDL and held in Boulder, CO June 29-July 1, 1981. The AMS Advanced Studies Institute on the Chemical and Meteorological Aspects of Atmospheric Source-Receptor Relationships was organized by ATDD and held in Oak Ridge in October 1986. The Third Southeastern Conference on Geophysical Fluid Dynamics was also held at ATDD in October 1986.

In August 1988, ATDD personnel participated in the Appalachian Mountain Air Chemistry Experiment (AMACE-88) near State College, PA. ATDD staff members set up and operated two surface eddy deposition and two balloon-borne atmospheric profile systems. Observations of eddy fluxes of momentum, heat, moisture and ozone were made.

K. S. Rao participated in the International Conference on Tropical Meteorology and Air Pollution, in New Delhi, India, in 1988, and presented two papers. One of the more important topics discussed was the problem of air pollution in relation to developing tropical countries undergoing rapid industrialization.

c. Planetary boundary layer (PBL) evolution and structure

ATDD conducted a one week per month boundary-layer measurement program in Oak Ridge using an instrumented tethered balloon system (tethersonde) from October 1981 until June 1982. Important classes of nocturnal flows were observed. Results of the study were the subject of an informal report prepared by Dr. Stephen Berman, an ORAU faculty research participant during the summer of 1982.

Methods for estimating dispersion coefficients, sensible heat fluxes, and evaporation rates by interpreting standard meteorological data were developed in 1986. This work was performed in conjunction with studies under the ASCOT, Canopy Micrometeorology, and Dry Deposition components of the ATDD program for DOE.

ATDD was invited to participate in a 1988 field study conducted by scientists from the Max Planck Institute for Chemistry, Mainz, FRG, in the savanna region of Venezuela. The ATDD performed tethersonde profilings through several diurnal cycles.

A comprehensive theoretical study of atmospheric gravity-wave-generated stress and vorticity in the PBL was completed in 1986. Analyses of sporadic turbulence in the nocturnal PBL over simple and complex terrain were completed. Data for this study were taken from the EPA/RAMS network and the Walker Branch Watershed site. Measurement capabilities were considerably expanded with the addition of a monostatic non-Doppler sodar (which remotely senses regions of atmospheric turbulence), uvw wind components, temperature profiles, and ozone concentrations at the Walker Branch site.

Through an interagency agreement with the U.S. Army Research Office, ATDD conducted a study of the statistics describing the intermittent breakdowns of the stable planetary boundary layer. C. J. Nappo reported on the work in 1988 in a final report to the ARO. Such breakdowns may be the dominant mechanism for nocturnal pollutant dispersion in many areas.

3. Diffusion and deposition studies

Work on sulfur deposition for the Tennessee Valley Authority began in 1981-82, and led to the development of a well-mixed sector-box model to estimate the airborne pollutant fluxes and deposition to the Camp Branch and Cross Creek TVA watersheds. As part of the DOE/NOAA collaborative efforts on evaluation of dry deposition fluxes from field observations, a computer routine for analyzing pollutant and meteorological gradient data was also developed. .

A statistical diffusion model for studying the effect of PBL dynamics on long-range dispersion was placed in operation in 1982 and named LTDM - Lagrangian Trajectory and Diffusion Model

In 1981-82, work was undertaken for the Nuclear Regulatory Commission (NRC) on diffusion from low level waste facilities. A paper by W. M. Culkowski on this subject was published in the proceedings of the NRC Symposium on Low-Level Waste Disposal: Site Characterization and Monitoring, held in 1982 in Arlington, VA. A review of several models suitable for low level waste disposal was published as a NUREG Report in 1984.

4. Canopy/atmosphere interaction (Forest meteorology)

The ATDD research site at the Walker Branch Watershed was acknowledged as one of the most heavily instrumented and intensively used forest meteorology research sites anywhere. Basic studies were conducted related to the interaction between the atmosphere and vegetation canopies, with emphasis on forests. It served as an intensive research site for dry deposition research under the aegis of NAPAP and as a monitoring site under NAPAP's National Trends Network. The research addressed the need to improve understanding of turbulent transport and deposition of materials (such as pollutants, water vapor, and carbon dioxide), sensible heat, and momentum within and immediately above forest canopies. The eventual goal of this program was to provide a method for deriving atmosphere-surface exchange rates from observations that can be routinely made.

