50th Anniversary

Oak Ridge National Laboratory

Health & Safety Research Division

Managed by Martin Marietta Energy Systems, Inc.,
for the
United States Department of Energy

ORNL/M-2108

A Brief History of the Health and Safety Research Division at Oak Ridge National Laboratory

G. D. Kerr
R. H. Ritchie
S. V. Kaye
J. S. Wassom

July 1992

Prepared by the
Oak Ridge National Laboratory
Oak Ridge, Tennessee 3783 l-6383
managed by
Martin Marietta Energy Systems, Inc.
for the
U.S. Department of Energy
under contract DE-AC05-84OR21400

PURPOSE AND MISSION OF THE HEALTH AND SAFETY RESEARCH DIVISION

THE HEALTH AND SAFETY RESEARCH DIVISION HAS AS ITS PURPOSE AND MISSION TO PROVIDE A SOUND SCIENTIFIC BASIS FOR THE MEASUREMENT AND ASSESSMENT OF HUMAN HEALTH IMPACTS OF RADIOLOGICAL AND CHEMICAL SUBSTANCES.

CONTENTS

FOREWORD

Each division at the Oak Ridge National Laboratory (ORNL) has been asked to prepare a brief history for ORNL's 50th Year Celebration. The Health and Safety Research Division (HASRD) formed a committee of staff members who had a distinct knowledge of the history of various research activities within the Division. The committee members were Rufus Ritchie (Instrumentation and Basic Physical Research), George Kerr (Applied Physical Research and Operational Health Physics), Steve Kaye (Environmental and Biomedical Research), and John Wassom (Biomedical and Environmental Information Analysis). Kerr served as chairman and prepared this report. The committee helped in the preparation of an outline and in the identification of either present or former staff members who could write a brief history on the various outline topics. Larry Davis served as electronic publisher, Vickie Conner designed the cover, Judy Aebischer was the technical editor, Sonia Rogers provided valuable secretarial assistance, and other HASRD staff members too numerous to mention have contributed materials and assisted in the review of the report prior to its publication.

INTRODUCTION

The Health and Safety Research Division **(HASRD)** has an illustrious history dating back to the successful operation of an experimental **uranium–** graphite pile at the University of Chicago in December 1942. Plans were soon under way for the construction of a Clinton Laboratories pilot plant at Oak Ridge, Tennessee, and larger production units at Hanford, Washington, as part of the Manhattan Project.[1] The purpose of the pilot plant was to train crews to operate the larger Hanford production units and to demonstrate the safe production and chemical separation of the fissionable ^{239}**Pu** isotope from uranium irradiated in the X- 10 pile at the Clinton Laboratories (Fig. 1). The Clinton Laboratories were renamed the Clinton National Laboratory in 1947 and the Oak Ridge National Laboratory (ORNL) in 1948.

Before the X-10 pile could begin to operate in November 1943, numerous health and safety **problems** had to be solved. Previously, a few people had worked on rare occasions with one or two curies of radium, but the new pilot plant operations would require working with unheard-of quantities of curies of radioactive materials as a routine procedure. Therefore, a Health Division was established, first at the University of Chicago and then at the Clinton Laboratories.

These Health Divisions consisted of a medical group, a biology group, and a physics group, whose efforts were divided along three major lines:[1]

1. Preemployment physical examinations and frequent reexaminations, particularly of those persons exposed to radiation, were adopted.

2. Research was carried out on the effects of direct exposure of people and animals from various types of radiation and the effects of ingestion and inhalation of various radioactive and toxic materials, such as uranium, plutonium, and the products of the fission reactions in a pile.

3. Tolerance standards were set for radiation doses, and instruments were developed for measuring the radiation exposures of personnel, continually measuring radiation intensities at various locations in the work place, and measuring for radioactive contamination of air, water, clothing, laboratory desks, etc.

The name "health physicist" was soon applied to those working in the physics groups of the Health Divisions at the University of Chicago and Clinton Laboratories.

Early health physicists, such as ***K. Z.*** Morgan, H. M. Parker, and E. 0. Wollan, brought to this field a thorough knowledge of basic physics and radiation instrumentation. They redesigned and adapted the early ionization chambers, film meters, electroscopes, electrometers, proportional counters, and **Geiger-Müller** counters to meet the requirements for personnel monitoring and for radiation survey of buildings and the environment.

A separate Health Physics Division (HPD) was formed at the Clinton Laboratories in 1946 (Fig. **2),** and its **first** director was K. ***Z.*** Morgan (Fig. 3). Trained as a cosmic ray physicist and thus aware of the importance of fundamental knowledge and research, Morgan instituted a vigorous program to upgrade existing instrumentation

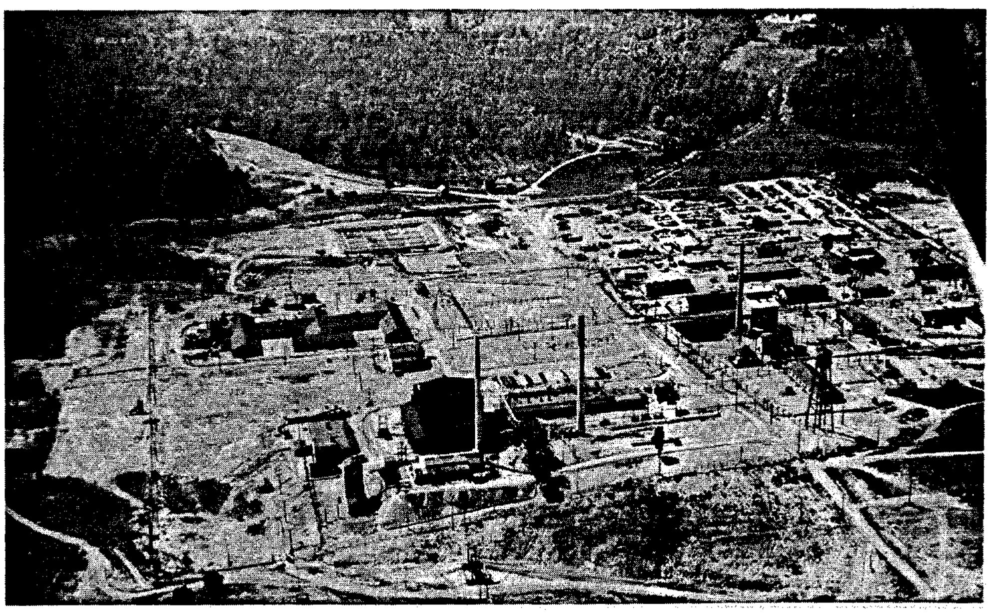


Fig. 1. Clinton **Laboratories** in **1944.** The large building in the center houses the X-10 pile. It is a National Historic Landmark and is open for viewing by the general public.

Fig. 2. Christmas party in 1646 for employees of the Health Physics Division at Clinton Laboratories.

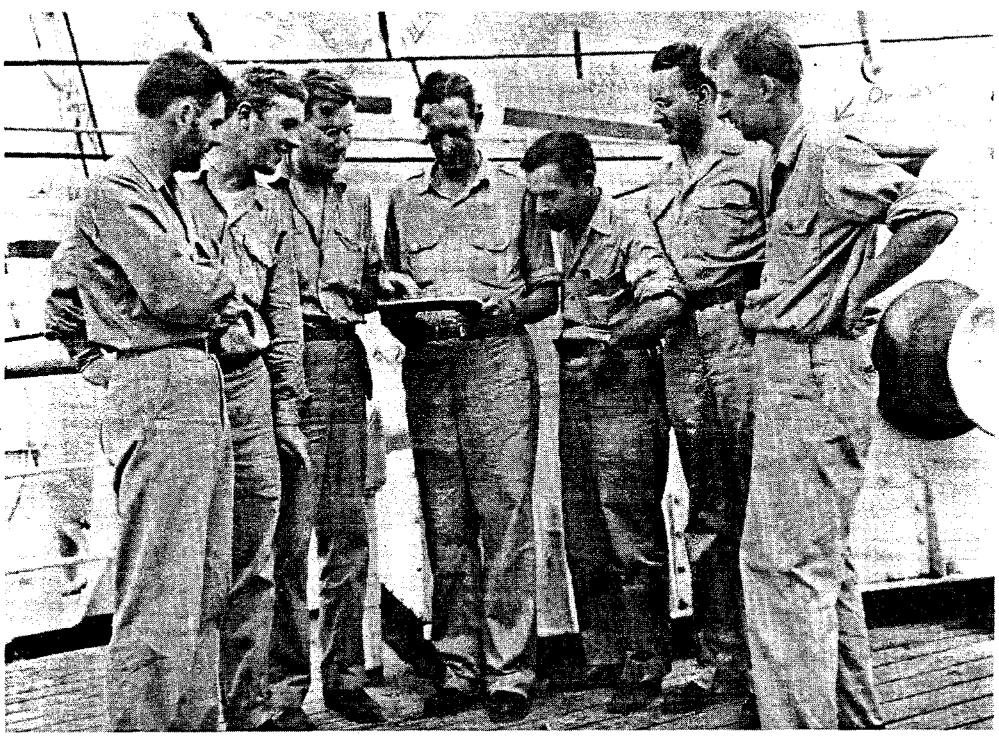


Fig. 3. Photograph taken in 1646 during the nuclear weapon tests of Operation Crossroads in the southern Pacific Ocean. Shown left to right are an unidentified person, Joe *Deal* (Clinton Laboratories), *Tom Bortner* (Clinton Laboratories), *K. Z.* Morgan (Clinton Laboratories), Joe *Cheka* (Clinton Laboratories), *W. H. Sullivan* (Clinton Laboratories), and Art **Snell** (Clinton Laboratories).

using improved techniques that were developed during wartime research in radar and in the Manhattan Project. With only a handful of talented young researchers under the outstanding leadership of Morgan and his successors John ***Auxier*** (Fig. 4) and Steve Kaye (Fig. 5), this modest beginning resulted in many important developments and became the basis for the present Health and Safety Research Division.*

HASRD was organized in April 1977 to augment ORNL's capabilities to deal with the broader problems of other energy technologies and the assessment of human health impacts of both radiological and chemical substances. Most of the research components of HPD were incorporated into HASRD. Also in April 1977, the Analysis and Assessments Section of the Environmental Sciences Division and the Medical Radioisotopes Group of the Operations Division were transferred to HASRD. Finally, the Information Research and Analysis Section of the Biology Division was added to HASRD in 1987. HASRD staff members have expertise for application in a variety of energy technologies (fission, fusion, coal, coal conversion, etc.), in nuclear medicine and radiation dosimetry, and in assessment of risk associated with a variety of hazards (radiological pollutants, chemical pollutants, lasers, etc.).

A convention used throughout this history is to italicize the names of HPD or HASRD staff members to set them off from the many other names that appear in the text and photographs.

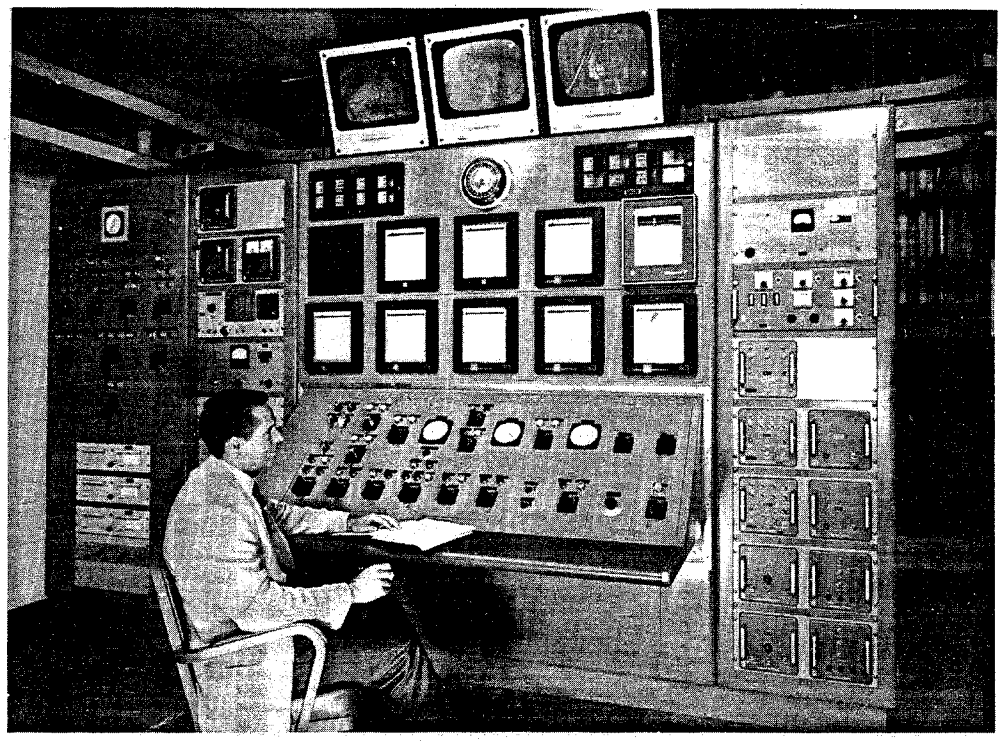


Fig. 4. Early photograph showing John ***Auxier*** seated in the control room of the Health Physics Research Reactor.