A Workshop on Plant Canopy Structure, sponsored by the U. S. Army Research Office, was held in Oak Ridge in April 1981. B. A. Hutchison served on the steering committee that planned and proposed the workshop, and was co-editor of the proceedings. ATDD also co-hosted the Forest Environmental Measurements Conference held in Oak Ridge, October 23-28, 1983. It was attended by 90 scientists from 12 countries. The conference proceedings were published in *The*

Forest-Atmosphere Interaction, edited by B. B. Hicks and B. A. Hutchison. ATDD and ORNL staff also participated in a study to assess the energy conservation potential of landscaping designed to ameliorate the microclimates of buildings, and served on the panel of a Workshop on the Amelioration of Building Microclimates, held in State College, PA in February 1981. Hutchison was one of the authors of a report on this subject prepared for ORNL in 1982.

Numerous dry deposition and radiation experiments were conducted at the Walker Branch site during the 1980s. Most of them were collaborative efforts and involved several other organizations, including the U.S. Army Engineers' Waterways Experiment Station, Colorado State University, Pennsylvania State University, University of Michigan, University of Nebraska, EG&G Energy Measurements Group, Oak Ridge National Laboratory, Argonne National Laboratory, NASA, and scientists from the University of Munich, Germany.

For example, in May 1983, a major experiment on dry deposition was conducted at the Walker Branch field site. Experimental capabilities from five collaborating institutions were combined to measure eddy fluxes of a range of pollutants, and to compare the results with data obtained by other methods (especially leaf-washing and surrogate surface techniques).

A collaborative study of thermal radiation exchanges in and above a fully-leafed deciduous forest was conducted at the forest meteorology research site in 1984. Measurements were made of broad band radiation distributions within and above the forest canopy, infrared radiation from the upper surface of the forest canopy, soil temperature profiles, routine climatological data, above-canopy radiation balances of solar, PAR, and allwave radiation, and the infrared temperature distribution within the canopy.

CO_2 flux measurements were first made at the Walker Branch site in 1984 using the eddy correlation technique. Two open-path fast response infrared gas analyzers, developed at Lawrence Livermore National Laboratory, and an ATDD modified commercial infrared gas analyzer were used to measure the turbulent fluctuations in atmospheric CO_2 concentrations.

Measurements of thermal radiation were made in and above the leafless forest canopy at the forestry site in late February 1985. ATDD provided research facilities, radiometric instrumentation, and data acquisition capabilities in addition to manpower for this effort. A collaborative study of canopy radiative transfers was conducted in early summer, 1986. Forest canopy signatures were determined using a near-infrared imaging laser system, a thematic mapper simulation, and an imaging thermal system using a helicopter as the sensing platform.

In 1986, a pilot study was conducted to measure eddy fluxes of carbon dioxide, water vapor, sensible heat and momentum at the floor of a deciduous forest. And in 1988, a related experiment to measure the fluxes to and from the floor of a deciduous forest was conducted. Exchange rates of water vapor, heat, momentum, CO_2, SO_2, and O_3 were measured.

In April 1986, a team of ATDD researchers was invited to participate in a cooperative turbulence study (Project WIND) conducted in an almond orchard near Chico, CA, by the U.S. Forest Service and U.S. Army Atmospheric Sciences Laboratory.

ATDD maintained a working relationship with several European groups active in the field of dry deposition, especially to forests, and participated in several collaborative experiments during the 80s. In March 1985, ATDD participated in a large multi-laboratory investigation (the TULLA campaign) of sulfur dioxide emission, transport and deposition in southern Germany. In September 1989, ATDD participated in BIVOTEX II in the Bavarian National Park, a study to investigate the vegetation-atmosphere exchange of ozone and volatile organic compounds, especially terpenes.

5. Atmospheric studies in complex terrain (ASCOT)

It was recognized in the earliest stages of the discussions and planning that led to the ASCOT program that field measurements would be an essential part of the work. A large number of field studies were conducted during the 80s, and ATDD participated in many of them. When R. P. Hosker became ASCOT field director in 1985, ATDD also assumed responsibility for organizing and directing several more.

ATDD staff participated in ASCOT experiments in the Anderson Creek Valley in California in 1979, 1980, and 1981, and in a drainage flow study conducted near Los Alamos on the Lone Spruce ski slope of Los Parajetos Mountain in June 1982. A team of five ATDD personnel, assisted by two people from the Rio Blanco Oil Shale Company, conducted experiments at several oil shale sites in western Colorado in August 1982, just before an exploratory ASCOT study in Brush Creek valley, north of Grand Junction. ATDD also operated a video system and a tethersonde system in the EPA-ERT Plume Impaction Study near Farmington, NM, during October 1982.

ATDD provided three measurement teams (two tethersonde systems and a flux measurement system) and support for quality assurance programs and documentation in the fall 1984 ASCOT experiment in the Brush Creek area north of DeBeque, CO. Exploratory studies were conducted by ATDD in September 1986, in the flow confluence zone at the junction of Brush and Roan Creeks in western Colorado. Overall program coordination, personnel, a tethersonde system, and a 6m instrumented tower were provided by ATDD for a large exploratory multi-valley ASCOT experiment held in the vicinity of Brush Creek Valley in western Colorado in July 1988. Six laboratories participated in the study; the goal was to determine the late afternoon, nocturnal, and morning transition flows within a number of valleys of different geometries and orientations.

The variations of plume dispersion parameters in the nocturnal drainage flow in a deep valley were studied by analyzing the mean wind and turbulence data obtained by Doppler sodars and instrumented towers during the ASCOT 1984 Brush Creek experiment.

Results of the ASCOT program were detailed in numerous reports and publications, and many of them have been listed in Appendix A. "Physical Measurements in ASCOT," by R. P. Hosker, Jr., in *Atmospheric Studies in Complex Terrain, Technical Progress Report, FY-1979 Through FY-1983*, provides an excellent look at the early program and the technologies used. ATDD staff authored four of the papers that appeared in the June and July 1989 issues of the *Journal of Applied Meteorology*; these volumes were devoted exclusively to the ASCOT program.

The state of Maryland, in 1985, requested this laboratory's participation on a Technical Advisory Committee on Complex Terrain Siting, a problem of interest to both the DOE and the EPA. Dr. R. P. Hosker was chosen to represent the ATDD.

6. Physical modeling

The ATDD wind tunnel was originally designed to permit experimental studies of the interaction between obstacles and fluid flow. It was modified in 1985 to conduct particle deposition studies to characterize the collection efficiency of a surrogate surface large-particle dry deposition collector developed by Carnegie-Mellon University under a contract with ATDD. Then in 1986, ATDD, ORNL, and Carnegie-Mellon completed work on a collaborative project on the evaluation of various surrogate surfaces as candidates for use in routine monitoring of the deposition of airborne particles.

A study of the effects of large buildings on dispersion of pollutants released at industrial complexes was conducted in 1985-86, as a joint venture of the ATDD facility and the larger wind tunnel of the EPA Fluid Modeling Research Laboratory in North Carolina.

Wind tunnel studies were conducted during the late 80s, in collaboration with ORNL staff, to determine the optimal design features for enclosing mature trees in an open-top chamber for a pollution exposure study. More than 100 potential configurations were explored. The work was the subject of a cover story for the *Journal of the Air Pollution Control Association*.

A wind tunnel technique using naphthalene sublimation was developed to study the effects of aerodynamics and configuration on dry deposition to building materials. Tests were also conducted on complex objects such as model statues, including the Statue of Liberty, to examine deposition rates relative to flat surfaces; this work was part of the NAPAP effort.

7. Emergency preparedness/management program

The subject of emergency preparedness was recognized as an issue of importance by those involved in the earliest studies of nuclear power and atomic energy. The magnitude of potential problems became more apparent following a series of major disasters, such as the Bhopal accident in India. In 1987, at the request of the DOE, ATDD established a separately funded special program, headed by W. R. Pendergrass, whose purpose was to provide support to the DOE Oak Ridge Field Office on matters related to the consequences of accidental atmospheric releases of hazardous materials from any of the research or production facilities under ORO jurisdiction.

While this program did not involve a research component, it did serve to reiterate and to bring back into focus the original purpose of the ATDD, i.e., to provide support to DOE on matters related to the atmospheric release of potentially dangerous materials, and to conduct appropriate research in line with the scientific interests of NOAA. The work was strongly related to other ongoing research efforts at ATDD, with other DOE programs (ASCOT, ARAC) also providing information relevant to assessment and enhancement activities.