Fig. 5. Early photograph of ***Steve Kaye*** (left) discussing the Plowshars Project with ***Walter*** Snyder (center), Don ***Jacobs*** , and ***Paul Rohwer*** (right).

THE FORTIES

Instrument Development and Basic Research

Toward the end of the **1940s**, the embryonic Divisional effort in research and development included the Instrument Development Group, which consisted of Sam Hurst, W. M. Hurst, Brian Wagner, and a few engineers. This group worked at improving instrumentation for neutron dosimetry in mixed radiation fields, which at that time consisted primarily of nuclear track emulsion and the Chang and Eng survey meter (Fig. 6). Sam Hurst joined the Division in the fall of 1948 and was responsible for a strong program in the development of new concepts in radiation dosimetry. In addition, the Experimental Physics Group, with Francis Davis and Paul Reinhardt, was concerned with the level of radioactivity in the Laboratory environs and began working closely with the U.S. Geological Survey to develop airborne radioactivity monitoring instrumentation (Fig. 7). The Special Problems Group, composed of Tom Bortner and Joe Cheka, studied the detection and characterization of radioactive particulates and addressed questions concerning beta-ray dosimetry. The Theoretical Physics Group, with Jake *Neufeld* and Walter Snyder [then a consultant to ORNL from the Mathematics Department of The University of Tennessee (UT)], was concerned with the basic interaction of radiation with matter. In the last few months of the decade, Rufus *Ritchie* joined this group.

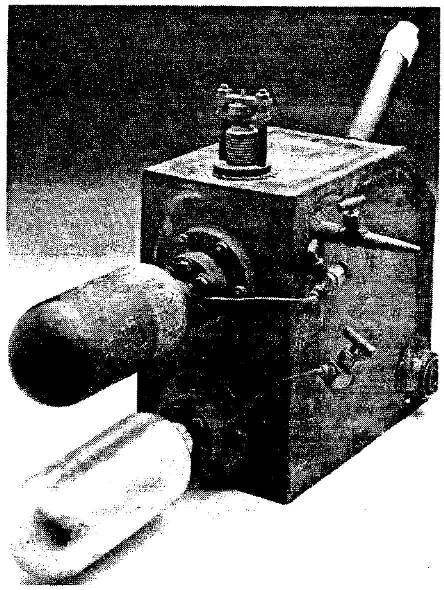


Fig. 6. Chang and Eng survey meter for neutrons and gamma-rays. dne chamber of this early type of survey meter was sensitive to only gamma rays, and the other chamber was sensitive to both gamma rays and neutrons. The neutron exposure was obtained by subtraction using the readings from the two chambers (photo obtained from Paul Frame of Oak Ridge Associated Universities).

Fig. 7. Airplane used by ths Airborne Gsophysks Unlt of ths U.S. Geological Survey and the Health Physics Division to make surveys of the levels of radioactlvity In the environs of the Oak Ridge Reservation during the late 1940s. Shown to the extreme right of the photograph are ***Paul Reinhardt*** and *Francis Davis* of Oak Ridge National Laboratory. A. Y. Sakakura, then with the U.S. Geological Survey, is shown **second** from the left.

Education and Training: 1940s to Present

In the 1940s health physics training programs were set up for all Laboratory employees, and many courses were offered for the training of those who were later to become health physics leaders in government, industry, and education. For example, numerous current and retired HASRD scientists received their training while working at ORNL in the forties, fifties, and sixties. In turn, these and other Division staff members have directed the training and dissertation research of over 240 M.S. and Ph.D. students since 1950 (Fig. 8). Health physics training in the 1950s was done chiefly through a master's level program with Vanderbilt University (Fig. 9). Myron Fair, Jake Neufeld, Natalie Tarr, Ross Thackeray, and Walter Snyder participated in this training under the leadership of Elda Anderson (Fig. 10). Also in the fifties, the initial group of health physicists, including Sam Hurst, Rufus Ritchie, Ed Arakawa, Ken Cowser, and Charles Melton, was taking courses at UT and receiving advanced degrees, thus beginning what was to become a long-standing ORNL/UT interaction.

The 1960s was a decade of increased cooperation with UT and several other educational institutions. Many future HPD staff members completed their M.S. or Ph.D. work in this decade. A partial list includes Jim Baird, Jim Carter, Conrad Chester, Bob Compton, Howard Dickson, L. C. "Doc" Emerson, Bimey Fish, Bob Hamm, Fred Haywood, Steve Kaye, Bill McConnell, DeVaughan Nelson, Paul Rohwer, John Stockdale, John Thorngate, and Harvel Wright, all of whom later (or concurrently) became ORNL staff members. Also in that decade, several senior HPD staff served as Ford Foundation Professors of Physics at UT. This list included Bob Birkhoff, Loucas Christophorou, Bob Compton, Sam Hurst, Eph Klots, Rufus Ritchie, Hal Schweinler, and Jim Turner. Ritchie and Christophorou continue in this capacity today. These people, and others, also directed the research of many graduate students during the scientific heyday of the late sixties. Three of these students (Linda Painter, Jim Parks, and Dennis McCorkle)

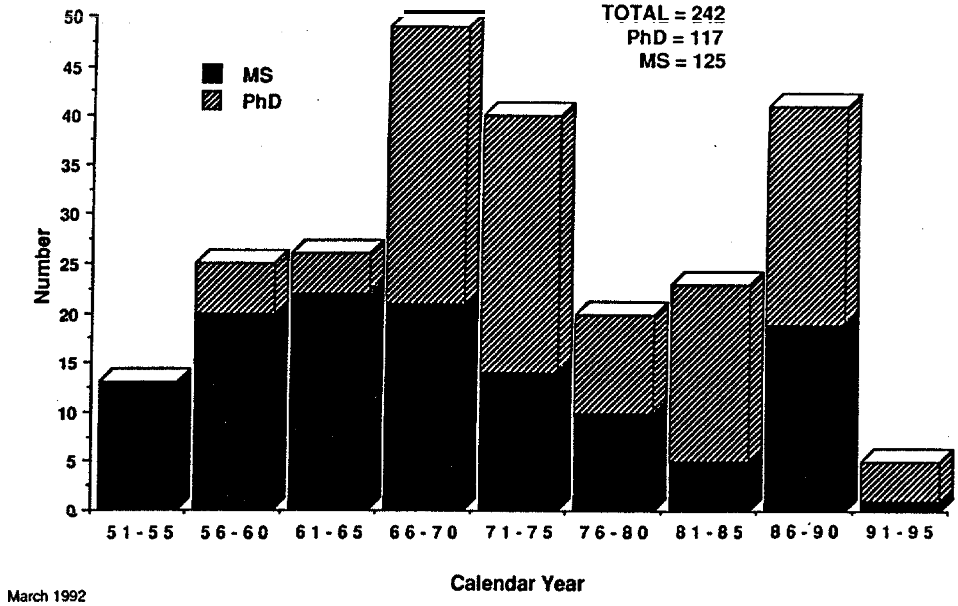


Fig. 8. Advanced degrees granted for dissertation research in the Health and Safety Research Division at Oak Ridge National Laboratory.

Fig. 9. Photograph made in 1952 during a training course for U.S. Atomic Energy Commission Health Physics Fellows from Vanderbilt University. Front (from left): R. B. Rhody, Barbara Winnemore, R. G. McCarty, John Auxier, Fred Sicilio, Joe Bergstein, Herbert Gursky, Oliver Burford, Richard Reinecke, Robert Lovell. Standing (from left): Robert Baker, Jim Turner, E. L. Alexander, Bill Mills, Jerrold Caplin, Roger Crawford, Wallace Campbell, Richard Collier, Birney Fish.

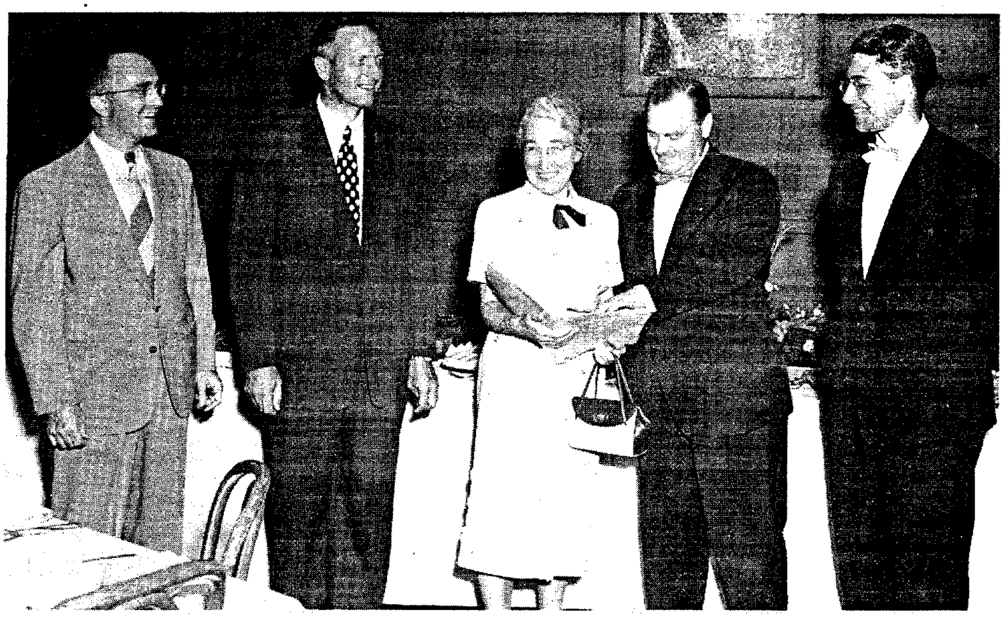


Fig. 10. Shown left to right in this 1955 photograph are Myron Fair, *K. Z. Morgan, Elda Anderson, Jim Hart, and H. P. Yockey,* all of Oak Ridge National Laboratory.

went on to become UT professors and currently maintain strong connections with ORNL. Throughout the decade ORNL scientists contributed to curriculum and new course development and helped UT to be named a Center of Excellence by the National Science Foundation.

The 1970s were a time of continued progress in all aspects of university/ORNL connections. In 1977 the research core of HPD joined with one section from the Environmental Sciences Division and one from the Operations Division to become the Health and Safety Research Division, headed by Steve Kaye. Again, education was a top priority. Figure 8 shows that the number of Ph.D. degrees peaked in the years between 1965 and 1975. The lower number of degrees in the period from 1976 to the present is partially mitigated by the presence of a much larger group of postdoctoral fellows. Again, many of the HPD staff members of this, era, such as Gerald *Alton,* John Auxier, Clay Easterly, Kathy Gant, George Kerr, John *Poston,* and Bruce Warmack, completed work on advanced degrees. Along with increasing interactions at all levels, this decade was dominated by the Science Alliance Program with UT. This program provided for the hiring of a number of "distinguished scientists" who would hold joint appointments with UT and ORNL. *Loucas* Christophorou headed the Laboratory's effort in this interaction. Also under the auspices of this program, Bob Compton began a joint appointment to the Chemistry Department at UT. In the eighties large numbers of undergraduate students came to the Laboratory from around the nation as a result of the emergence and expansion of programs sponsored by ORNL, Oak Ridge Associated Universities, and the U.S. Department of Energy (DOE).

For nearly 50 years HPD and HASRD have been in the forefront of the educational process involving ORNL scientists in conjunction with neighboring colleges and universities. Hundreds of America's present cadre of physical scientists received their training at ORNL. HASRD's health physics graduates are plying their trade'around the world. These ORNL/HASRD/university interactions have grown and expanded. Links with Historically Black Colleges and Universities and other minority institutions have been strengthened, and precollege education (for high school teachers and students) have become a priority. DOE's recent emphasis on education simply underlines these previous efforts and ensures that they will continue into the twenty-first century.

THE FIFTIES

Instrument Development and Basic Research

The period from 1950 to 1959 was an exciting one. In the field of instrument development, several different methods for measuring neutron dose in the presence of gamma rays were developed under the creative leadership of Sam Hurst.3 In the area of basic research, Bob *Birkhoff*, another outstanding physicist, joined the Division as a consultant from The University of Tennessee (UT) Physics Department and later became a full-time staff member at ORNL. He was responsible for a vigorous experimental research program on the interaction of electrons with matter.

Several of the instruments developed under Hurst's leadership employed proportional counters. His M.S. thesis work on the properties of these devices at the University of Kentucky in the period 1947–48 served him well in this connection. One of the first of these instruments was the "count rate neutron dosimeter." Shortly afterward, a nondirectional neutron dosimeter was developed, again using a proportional counter, but based on the Bragg-Gray principle, also with excellent gamma-ray discrimination properties. A very clever and simple system of pulse integration using a binary scaler was incorporated into this instrument (Fig. 11). Toward the end of the decade, a gamma dosimeter was developed using a Geiger-Müller counter, which is sensitive to the total number of interactions of the gamma rays incident on the system with the counter and has high discrimination properties for neutrons. Another innovative development was the neutron threshold detector system, which has been used extensively in nuclear accident dosimetry and in studying the characteristics of radiation yields of nuclear devices for the Japanese atomic bomb dosimetry program. Figure 12 shows the use of threshold detector units (TDUs) during a weapons test at the Nevada Test Site, and Fig. 13 shows ORNL staff members at the Zero Power Reactor of the Boris Kidric Institute in Yugoslavia following a nuclear criticality accident in 1958.

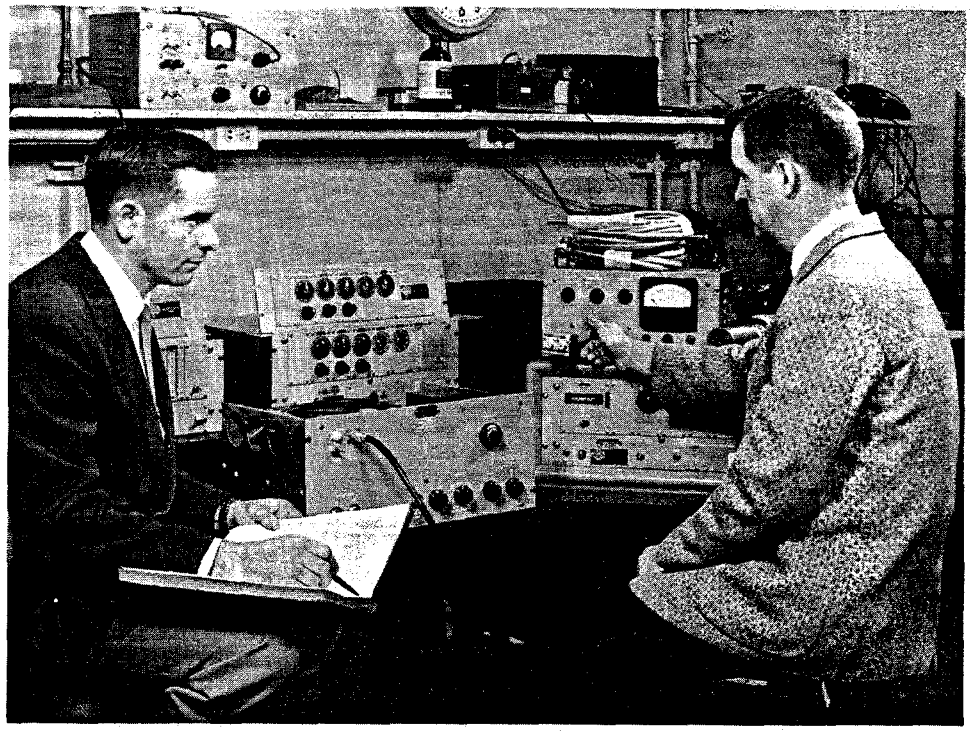
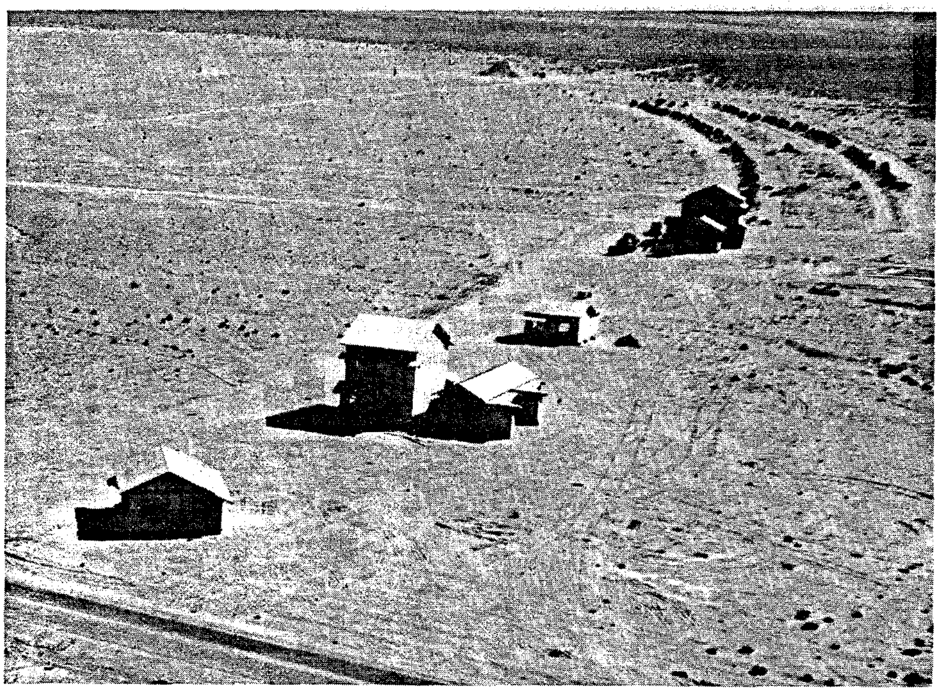


Fig. 11. Early photograph of *John Auxier* and *Sam Hurst* discussing the "Radsan" for neutron dose measurements and "Phil Dosimeter" for gamma-ray measurements in a mixed neutron and gamma-ray field.

In a related but more basic radiation physics research effort, Hurst (with Tom Bortner and others) began to study the total ionization produced when alpha particles dissipate their energy in a gas. In most gas mixtures there is a gradual dependence of total ionization on the gas composition, but in the noble gases such as helium and argon, dramatic increases in ionization are observed even for traces of gas impurities. Such effects were known to Neils Bohr, who postulated that excited states of helium could be responsible; this was later called the Jesse effect in honor of the careful work of W. P. Jesse at Argonne National Laboratory. The work by Hurst and collaborators was to be conducted over many years and finally led to definitive resolution of the Jesse effect (Bohr was right!). The definitive measurements were made with a laser ionization technique called resonance ionization spectroscopy (RIS) (see THE SEVENTIES).

Another focus of this research program was to study the behavior of the free electrons produced in a gas by



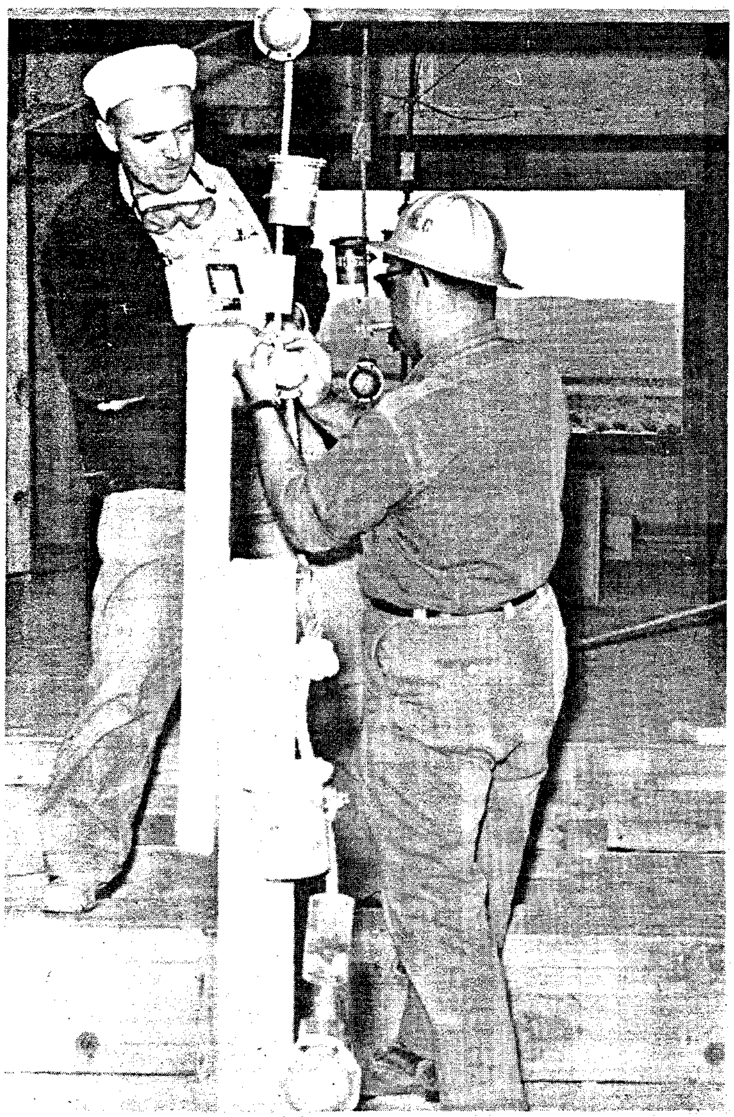


Fig. 12. Photographs made in 1958 during a weapons test at the Nevada Test Site. The bottom photograph shows *Tom* ***Burnett*** (with a test site worker) installing a neutron threshold detector unit inside one of several replicas of Japanese-type houses.

alpha particles. Thus another long-term effort known as gaseous electronics was started in the fifties. This research included the study of electron mobility, diffusion, and attachment (to form negative ions) in a gas. Extension of this work through later studies by Bob Compton and by ***Loucas*** Christophorou helped to establish a well-known area of research within the Division.

Beginning early in the decade, Bob ***Birkhoff*** **(Fig. 14)**, with the encouragement of K. Z. Morgan and the help of a number of graduate students from UT and other southeastern universities, constructed a beta-ray spectrometer and began a fruitful program of study of the basic interactions of charged particles with matter. He wrote a comprehensive chapter on “The Passage of Fast Electrons Through Matter” for the prestigious **Handbook for Physics**[4] and provided stimulating and original leadership in the study of electron slowingdown spectra in matter. Some measurements of such spectra that were made in this program have not been duplicated to this day and have been of great importance to the understanding of electron interactions in condensed matter.

Working with ***Birkhoff*** **in** theoretical analysis of electron energy loss data, Rufus ***Ritchie*** postulated that a Poisson distribution of such losses should show the effects of plasma oscillations. Mean free paths for electrons were thereby deduced from experiment for the first time. ***Jake*** Neufeld and Ritchie studied aspects of nonlocal dielectric theory dealing with dynamical, long-range effects of penetrating charged particles on condensed matter. They developed a dielectric formulation of the response of a quantum plasma and studied the spatial and temporal distribution of excited electrons around a swift ion in such a medium. This theory has had important ramifications in understanding the channeling of ions through open regions in crystals. Ritchie also predicted that **charged-**particle energy losses to surface plasmons should be observable; some 3 years later this theoretical study was amply confirmed by experimenters in Australia. The surface **plasmon** has proved to be of great importance in surface science and is a prominent feature in electron energy loss experiments, in low-energy electron diffraction, and in Auger electron spectroscopy. The high degree of current interest in the surface **plasmon** is illustrated by the designation of Ritchie's original paper on the subject as a "Citation Classic" by **Current Contents**[2]

During this period the Theoretical Physics Croup, consisting of ***Jake*** Neufeld, Walter Snyder, and Rufus Ritchie, made a number of important advances involving the basic theory of the stopping power of matter for charged particles using quantum dielectric theory; the charge states of heavy, swift ions in matter; the characteristics of charged-particle tracks in condensed matter; the study of displacement cascades in solids; and the use of Monte Carlo techniques to determine the tissue dose in phantoms from neutron radiation. The neutron radiation calculations of Snyder in collaboration with John Auxier and Troyce Jones were the topic for a book chapter in the 2nd edition of **Radiation Dusimetry**[6] **and** the basis for protection against neutron radiation.'