DOE provided funds and made special arrangements early in 1987 for procurement of major equipment needed for the emergency preparedness/management program. DOE also provided a modular office unit, located behind the permanent ATDD facility, to house the program. In October 1987 the first meteorological site survey at Fernald, Ohio, was conducted. This was followed by a second one at Paducah, KY in April 1988, and a third at Portsmouth, OH in November 1988. In 1989 a year-long survey of the Oak Ridge area was initiated with an array of 24 towers erected in strategic areas within and surrounding Oak Ridge. A tall tower near the old Fast Breeder Reactor had six levels of instruments installed to provide vertical profile data on wind speed and direction, temperature, and relative humidity. Data were collected automatically by radio telemetry from the solar powered stations, and analyzed on desktop computers. Data analyses and report preparation were begun immediately after each survey.

A Hazardous Atmospheric Release Model (HARM, soon modified to HARM-II), a comprehensive emergency response modeling system, was developed and installed in the ORO emergency response center, incorporated into the routine plant operations at three ORO installations, and into several state emergency management centers. The model provides real time projections for both radiological and reactive chemical releases into the atmosphere. It is maintained by ATDD as a state-of-the-art defensible dispersion prediction system. ATDD also established a Weather Information Center, relaying daily forecasts to the ORO response center and to the shift superintendent's offices at all ORO facilities.

A formal review of the Emergency Response/Management Program was held in August 1988.

8. Personnel

Sue Sheffield, division secretary, and meteorologist Searle D. Swisher retired in 1986. Sharon Conger was employed as the new secretary in June 1986. Barbara Johnson, who became Administrative Officer upon the retirement of Ruth Green, was employed in 1989. Various other scientific, technical, and support personnel were added, as listed in Appendix B.

Eight foreign scientists from eight different countries worked, studied, and conducted research on topics of interest to the ATDD during the 1980s. Among them were Dr. Byung Woo Kim, an IAEA Fellow from Korea; Dr. Manju Kumari of the Indian Institute of Technology, sponsored by the U.S. National Science Foundation; Mr. Guo-Jun Ma from China, sponsored by the World Health Organization; Dr. W. L. Physick from Australia, sponsored by the CSIRO and ATDD/ORAU; Mr. Hilmi Subuncu, IAEA Fellow from Turkey; Dr. R. Seshu Tangirala from India, sponsored by CIES and the Indo-American Fellowship Program; Mr. Bart van den Hurk, a graduate student from The Netherlands; Mr. Wang Hanjie from China; and Dr. Yar Yariv, with the Israel Atomic Energy Commission.

9. Other

Beginning in 1981 with one desktop computer shared by the scientific staff, a fundamental change that occurred during the 80s was the installation of desktop computers (PCs) for virtually all staff members. This greatly reduced reliance on mainframe computers, significantly improving productivity in data analysis, model development and testing, and report preparation.

Several reviews of the ATDD program were conducted during the 1980s. The first was a review by NOAA's Environmental Research Laboratories in October 1981. This was followed by Department of Energy reviews in April 1982 and in January 1988. Reviews of specific portions of the program were conducted at various intervals throughout the period.

Dr. R. P. Hosker, Jr. was appointed as a consultant to the Advisory Committee on Reactor Safeguards (ACRS) in 1982, succeeding F. A. Gifford; this work continued until 1988.

ATDD accepted an invitation of the Chinese Environmental Protection Office, Ministry of Water Resources and Electric Power, for R. P. Hosker to visit, at their expense, Beijing and Nanjing, China in 1985 to present a series of lectures, and to discuss research programs of mutual interest and possible collaboration between MWREP scientists and ATDD.

In 1989 the National Research Council selected ATDD for participation in NRC's post-doctoral research fellow program. Potential areas of collaboration include complex terrain turbulence studies and dispersion modeling, dry deposition research, and air-surface exchange.

James D. Womack represented the ATDD as part of a U. S. delegation attending an International Symposium held in Cracow, Poland in June 1989. The symposium was sponsored by the U. S. National Park Service, the Department of the Interior, and the Polish Ministry of Culture. Its purpose was to study the effects of pollution upon Poland's national monuments, including the famed salt mine sculptures at Weiliczka, located in the suburbs of Cracow. Womack presented a paper describing NOAA's dry deposition network monitoring program.