An important professional development in this decade was the establishment of **the** Health Physics Society in 1955 through the initiative of K. *Z.* Morgan and other members of the

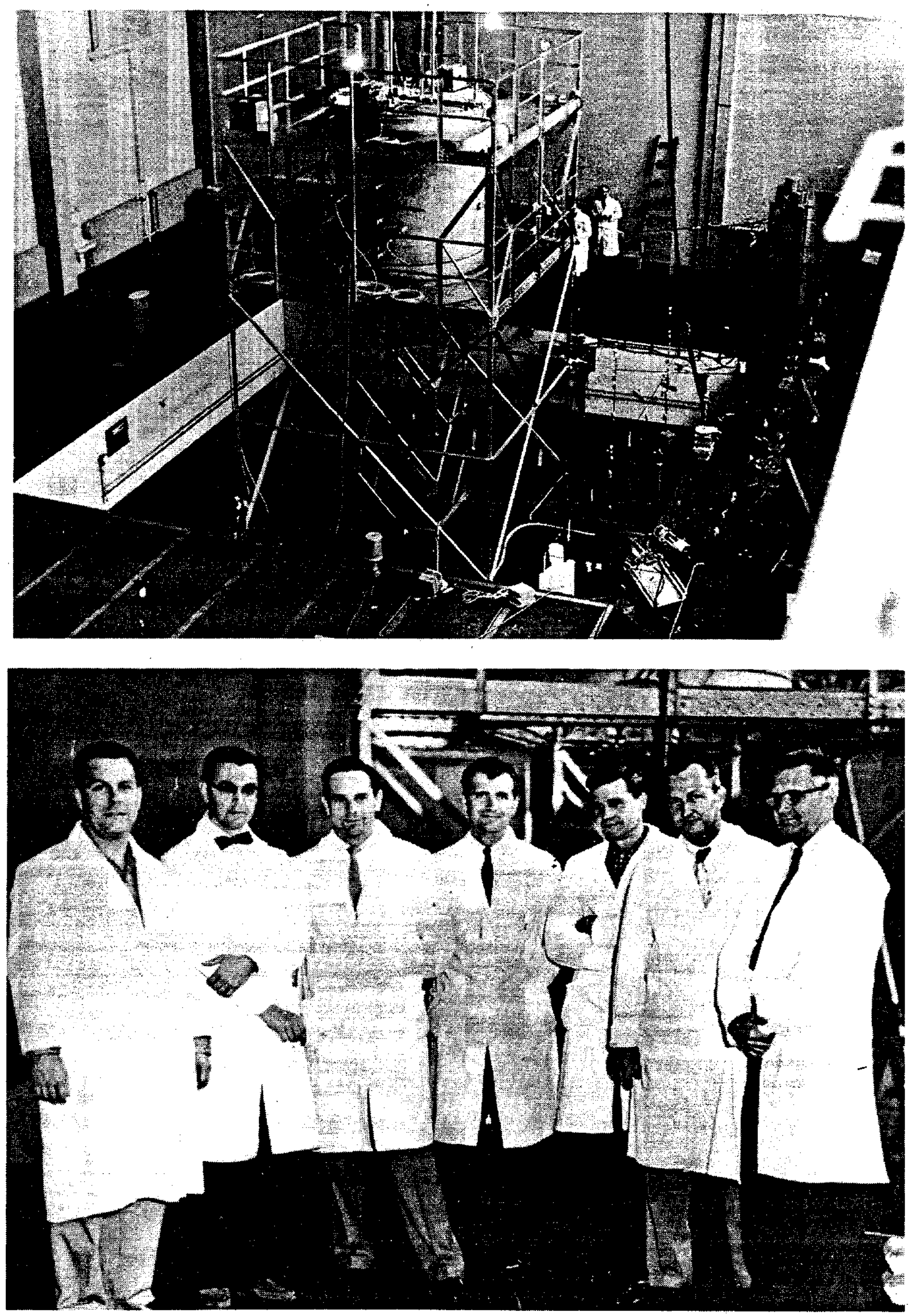


Fig. 13. Photographs made following a 1959 criticality accident at the Zero Power Reactor of the Boris Kidric institute at Vinca, near Belgrade, Yugoslavia. Shown from left to right in the bottom photograph are *Fred Sanders, Rufus Ritchie, John Auxier, Sam Hurst, Brian Wagner, Paul Reinhardt,* and Dixon Callihan, all of Oak Ridge National Laboratory.

Fig. 14. Early photograph made outside the Mayflower Restaurant in Oak Ridge. Shown facing the camera from left to right in the middle of the photograph are *Hume Craft, Bob* ***Birkhoff,*** *Joe Cheka,* and *Rufus Ritchie.*

Division. The impact of this Society on the profession of health physics has been great indeed; the Health **Physics Journal** and the board certification of health physicists have resulted. To commemorate the 25th anniversary of the founding of the Health Physics Society in 1980, the Society published a special issue of the **Journal**[8] that contained a collection of 22 previously published papers and documents having to do with events of some importance, historically or otherwise. The following ORNL publications were featured in the collection:

K. Z. Morgan, "The Responsibilities of Health Physics," **The Scientific Monthly, 93-100** (August 1946).

K. Z. Morgan, "Tolerance Concentrations of Radioactive Substances," Journal **of Physical and Colloid Chemistry 51(4), 984–1003** (July 1947).

W. ***S.*** Snyder, "Calculations for Maximum Permissible Exposure to Thermal Neutrons," **Nucleonics 6(2), 46-50** (February 1950).

G. S. Hurst, J. A. Harter, P. N. ***Hensley,*** W. A. Mills, M. Slater and P. W. Reinhardt, "Techniques of Measuring Neutron Spectra with Threshold Detectors-Tissue Dose Determinations," **Review of Scientific Instruments 27(3),** 153-156 (March 1956).

J. A. ***Auxier,*** "Dosimetry. A. Physical Dose Estimates for A-bomb Survivors-Studies at Oak Ridge, U.S.A.," **Journal of Radiation Research 16** (Tokyo), Supplement, 1-1 1 (1975).

Internal Dose Program: 1950s to Present

Internal dosimetry began to emerge as an identifiable Division activity in the late 1940s while K. Z. Morgan and

C. H. Perry were serving as chairman and working secretary, respectively, for a subcommittee of the National Committee on Radiation Protection (NCRP). Objectives of that early subcommittee work included quantification of maximum permissible amounts of radionuclides in the human body, maximum permissible concentrations of radionuclides in air and water, and concentrations of radionuclides in urine, feces, and exhaled air. Early analyses of body fluids in support of internal dose studies focused on ^{235}U. In 195 1 efforts to calculate'intemal dose expanded, among the principal participants were Mary Jane Cook and Mary Rose Ford. A subcontract with Isabel Tipton at UT facilitated the start of what would become a long-term arrangement for qualitative and quantitative spectroscopic analyses of trace elements in human tissue. The services of the ORNL Mathematics Panel were utilized to analyze data from the spectrographic analyses.

The Health Physics Division (HPD) became active in supporting the International Commission on Radiological Protection (ICRP) as well as the NCRP, and a report entitled "Maximum Permissible Internal Dose" was prepared for publication in 1954.[9] The internal dose program also included animal experiments to study radionuclide uptake fractions and other parameters of importance in estimating radionuclide behavior in man. By 1955 internal dosimetry activities were part of an Applied Radiobiology Program led by Ed *Struxness*, and the metabolism and excretion of uranium by humans were being investigated in detailed studies by Bob Bernard (Fig. 15). At that time, animal studies were expanded to include inhalation of uranium aerosols by dogs. Throughout the late 1950s, Walter Snyder and others continued to refine internal dose estimation methodology on the basis of the growing body of data being assembled from various sources such as ingestion and inhalation studies, whole body counting, metabolic modeling, excretion analysis, and human tissue analysis. The work of the Division was also being used extensively to develop and update National Bureau of Standards (NBS) handbooks, which are used extensively throughout the technical community to estimate radiation dose.[10]

Fig. 15. *Bob Bernard* and Steve *Kaye* at *Bob's* retirement party in 1985.

In 1960 the Internal Dosimetry Section was formed under Walter Snyder. Work such as that done for NCRP, ICRP, and NBS was now conducted for the Federal Radiation Council as well. Topics of particular interest included stable element metabolism in humans, variability in trace element concentrations in human tissues, nonuniformity of radionuclide concentrations in tissue, trace elements in diet and excreta, dependence of internal dose on the age of the exposed individual, and use of Monte Carlo calculational techniques. An Information Center for Internal Exposure was established by Snyder, Bob Bernard, and Clayton Holoway in 1965. A massive effort was expended in revision of "standard man" for the ICRP. The calculations of effective energies used in dose estimation were also extensively reviewed and extended, largely through the work of L. T. Diliman (a consultant to ORNL from the Physics Department at Ohio Wesleyan University).

Throughout the late 1960s and into the 1970s, internal dosimetry programs focused on compartmental modeling of cross irradiation among source and target body organs; dose to developing fetus, infants, and children; and development of the so called Snyder-Fisher Phantom? Extensive data tables were developed, which provided estimates of absorbed dose per microcurie-day of isotope residence in various body organs. Pamphlets providing absorbed fractions and other dosimetry information were prepared for the Medical Internal Radiation Dose Committee of the Society of Nuclear Medicine. Walter Snyder became chairman of the ICRP Task Group on Reference Man. [12] In the mid- 1970s the studies were centered in the Medical Physics and Internal Dosimetry

Group under John *Poston* and subsequently in the Metabolism and Dosimetry Research Group under Keith Eckermun (Fig. 16). In the 1980s areas of focus included development of computer codes to estimate microcurie-days of residence for internally deposited radionuclides; development of maternal, fetal, and pediatric phantoms; improvements in radionuclide decay scheme data; sensitivity of internal dose estimates to the particle size of inhaled radionuclides; and calculation of **50-year** dose commitments (Fig. 17). This program continues to provide important data for assessing radiation doses in the nuclear **industry**[13] and in nuclear **medicine.**[14]

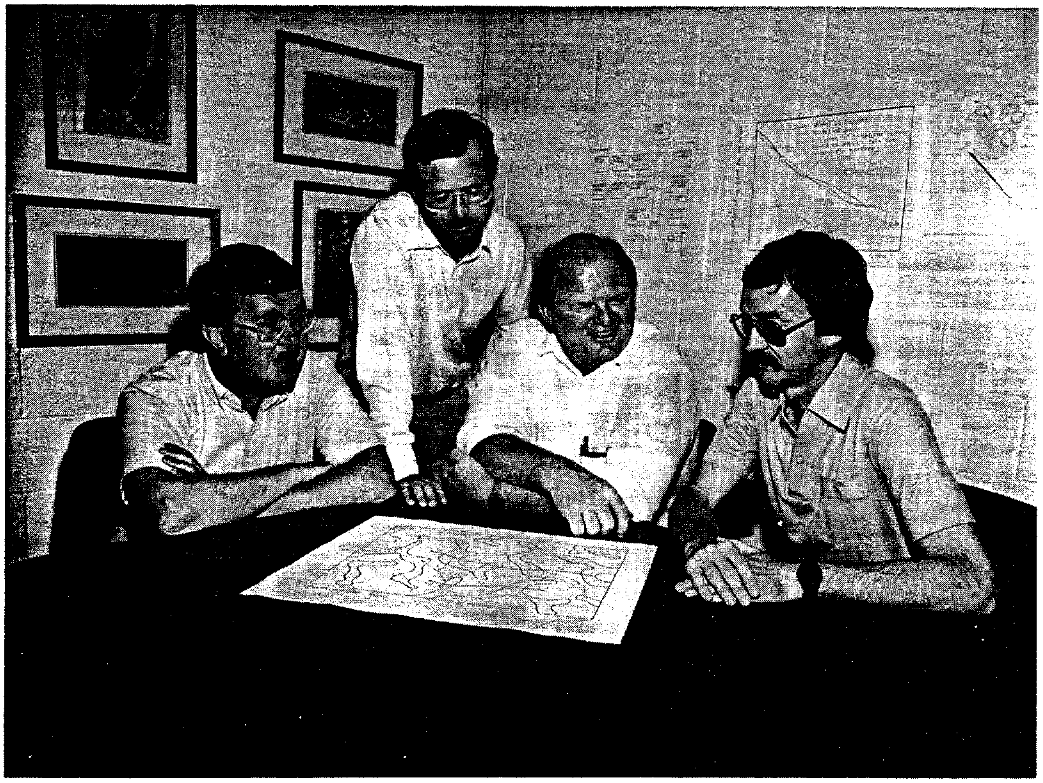


Fig. 16. The Metabolism and Dosimetry Research Group of the Health and Safety Research Division in 1966. Shown from left to right are George *Kerr,* ***Mark Cristy,*** *Keith* ***Eckerman,*** and Rich ***Leggett.***

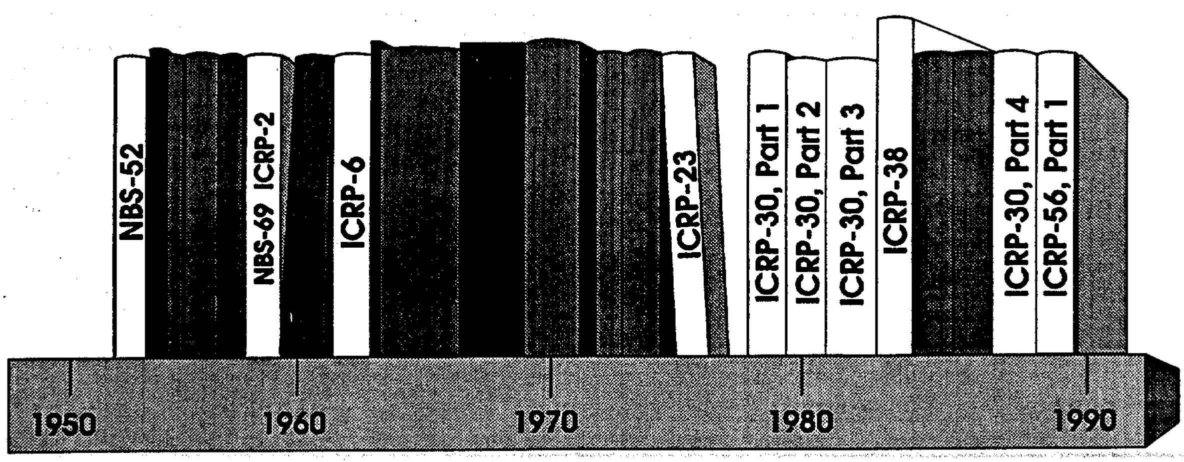


Fig. 17. The bookshelf highlights a number of major radiation protection handbooks from the National Bureau of Standards (NBS) and International Commission on Radiological Protection (ICRP). Although the handbooks are reports of national and international committees on internal radiation dosimetty, these reports are known throughout the radiation protection community as products of the Health Physics Division (1950s to 1977) and the Health and Safety Research Division (1977 to present).

Japan&e Atomic Bomb Dosimetry: 1950s to Present

Soon after the bombings of Hiroshima and Nagasaki in August 1945, U.S. military medical teams entered those cities and began working with Japanese scientists who were already studying the physical and medical effects of the bombings.[15] In 1946 President Harry S Truman approved a directive to the National Academy of Sciences to initiate a long-term medical study of the surviving populations in Hiroshima and Nagasaki. The Academy established the Atomic Bomb Casualty Commission (ABCC) in 1947 with funding provided by the U.S. Atomic Energy Commission (AEC), and investigations began shortly thereafter. The Japanese National Institute of Health aided the investigations by establishing branch laboratories within ABCC at both Hiroshima and Nagasaki. In April 1975 ABCC was officially dissolved and replaced by a binational organization known as the Radiation Effects Research Foundation (RERF). The government of Japan, through the Japanese Ministry of Health and Welfare, and the U.S. government, through the U.S. Department of Energy (DOE), share equally in the funding of RERF. The U.S. funds are made available through the National Academy of Sciences as contractor to DOE and previously AEC. The HPD staff members who made important contributions to the early dosimetry programs of ABCC include Ed Arakuwa, John Auxier, Joe Cheka, Fred Haywood, Harry Hubbell, Sam Hurst, Troyce Jones, George Kerr, Phil Purdue, Rufus Ritchie, Fred Sanders, Bill Shinpaugh, and John Thorngate. Kerr has also served continuously as a U.S. consultant on radiation dosimetry to RERF since 1975.

Tentative 1957 Doses. During Operation Teapot at the Nevada Test Site (NTS) in 1955, ORNL, in collaboration with the Los Alamos Scientific Laboratory (LASL), conducted a series of experiments that provided a much better understanding of weapon radiation fields.[16] Gamma radiation dosimetry utilized tetrachloroethylene chemical dosimeters, and neutron flux and dose distributions were measured with neutron threshold detector units. These Operation Teapot studies indicated the possibility of a definitive description of the radiation fields from the Hiroshima and Nagasaki bombs.

Consequently, in early 1956, a survey team, including members from the Medical College of Virginia, AEC, LASL, and ORNL, visited ABCC in Hiroshima and Nagasaki to determine the feasibility of a dosimetry study (Fig. 18). Several ABCC studies had already reported an elevated incidence of cataracts and leukemia in the surviving populations, especially in Hiroshima. After reviewing records and examining typical shielding configurations for survivors, the survey group recommended that a dosimetry program be initiated. Emphasis was to be placed on the shielding provided by Japanese-type houses because of the high structural uniformity of the houses and the large number of survivors who were inside such buildings when exposed. As a result of the survey

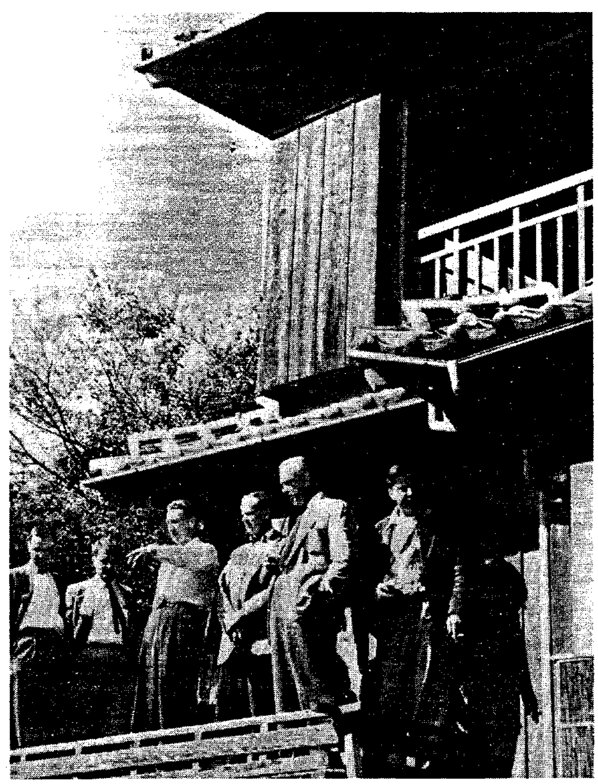


Fig. 16. Photograph of survey team sent to Japan in 1956. Shown from left to right are *Rufus Ritchie* [Oak Ridge National Laboratory (ORNL)], Sam *Hurst* (ORNL), Ken Noble (Atomic Bomb Casualty Commission), Bill Ham (Medical College of Virginia), Bob Corsbie (U.S. Atomic Energy Commission), and Payne Harris (Los Alamos Scientific Laboratory).

group, a program was established at ORNL and designated as Ichiban-a Japanese word meaning first or number one-because it was considered to be the top-priority HPD program during the late fifties and early sixties.

A pilot study of the shielding provided by Japanese houses was conducted during Operation Plumbbob at NTS in 1957. The materials used in their construction were shipped from Japan to NTS, and they were built by American craftsmen using ABCC plans and specifications for a typical Japanese house. The imported materials included the framing and sheathing, ceramic tiles and embedding clay for the roof, bamboo lathing, and oyster shells and seaweed for the stucco material of the walls. Figure 19 shows one of the two Japanese-type houses constructed for Operation Plumbbob.

After completion of the analysis of data from Plumbbob, a summary of all dosimetry information applicable to the survivors was prepared and transmitted to the shielding group at ABCC.[17] Designated as T57D, this tentative dosimetty served as a guide for determining dose values from the shielding histories of the exposed individuals. With the assignment of Ed *Arakawa* to Hiroshima from 1958 to 1960, the shielding results from the nuclear weapons test at NTS were applied in medical follow-up studies of the survivors by ABCC. These studies, together with the calculations for the weapon radiation fields by E. N. York of the Air Force Special Weapons Laboratory, led to the assignment of gamma-ray and neutron dose values to individual medical records for the survivors instead of the previously used broad dose-value categories based on distance from the hypocenter of the bombs.[18]

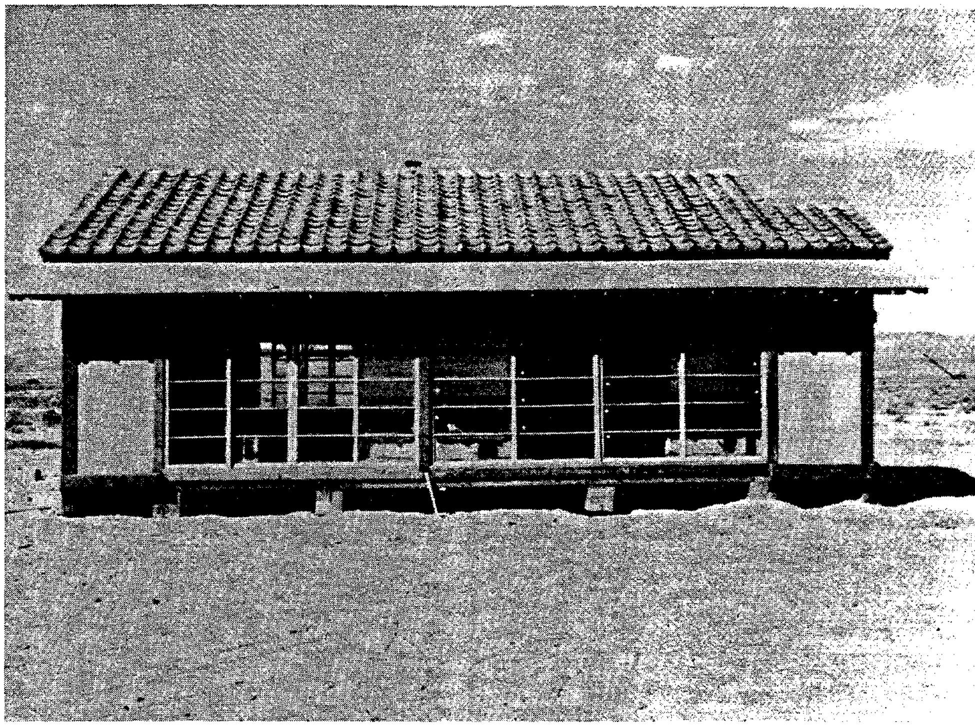


Fig. 19. Photograph of one of two Japanese-type houses constructed at the Nevada Test Site during Operation Piumbbob in 1957.

Tentative 1965 Doses. Following Operation Plumbbob, laboratory studies of the shielding coefficients of Japanese and American building materials were conducted by John *Auxier,* Fred Sanders, and Wendell *Ogg.* Cement–asbestos board, commercially available in large sheets, was found to be suitable as a substitute for the mixture of clay, oyster shells, and seaweed wall plaster and for the embedding clay and tile roofs of Japanese houses for both neutrons and gamma rays. The wood framing used in Japan fitted well with the substitution of cement-asbestos board, and domestic materials were used to construct Japanese house replicas for shielding studies during several later weapons tests at NTS (Fig. 12).

During Operation Hardtack II in 1958, a large number of collimators were used for measuring the angular distributions of the neutrons and gamma rays from a nuclear weapon, and seven replicas of Japanese houses were constructed for use in the shielding studies. Emphasis was placed on evaluating the shielding as a function of house size, orientation, and position relative to other nearby houses. Because of the durability of the wall board, six of the seven houses were repaired and used three times and the seventh was used twice. The measurements at weapons test sites ended with the Limited Test Ban Treaty of 1962.

Consequently, it was decided to do a definitive study of the neutron and gamma radiation fields at large distances from a small fission source (i.e., a small unmoderated and unshielded reactor). The Health Physics Research Reactor (Fig. 20) was suspended on a hoist car, which in turn was mounted on a 465-m tower at NTS (Fig. 21). Designated. as Operation **BREN,** the experiments were conducted under the leadership of John *Auxier* and Fred Sanders during the spring and early summer of 1962. A ^{60}**Co** source of about 1200 curies was substituted for the reactor at the completion of the reactor studies and was used to simulate

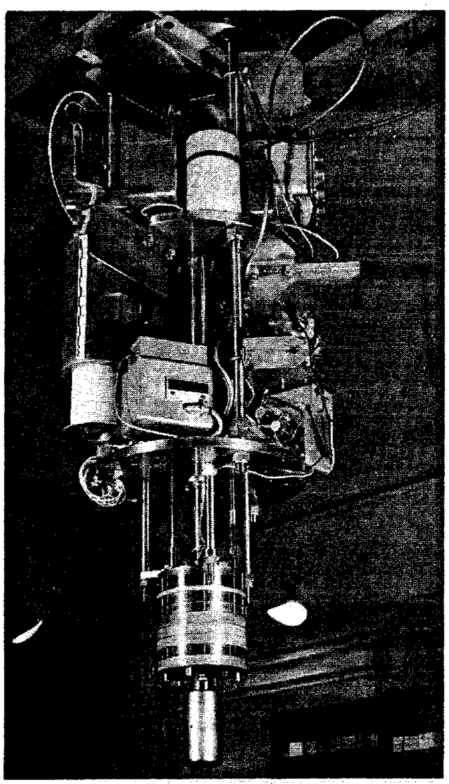


Fig. 20. The Health Physics Research Reactor. Shown toward the bottom of the photograph is the reactor core, which was unshielded and measured about 28 cm (11 in.) long by 22 cm (8.5 in.) in diameter.

the gamma radiation fields from the fireball of a nuclear weapon. During Operation BREN, extensive measurements were made of the radiation fields both in the open, in Japanese houses, and in clusters of Japanese houses.