The ATDD has long maintained a strong interest in public education and hosted hordes of elementary school children every year, presenting talks, demonstrations, and facility tours related

to the research programs. Of particular interest to the children was a small chamber made of clear Plexiglas designed to simulate a vortex ("tornado"), developed in 1988 by Tilden Meyers, Robert Mayhew, and R. P. Hosker.

The NOAA Office of Inspector General conducted an unannounced inspection of the ATDD during the week of January 23, 1989. On the whole, their report was complimentary of the ATDD management and administrative procedures. A few minor issues were readily resolved.

VI. The 1990s

With the decade of the 90s just starting, predictions regarding the focal point of the decade would be somewhat premature. Basic research related to atmospheric dispersion studies continues. Complex terrain and air-surface exchange experiments and subsequent data analyses occupied much of 1990 and 1991; it appears that the same will be true of 1992. The aftermath of the Persian Gulf War occupied the time of one scientist full time and several others part-time for many months in 1991. Sharon Conger, ATDD secretary, gained a considerable following throughout NOAA as the Saudi Arabia/Kuwait travel expert.

The ATDD directorship changed hands once again. Bruce B. Hicks departed in June 1990 for his new position as Director of the Air Resources Laboratory in Washington, D.C. He was succeeded by Dr. R. P. Hosker, who has been with ATDD since 1971. Ruth A. Green, the ATDD Administrative Officer, retired in 1990 after 33 years of government service.

Efforts began to extend research into other related areas, such as the Global Monitoring for Climatic Change (GMCC) program. Funding for the NAPAP program was extended by Congress, as part of the Clean Air Act Amendments, but the role that NOAA/ATDD will play in the future program has not yet been clearly defined. Work on the organizational structure of NAPAP is now under way.

1. Plume transport and dispersion

In 1989 ATDD began a two-phase study, "Sheltering Against Airborne Radioactivity," for the National Aeronautics and Space Administration. The first phase focused on potential exposure of people riding in automobiles; the second phase involved the matter of dispersion and likely zones of influence along transportation routes (both surface and atmospheric) and took into account the peculiarities of dispersion in a gravity-free environment. This work was begun as a DOE/NASA interagency agreement, but subsequently was renegotiated as a NOAA/NASA agreement. Work is now in progress on both phases of the project and is expected to continue through at least FY 1993. The Air Resources Laboratory was also asked by NASA to evaluate the dispersion models in use by the Meteorological and Range Safety Support system at Kennedy Space Center. The review team was led by R. P. Hosker and included two additional ATDD scientists, K. S. Rao and R. M. Eckman.

ATDD staff spent several weeks in June and July 1990 participating in NOAA's ROSE (Rural Oxidants in the Southern Environment) field campaign in a vast loblolly pine plantation in Sumter County, Alabama. ATDD performed tower-based meteorological and ozone concentration measurements; tethered balloon meteorological and ozone concentration measurements; tower-based eddy flux measurements; and aircraft-based flux-measurements. ATDD also participated in ROSE II, held in Meridian, MS and rural Alabama during June 1992. ATDD's experimental effort featured a tower-mounted eddy correlation flux system to measure surface-atmosphere exchange

of sensible heat, latent heat, ozone, NO_2, and CO_2. Measurements of NO_y and NO fluxes were also attempted. In addition to the tower-based measurements, airborne measurements were conducted from June 18 to June 21.

ATDD participated with Los Alamos National Laboratory (LANL) and the Mexican Petroleum Institute (IMP) in the first field experiment of the Mexico City Air Quality Research Initiative (MCAQRI) conducted September 10 - 21, 1990. MCAQRI is a three-year program (Fys 91-93) jointly funded by the U.S. Department of Energy (through LANL) and the IMP to study the unique air pollution problems of Mexico City, train IMP personnel on data gathering techniques, and help Mexican authorities identify options for improving Mexico City air quality.

2. Dispersion studies

During October 1990, ATDD scientists participated in the NCAR/NOAA turbulence experiment near Carpenter, WY. The purpose of the program was to evaluate the atmospheric turbulence kinetic energy balance in a horizontally homogeneous surface boundary layer, measuring every term of the energy balance directly, using-state-of-the-art sensors. ATDD installed and operated two microbarograph networks during most of the experimental period; the objective was to observe the effects of gravity waves on turbulence in the planetary boundary layer.

In 1991 a research proposal "Waves and Stability in the Planetary Boundary Layer," was funded by the U. S. Army Research Office. The study analyzed the data from the Oak Ridge meteorological site survey program and the atmospheric pressure data obtained by the ATDD microbarograph array.