In 1964 a set of nine-parameter formulas was developed that could be used to calculate the shielding for survivors exposed inside a **house.**[19] The nine parameters allowed the shielding to be calculated as functions of such things as orientation, house size, location of a survivor inside the house, location of the house with respect to other nearby structures, and proximity of a survivor to an unshielded window facing the hypocentei of the bomb. Other ‘techniques were later developed for estimating the shielding of survivors in other situations such as outside and partially shielded by a house or wall, inside a steel-frame factory building of light construction, **etc.**[16]

In 1965 a new set of equations for the weapon radiation fields in the open were communicated to ABCC for use in their studies. Ideally, these equations would have been established from test firings of exact duplicates of the Japanese weapons. Some information was available from early tests of several Nagasaki-type weapons, but the Hiroshima weapon was the only one of its type that was ever fired. Hence, the weapon radiation fields in the open in Hiroshima had to be constructed using indirect evidence from calculations and experiments with reactors. These data were published in **an** article in **Health Physics**[20] and designated as **T65D.**

In the 1970s the transport of radiation within the body of the survivors was calculated by Troyce Jones and coworkers,*' and the results were provided as sets of organ

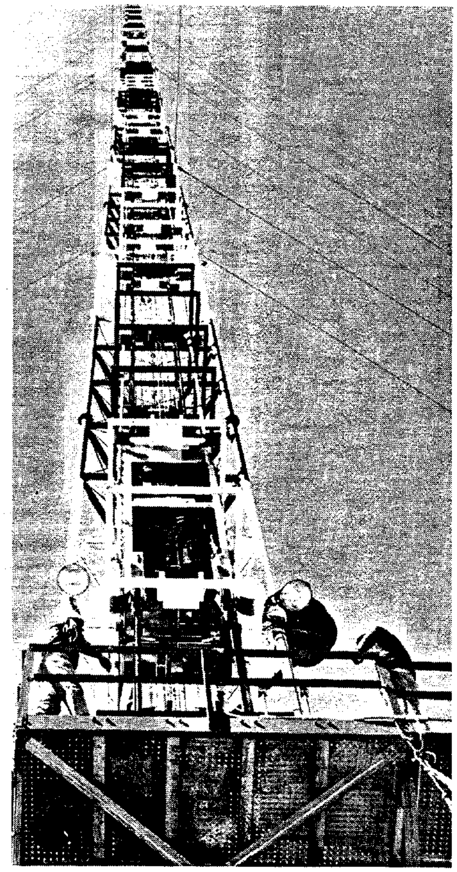


Fig. 21. The Health Physics Research Reactor mounted on hoist car of the BREN Tower.

dose **factors.**[22] For leukemia, the organ of interest was the bone marrow, and for other cancers, the specific organs of interest were the female breast, thyroid, lungs, etc. For studies of survivors exposed in utero, the radiation dose to the fetus was needed, and for studies of the first generation offspring of survivors, the radiation dose to the testes and ovaries of the parents was important. The **T65D** system of dosimetry served as a basis for radiological risk assessment throughout the 1970s.

Dosimetry System 1986. In the late 1970s Harald **Rossi** (Columbia University) and Chuck Mays (University of Utah) proposed that the NCRP reduce the permissible dose limit for neutrons by a factor of 10 on the basis of risk estimates derived from the medical follow-up studies of the atomic bomb survivors in Hiroshima and Nagasaki.[23] NCRP responded to this proposal in two ways: (1) it issued a cautionary statement to alert the technical and industrial communities about a possible change in neutron dose limit following a review by NCRP[24] and (2) it formed a task group under the chairmanship of Harold Wyckoff to investigate the accuracy of the T65D system of dose estimation for individual survivors.[25] This task group concluded after considerable study that the material in the open literature and in unclassified laboratory reports was insufficient for a determination of the accuracy of the T65D system. Eventually, the task group recommended that a person with the proper security clearances should complete the review using both classified and unclassified sources of information. They hoped enough information could be made publicly available to provide a secure foundation for recommendations concerning the permissible dose limit for neutrons. The U.S. Energy Research and Development Administration (ERDA, now DOE) responded by funding George Kerr of HASRD to start such a study in 1979. He not only included classified data in his study but began incorporating much new data that had not been applied yet to the Japanese atomic bomb studies. Use of these new data brought other investigators into the study; they came to the conclusion that the T65D system contained errors, and the need for further research was discussed at a DOE symposiurn in the fall of 1981.[26]

Following the DOE symposium, a Working Group on A-Bomb Dosimetry Reassessment was formed under the chairmanship of Robert Christy (California Institute of Technology), and two ORNL staff members were selected to serve on this DOE working group: George Kerr (HASRD) and Joe Pace (Engineering Physics and Mathematics Division). A Japanese working group was also formed under the chairmanship of Eizo Tajima (Japanese Atomic Safety Commission), and four U.S.-Japan joint workshops on atomic bomb dose reassessment were held: (1) at Nagasaki, Japan, February 16–17, 1983; (2) at Hiroshima, Japan, November 8–9, 1983; (3) at Pasadena, California, March 12-15, 1985; and (4) at Hiroshima, Japan, March 15–17, 1986. The proceedings were published for the first workshop in 1983" and for the second workshop in 1984.[28] Special binational groups were appointed at the third workshop to prepare chapters on various topics for a final report on the new dosimetry. The final two-volume report was published following the fourth workshop in 1986.[29] Volume 1 describes the technical basis and Vol. 2 presents supporting technical data for the new dosimetry system, which is designated as Dosimetry System 1986 (or DS86). In 1986 and 1987 Kerr was on temporary assignment in Japan and assisted the RERF in the application of DS86 to individuals in their medical follow-up studies. The DS86 system of dose estimation for individual survivors provides a significant improvement over the T65D system. A principal discrepancy in the T65D and earlier dosimetry systems was the large overestimate of the neutron dose at Hiroshima that led to misinterpretation of the biological data from the medical follow-up studies of the RERF. Risks were attributed to neutrons that should have been attributed to gamma rays. The new DS86 dosimetry for Hiroshima and Nagasaki and its implications for risk estimates are discussed in the Proceedings of the 23rd Annual Meeting of the NCRP[30] and elsewhere.[31]

The Sixties

Nuclear Accident Dosimetry

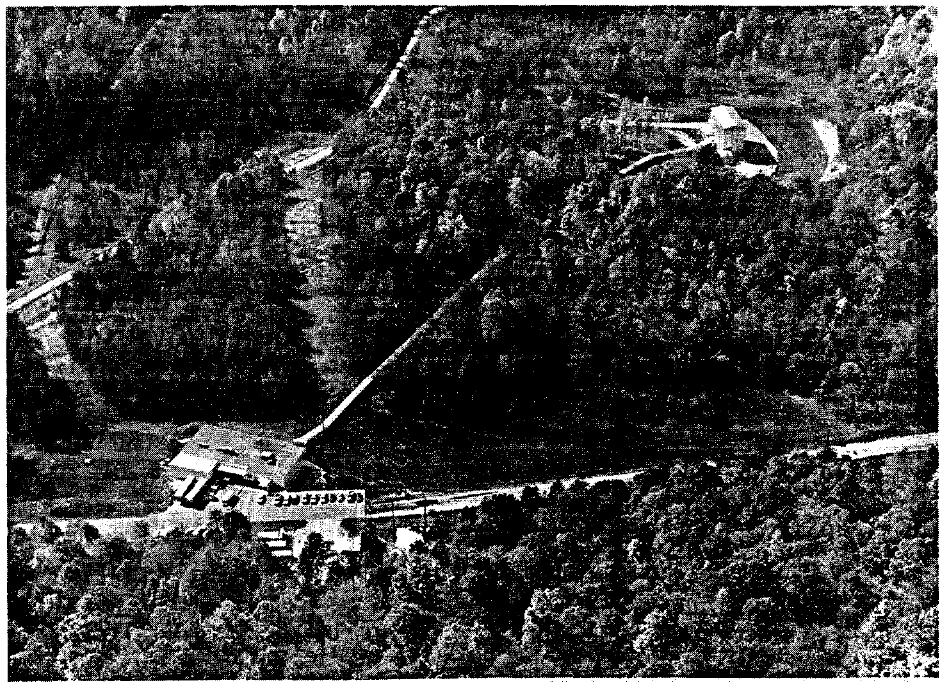


Fig. 22. Aerial view of the Dosimetry Applications Research (DOSAR) and Health Physics Research Reactor (HPRR) facilities in the early 1960s. The DOSAR facility housing the research laboratories and reactor control room is in the foreground, and the building housing the HPRR is shown above.

A total of 15 nuclear criticality accidents occurred in the United States during the fifties. From 1955 to 1959 there were eight such accidents during which 30 persons received significant radiation doses. Two of these accidents were in Oak Ridge. It is not surprising, therefore, that there was significant interest in accident dosimetry in the sixties. The research, development, and testing associated with accident dosimetry were centered in the Dosimetry Applications Research (DOSAR) Group, which put the Health Physics Research Reactor (HPRR) into operation at ORNL in 1963 (Fig. 22).

Dosimeter Development. Existing personnel dosimetry systems (primarily photographic emulsions) were inadequate for monitoring doses that could be encountered during nuclear criticality accidents (e.g., 0.10-10 Gy). Totally different types of monitoring systems had to be developed for this application. Research and development centered on three types of nuclear accident dosimeters: activation foils, threshold detector units (TDUs), and activation of sodium in blood.

Activation Foils. Foils of materials such as ^{32}S ^{58}Ni ^{63}Cu ^{103}Rh ^{115}In, and ^{197}Au become radioactive when bombarded with neutrons. They are activated by neutrons of different energies and can be used in sets to provide spectrum information. The methodology was developed so that the induced activity of the foils is measured and the fluence calculated and combined with fluence-to-dose conversion factors to yield an estimate of the neutron dose.

TDUs. TDUs operate very much like activation foils. The main difference is that TDUs use fission reactions instead of, or in addition to, neutron capture reactions to detect neutrons (Fig. 23). The TDUs designed at DOSAR used fission reactions in ^{237}Np, ^{238}U, and ^{239}Pu foils to detect neutrons directly by measuring the activity of the resultant fission products or by counting fission product tracks in an adjacent track-detecting material such as polycarbonate. Additional activation foils of ^{32}S and ^{197}Au were added to allow further spectral definition.

Blood Sodium. After neutron irradiation, a fraction of the ^{23}Na in blood becomes radioactive ^{24}Na and emits gamma rays with energies of 1.38 and 2.76 MeV. Techniques were developed so that blood samples from irradiated persons can be analyzed and related to whole-body neutron dose.

Dosimeter Testing. HPRR was a fast-pulsed nuclear reactor and was the ideal research tool for simulating a nuclear criticality accident (Fig. 24). HPRR was well-characterized for delivered dose and neutron energy spectra and was used by DOSAR researchers throughout the sixties to test the various nuclear accident dosimetry techniques and hardware.

Nuclear Accident Dosimetry Intercomparison Studies. With the rash of nuclear accidents in the late fifties, federal laboratories rushed to adopt ‘and install nuclear accident dosimetry systems. Because of time limitations and the lack of adequate test facilities, most of those systems received only cursory testing and evaluation before deployment. It was decided to make HPRR available for comprehensive and comparative studies of the accuracy and utility of the various accident dosimetry systems. Consequently, an annual series of nuclear accident dosimetry (NAD) intercomparison studies was started in March 1965 (Fig. 25), and 22 of these valuable NAD intercomparison studies were held before the shutdown of HPRR in 1987.