3. Persian Gulf response

ATDD's involvement with the response to the massive oil fire plumes in the Persian Gulf area began in March 1991 with the provision of a simple direct and diffuse solar radiation measurement system for use by G. E. Start (ARL/FRO) on site in Saudi Arabia and Kuwait. W. P. Pendergrass went to the Gulf on April 3, to relieve Start, and to act as head of the U.S. Interagency Air Monitoring Team. Subsequently, ATDD arranged for the shipment of a network of DOE/ORO owned, solar-powered, instrumented meteorological towers to be shipped to Kuwait to assist with estimates of initial plume transport and dispersion in the complex flow fields encountered. Three other ATDD scientists travelled to the Gulf to assist with tower installation. Pendergrass also represented the U.S. Monitoring team at a meeting of the World Meteorological Organization (WMO) held April 27-30, 1991, in Geneva, Switzerland. The meeting addressed the questions of what the international meteorological community could do to understand the plume impact problem, and how to develop improved predictive capability.

4. Canopy/atmosphere interaction

Dr. Dennis Baldocchi spent six weeks during 1990 at the Meteorological Institute of Stockholm University as an invited guest scientist. He participated in a collaborative experiment to study the chemical, meteorological, and biological processes contributing to the turbulent transfer of ozone, heat, water vapor, and momentum over a coniferous forest. He also presented lectures related to turbulent transfer and turbulence in a deciduous forest.

An eddy correlation experiment was conducted during July-August 1990 at the Huntington Forest Research Site in Newcomb, NY, a deciduous forest site in the heart of the Adirondack State Park. The objective of the experiment was to measure directly the dry deposition of SO_2 and O_3.

5. Air-surface exchange/Dry deposition

In a pioneering effort, ATDD staff developed a "generic" Mobile Flux Platform (MFP), in response to research needs for a low cost system capable of measuring representativeness and spatial variability of air-surface exchange over various ecosystems. The system utilizes inexpensive sensors and computers to remove the effects of vehicle motion from fluxes measured from a moving platform. It was initially tested on a light airplane. The MFP was fully described in a NOAA Technical Memorandum by T.L. Crawford, R. T. McMillen, and R. J. Dobosy.

ATDD, Argonne and Los Alamos National Labs, and Pacific Northwest Labs were among the participants in a new DOE-sponsored program, Atmospheric Radiation Measurements (ARM), to conduct studies related to understanding the energy balance affecting the earth's atmosphere, e.g., the impact of clouds on energy and the energy budget. ATDD provided equipment and personnel for the ARM field experiment held in Boardman, OR in June 1991. ATDD researchers attempted to measure all the factors contributing to the partitioning of solar and terrestrial energy into sensible, latent, and soil heat fluxes, using two tower-based eddy correlation systems, and an airborne Mobile Flux Platform system.

ATDD again collaborated with several DOE laboratories and universities, including Pacific Northwest Laboratory, Argonne and Los Alamos National Laboratories, and Texas A & M University, in a second intensive ARM field experiment at Boardman, Oregon, during the first two weeks of June 1992. These experiments, at a site characterized by an abrupt change in surface conditions from dry desert to optimally irrigated farmland, provided a data set exhibiting a strong signal due to the inhomogeneous surface. ATDD collected mean and eddy correlation flux measurements from the airplane version of the ATDD Mobile Flux Platform. Also during this study, heat, moisture, and CO_2 fluxes were measured over a potato field with a stationary and a mobile flux station.

Data collected at the Oak Ridge CORE site were sent to the Harvard school of Public Health, to be included in the Twenty-four City Acid Aerosol Health Effects Study. Included in the data set was the complete 1989 record of ozone concentrations at the CORE site.

6. Air-sea exchange

In June 1990, ATDD conducted an experiment in the Florida Keys to develop and demonstrate ship-borne techniques for measuring CO_2 exchange between the sea and the atmosphere. Two instrument systems developed at ATDD during the late 80s were used in the experiment: an open path H_2O/CO_2 fast response gas analyzer based on infrared absorption techniques, and a modified version of the Mobile Flux Platform (MFP) which allows turbulent flux measurements on "generic" moving platforms without the expense of an inertial navigation system. ATDD staff presented seven papers at the AMS Seventh Conference on Meteorological Observations and Instrumentation, Session 2: Atmospheric Flux Measurements over Oceans, January 13-18, 1991, New Orleans, Louisiana.

A new project to directly measure air-sea exchange of momentum, heat, and moisture within the western Pacific warm pool system, has been initiated by ARL. The project supports the International Coupled Ocean-Atmosphere Response Experiment (COARE) specifically responding to COARE'S highest priority goal: "to describe and understand the principal processes responsible for the coupling of the ocean and the atmosphere in the western Pacific warm pool system." The project will be carried out by ATDD in collaboration with the National Atmospheric Research Laboratory of New Zealand during January and February, 1993. A Mobile Flux Platform system will be deployed on a small sailing vessel.

7. Atmospheric studies in complex terrain (ASCOT)

The 1990 ASCOT field study was conducted from February 28 through March 14, 1990 in the portion of the eastern Tennessee River Valley surrounding Oak Ridge and Knoxville. Teams from Argonne, Lawrence Livermore, and Los Alamos National Laboratories, Pacific Northwest Laboratories, and the University of Kansas participated in the ATDD-led study. The array of towers set up earlier for the Oak Ridge site survey under the DOE emergency management program were also utilized. ATDD operated a dual-theodolite pibal/airsonde station on the Cumberland plateau. Turbulent flux measurements (momentum, heat, water vapor, and ozone) were conducted by ATDD on the Walker Branch tower and at the northernmost tethered balloon site. The ATDD Mobile Flux Platform was installed on a light airplane and flown over a series of ridges. ATDD also carried out a total of 85 instrumented tethered balloon ascents at a site in Union County, northeast of Knoxville. The Waves and Turbulence Experiment (WATEX), a joint ATDD/Argonne study, was designed to observe episodes of gravity wave turbulence interactions, and was an important component of the ASCOT 1990 field study. For this segment, ATDD developed and assembled ten microbarographs. Data analysis for all components of the study began immediately after the experiment ended. After the completion of this study, R. P. Hosker resigned as ASCOT Field Director, because of new duties as ATDD Director.

The 1991 ASCOT field study was held near Rocky Flats, Colorado, January 28 - February 8. Three tethersondes, an airsonde, a rawinsonde, and WPL Doppler lidar were used to examine the wind and temperature patterns of the flows emerging from the Front Range onto the plains near the DOE Rocky Flats facility. ATDD's tethersonde team performed 52 successful flights, and operated a meteorological tower.

A talk on "Mesoscale wind fields on the Oak Ridge Reservation" was presented by an ATDD scientist at the First Annual Walker Branch Watershed Symposium in March 1990. Preliminary data from the Oak Ridge site survey were discussed.

8. Emergency preparedness/management program

Improved versions of HARM-II were installed on workstations for K-25 and the Feed Materials Production Center (Fernald). Further improvements are under way. Program documentation and training materials were developed, for training of site operators in use of the HARM-II code.

At the request of DOE, W. R. Pendergrass is serving as a member of the Meteorology Subpanel of the Interagency Nuclear Safety Review Panel. The panel reviews all safety analysis documents concerning space shuttle missions involving nuclear materials used in power-generators. Pendergrass also serves as a member of the DOE Dose Assessment Subcommittee, which provides guidance and recommendations to DOE on matters related to atmospheric releases of hazardous materials.

In March 1991, ATDD formally presented to the Department of Energy and Martin Marietta personnel the results of the Oak Ridge site survey. ATDD recommended that ten supplemental towers be installed around Oak Ridge to provide an adequate representation of the regional-scale wind field. However, DOE then requested and was provided with recommendations for locating an array of towers around each of the three Oak Ridge plant sites, covering local scale flows. Implementation of this network is still pending.

9. Other

Dr. K. S. Rao was selected by the U.S. National Science Foundation to participate in the U.S.-India Exchange of Scientists program, and visited India during February and March 1992. In February and March 1992 R. P. Hosker, Jr., headed a team of five U.S. scientists from NOAA, ORAU, National Park Service, and Caltech that conducted exploratory studies of atmospheric moisture content and pollutant concentrations within the endangered Wieliczka Salt Mine World Heritage site. In collaboration with a Polish Academy of Sciences team, equipment was installed and training provided for a one year-measurement program to determine the likely sources of moisture in the mine that are causing the centuries-old monuments and carvings in the salt to deteriorate.