National Standards. Personnel from ORNL, with their wealth of experience in accident dosimetry, were

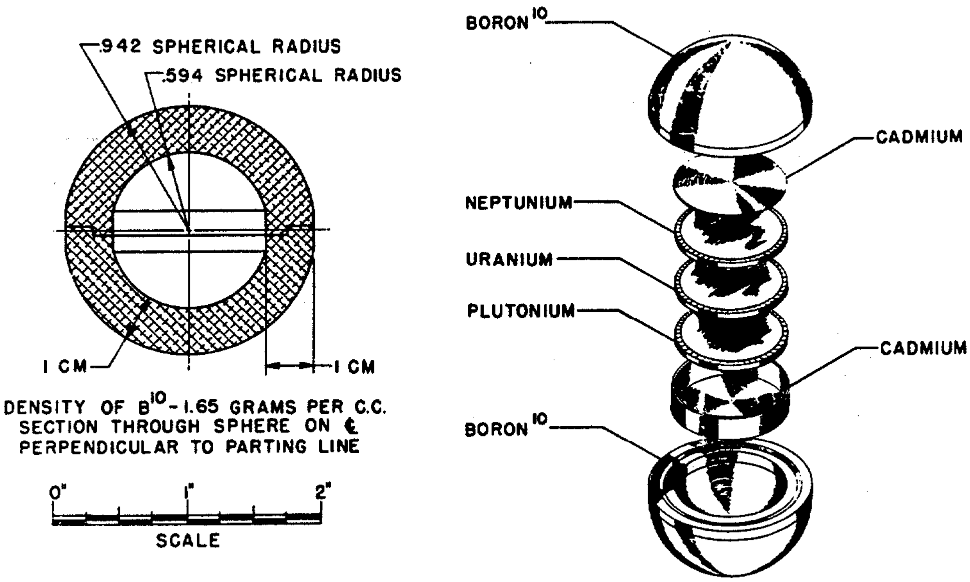


Fig. 23. Schematic of a neutron 'threshold detector unit showing the outer shields of ^{10}B and cadmium and the three fission foils of ^{237}Np, ^{238}U, and ^{239}Pu.

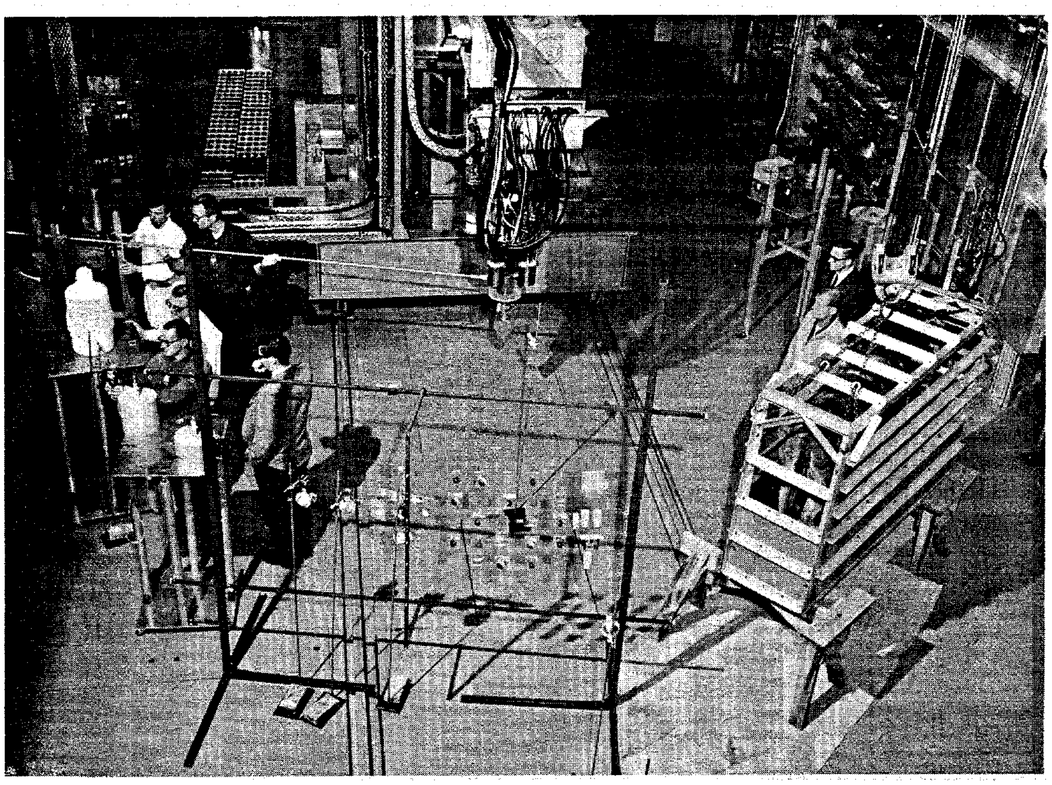


Fig. 24. Photograph of the Health Physics Research Reactor and setup of nuclear accident dosimeters for an early intercomparison study. The burro on the right was used as **a** human analogue to obtain data on neutron activation of blood sodium following a nuclear criticality accident.

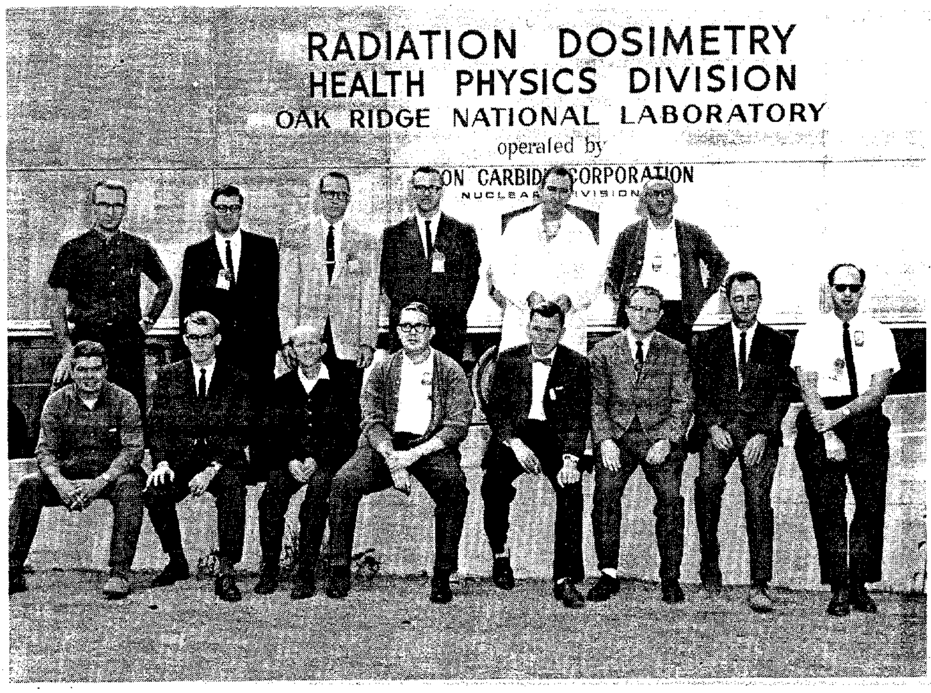


Fig. 25. Photograph of the participants in an early intercomparison of various nuclear accident dosimetry techniques and hardware. Oak Ridge National Laboratory staff members shown in the photograph are Walt Giliey (3rd from left on front row), George Kerr (4th from left on front row), Dennis Johnson (1 st from left on' second row), and John ***Poston*** (5th from left on second row).

chiefly responsible for the development and implementation of the **American National Standard: Dosimetry for Criticality Accidents?*** Information gained from ORNL research, developmental HPRR test results, and **NAD** studies was vital to this standard. The quality of the nuclear accident dosinietry work performed at DOSAR during this period is demonstrated by the fact that this standard was **reaffirmed** in its entirety in 198 1 and is still in effect today.

Solid-State Dosimetry

Paralleling the nuclear accident dosimetry work was a program to improve radiation monitoring capabilities using new solid-state devices. Klaus Becker was hired in 1967, and a vigorous program was initiated to produce improved dosimeters with tissue-equivalent response and high sensitivity to fast neutrons or short-range radiations. Dick Gammage joined the group in 1970 to strengthen a team composed of Becker, Joe Cheka, visiting scientists such as **Augusto Moreno** and Guillermo Espinosa from Mexico City, graduate students, and foreign guests on fellowships from the International Atomic Energy Agency. The program focused on improved types of plastic track-etch detectors and new etching techniques for neutron dosimetry and radon monitoring, exoelectron emission from lunar materials, exoelectron dosimeters to measure short-range radiations such as the beta rays from **tritium** and ^{14}C, and thermoluminescent dosimeters having novel ingredients **with** more attractive response characteristics. The program had strong international ties. Becker was instrumental in organizing several early international solid-state dosimeter and exoelectron conferences behind the Iron Curtain and in testing dosimetry systems under the often harsh environmental conditions that existed in developing countries. Becker returned to Germany in 1975. Gammuge continued the program until funding was converted to occupational monitoring problems associated with the production of synthetic fuels (see Synfnel Research Program in **THE** SEVENTIES).

Basic Radiation Physics Research

The basic radiation physics programs in the Health Physics Division had grown to about 25 permanent staff members in the early **1960s,** plus an average of about 10 graduate students per year. The latter were drawn primarily from The University of Tennessee (UT) and from Vanderbilt University. By this time research topics included the stopping power of matter, collective electron modes in condensed matter, excitation and ionization processes, the motion of electrons in gases, electron capture to the negative ion state, and **ion–** molecule reactions. There were also major theoretical efforts relating to the interaction of radiation with matter and the transport of radiation.

Advances in the gaseous electronics program, under Sam Hurst's leadership, included the application of the time-of-flight (TOP) concept to measurement of the properties of electrons diffusing through gases and to the determination of capture cross sections, drift velocities, and diffusion **coefficients** from such measurements through computer analysis of TOF data. An outstanding discovery made in this period was that the diffusion coefficient of electrons in an applied electric field depends on whether diffusion occurs parallel with or transverse to the field. Francis Davis, Tom Bortner, and Paul Reinhardt were involved in this effort. In addition, work was begun on experimental study of photon emissions from gases irradiated by swift-charged particles. This led later to important work on energy pathways in such systems. Talented people such as ***Loucas*** Christophorou and Bob Compton joined the group in **mid**-decade. Sam Hurst and both of these researchers arc now Corporate Fellows of Martin Marietta Energy Systems, Inc. (Energy Systems).

The program of Bob ***Birkhoff's*** group involved extensive experimental work on electron energy loss spectra in many different materials; measurements of electron slowing-down spectra in solids; and pioneering work on the dielectric functions of liquids, including the important case of liquid water. Emphasis was placed on the existence of collective modes in these media. Collective modes of electron and atomic motion in condensed matter arc of great importance in determining the **manner** in which energy is absorbed from ionizing radiation.

To better understand how surface plasmons are manifested in experiment, Rufus Ritchie **and** his students developed the theory of light emission **from** solids bombarded by **swift**-charged particles. This accounted for both surface plasmon-photon coupling and the generation of **bremsstrahlung,** or "braking radiation," emitted when a penetrating particle is "slowed down" in the solid. The theory was developed in close collaboration with the experimental program of Ed Arakawa, who returned to the Health Physics Division (HPD) in 1960 after a 2-year assignment in Hiroshima and whose ingenuity and expertise in the laboratory have enabled him to make many important contributions to the field of surface physics. The first mathematical expression for the characteristic energy of the fully retarded surface **plasmon** was given by workers in Ritchie's group during this period. This has significant implications in understanding surface electromagnetic waves in solids, which are currently being investigated intensively in areas such as integrated optics. The group was also the first to apply hydrodynamical theory and quantum dielectric theory to study the surface **plasmon** within the "specular reflection model" (now as a standard theoretical tool to study collective modes such as the surface **plasmon** and surface polaritons) and the first to use quantal Monte Carlo methods to determine the dielectric function of the electron gas and to study the annihilation of positrons in such a system.

In addition, this group worked closely with ***Birkhoff*** **and** his collaborators in designing a spherical electrostatic electron energy analyzer, dubbed the **"Keplertron,"** that was built and used extensively in measurements of electron slowing-down spectra in solids that are due to distributed electron sources. These data were analyzed and interpreted by the theory group and remain even today the only such data in existence. In this effort, several theoretical constructions of such spectra were made. This effort led them to develop new approximations for the dynamic response functions of solids that have been very useful in arriving at transport parameters of electrons in condensed matter and **were** the basis for theoretical cross sections used in transport codes developed in the 1970s.

Several researchers important to the continuing development of our programs joined the staff in the early 1960s. Among these talented people were Harvel Wright, Bob Hamm, and Jim Ashley, former UT graduate students, who pioneered in theoretical studies of electron and ion interactions in condensed matter. Jim Turner, an important contributor to this and many other efforts in the Division, joined the group from the U.S. Atomic Energy Commission (AEC); he was recently named a Corporate Fellow of Martin Marietta Energy Systems, Inc. (Fig. 26). During this period, important theoretical work was begun on the transport of high-energy radiation using the Monte Carlo method. Neufeld, Wright, Turner, and Snyder were intimately involved **in** this effort (Fig. 27). They were members of the High-Energy Dosimetry Task Group of the International Commission on Radiological Protection. Neufeld continued in research on collective modes in plasmas, while Snyder became heavily involved in internal dosimetry studies. Turner was the driving force behind completion of the textbook **Principles of Radiation Protection,**[33] which incorporated the health physics lectures of K. Z. Morgan, ***Elda*** Anderson, Myron Fair, and others, with contributions by **the** HPD research staff.

The coupling of nonradiative surface plasmons with surfaces was first observed experimentally by Ed Arakawa and UT graduate student Jim Stanford. They showed that an unexpected dip in the reflectance spectrum of silver, magnesium, and aluminum was due to the microscopic roughness of these surfaces, which furnishes the momentum needed to satisfy the energy-momentum conservation requirements. This process is now widely used in many

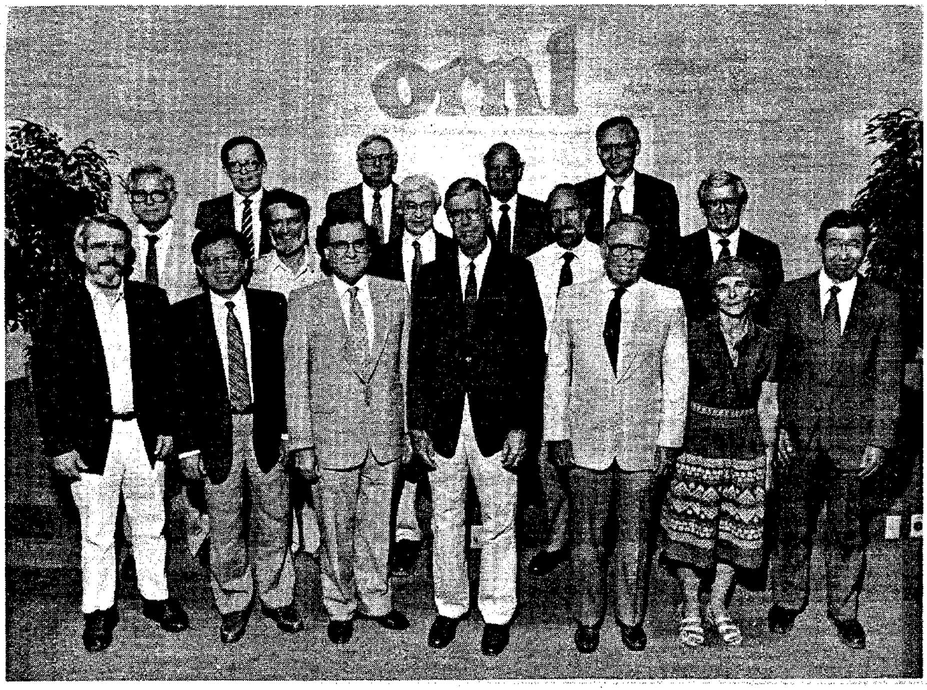


Fig. 26. Corporate Fellows of Martin Marietta Energy Systems, Inc., in 1990. Front row (from left to right): Paul F. Becher [Metals and Ceramics (M&C)], C. T. Liu (M&C), *Loucas Christophorou* [Health and Safety Research Division (HASRD)], Herbert A. Mook, Jr. (Solid State), Peter Mazur (Biology), Liane B. Russell (Biology), Samuel H. Liu (Solid State). Second row: Lester C. Oakes (Instrumentation and Controls), Francis G. J. Perry (Engineering Physics and Mathematics), Rufus *Ritchie* (HASRD), Eric Hurst (Energy), Richard F. Wood (Solid State). Third row: Thomas J. Wilbanks (Energy), Fred C. Hartman (Biology), *Jim Turner* (HASRD), Bob *Compton* (HASRD).

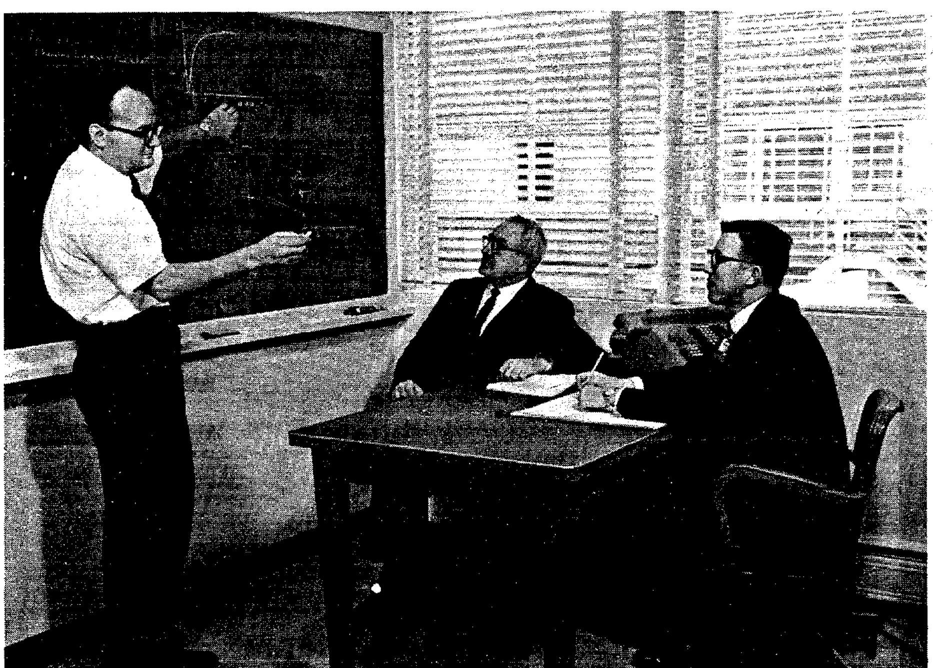


Fig. 27. Early photograph of several members of the High-Energy Task Group of the International Commission on Radiological Protection. Shown from left to right are *Jim Turner, Jake Neufeld,* and *Harvel Wright.*

experimental applications and also as a diagnostic tool for quantitative surface roughness measurements.

During this period, **Physical Review Letters** published a paper by *Arakawa, Birkhoff,* and Vanderbilt graduate student Bob Herickhoff that clearly demonstrated the radiative decay of plasmons from aluminum through the detection of very feeble, discrete, vacuum ultraviolet (UV) photons emitted when a thin aluminum film is bombarded by high-energy electrons." In order to obtain absolute photon intensities for comparison with theory, a unique grating calibrator and a vacuum UV polarizer were developed (Fig. 28). These two instruments are now widely used throughout the world. The agreement of the experimental data with the theoretical work is a piece of landmark research that is quoted in many standard textbooks.[35]

The first measurements of electron energy distributions from surfaces irradiated by high-energy photons beyond the cutoff of lithium fluoride (LiF) windows under ultrahigh vacuum conditions were made by *Arakawa* and UT graduate students Jim Stanford and Bob Vehse. This required the development of entirely new techniques for measurement; in some cases, this meant the use of thin, self-supported metal films to separate the low-vacuum light source and monochromator from the high-vacuum sample chamber. Their results on nickel resolved a heated controversy concerning an anomalous structure that was shown to arise from submonolayer coverages of the nickel surface with oxygen. Discrete energy losses suffered by photoelectrons during the escape processes from the medium into vacuum were observed in silver and palladium and reported in **Physical Review Letters.**[36] In the latter part of this decade, Wendy Williams (now Wendy England) joined the group and, together with Bob *Hamm*, assistedin analyzing the important experimental data obtained by Ed *Arakawa* and his students. The Second International Conference on Vacuum UV Radiation Physics was held in Gatlinburg in 1968 under the cochairmanship of *Arakawa* and *"Doc" Emerson* (Fig. 29).

Stopping-power theory received critical attention. Ritchie and Turner were members of the National Academy of Sciences-National Research Council Subcommittee on Penetration of Charged Particles, chaired by U. Fano. Work at ORNL concentrated on ultrarelativistic stopping powers and mean excitation energies.

Fig. 28. Photograph of Ed *Arakawa* aligning a triple-refiection vacuum ultraviolet polarizer developed at Oak 'Ridge National Laboratory with theoretical help from *Bob Hamm.*

Environmental Radiation Studies

Plowshare Project. A challenge of international scope was presented to the Division by the **AEC's** Plowshare Project: develop a new modeling methodology for predicting radiation doses to the public following the release and movement of radioactivity along environmental pathways. This information was needed because **AEC** was considering the use of nuclear detonations to excavate large land masses (e.g., a new canal through the isthmus in Central America) and to stimulate' the flow of natural gas from impermeable rock strata deep underground in the western United States. Using experience with ecosystem models and radiation dosimetry, Steve Kaye and Paul Rohwer responded and successfully developed a new methodology tailored to predict the potential radiological doses to humans from Plowshare applications.

Fig. 29. Photograph of Oak Ridge National Laboratory participants relaxing at a cookout held at the Second international Conference on Vacuum UV Radiation Physics in Gatiinburg in 1960. Pictured are (left to right) Bob ***Birkhoff,*** *Beverly Sweden,* Bob **MacRae,** *Sharon Fuller,* ***Eph Klots,*** *Jim Ashley,* and Linda Painter (photo by *Ed* ***Arakawa***).

The new methodology was based on the adaptation of engineering systems analysis techniques used to model the movement of vented radionuclides through environmental pathways that could expose humans. This predictive modeling approach was new in its application to the Plowshare Project in the late 1960s and represented an advance over static calculations because various scenarios could be evaluated with dynamic systems analysis models. AEC decided to terminate the Plowshare Project by the end of the decade, but environmental systems analysis remains as a major predictive tool that is now routinely used by scientists worldwide for assessing radionuclide releases.

Clinch River Study. The Division also completed a comprehensive study to assess the extent and possible impacts of radiological releases into the Clinch River, which was receiving effluents from ORNL's operations. The extensive measurements resulting from the Clinch River study were utilized in a number of ORNL documents to estimate total releases, pathways resulting in human exposures, and dietary factors contributing to doses received by populations living downstream from the nuclear operations. The comprehensive nature of this study made it useful as a model for similar studies at nuclear sites in the United States, and locally it set the stage for good public relations with downstream communities which continue to this day.

Woody Cottrell, who joined HPD in 1946 and currently works in HASRD, led the radiological, sediment sampling program down the Clinch and Tennessee rivers (Fig. 30). From both a historical and an environmental assessment standpoint, this study is significant because it demonstrates that, even back in the 1950s, there was a concern with the off-site migration of radionuclides from the Oak Ridge Reservation and with the potential human health hazards associated with the "downstream reconcentration of radioactive materials."[37] The results of the study are currently cited in various ORNL Environmental Restoration documents.

Fig. 30. Boat and equipment used in river surveys. Shown are *Harold Abee* (left), *Woody Cottrell*, and *John Davis* (right).

Biomedical and Environmental Information Analysis: 1960s to Present

During the 1960s, efforts to collect and organize technical information at ORNL were increasing rapidly. This was due primarily to the attitude of ORNL's management that such work was a worthy and natural part of science. The catalyst for this thinking was a report issued in 1963 by a Presidential Science Advisory Committee, chaired by then ORNL Director Alvin Weinberg.[38] The report called on the scientific community at large to become actively involved in the collection and organization of technical information. With this report as a stimulus, involvement of the Laboratory's research personnel in information work was encouraged. By the late 1960s, over 20 technical information centers or activities were in operation at ORNL, and most of these were embedded in research divisions. These information activities were the forerunners of those that would form in 1987 the components of the Biomedical and Environmental Information Analysis (BEIA) Section of HASRD.

Building on the foundations established during the previous decade, the 1970s were a time of continued growth and development for information centers and related activities at ORNL. The support from upper management for these activities continued and was a significant factor in helping them flourish. During this time the Environmental Information Systems Office (EISO) was formed (Fig. 3 1). This organization was attached to the Office of the Associate Director of Life Sciences with the mission to serve as an umbrella for the varied information activities scattered throughout several Laboratory divisions. In 1971 EISO was organizationally moved to the Information Division and changed its name in 1974 to the Information Center Complex (ICC). The ICC mission remained essentially the same as that of EISO. During the mid-1970s several of the remaining technical information centers that were still part of research divisions [e.g., the Toxicology Information Response Center (Fig. 32), the Environmental Mutagen Information Center, and the Environmental Teratology Information Center (Fig. 33)] were organizationally transferred to ICC. These transfers, with a few exceptions, ended for the time being the organizational relationship between research divisions and information centers. In this altered environment, information center growth reached a plateau, so other work activities were initiated for federal agencies by ICC component groups working independently and with other ORNL groups. This work focused primarily on reviewing health hazards of environmental agents and on preparing environmental assessments reports and similar documents on radiological and chemical pollutants (Fig. 34).

In the 1980s changes were occurring in the way funds were being allocated for information projects. Support for straightforward information work (i.e., the building of information files for support of a scientific or technical discipline) was waning. By 1989 the only such information center remaining in the BEIA Section was the Environmental Mutagen Information Center (EMIC). Because of the changes in information

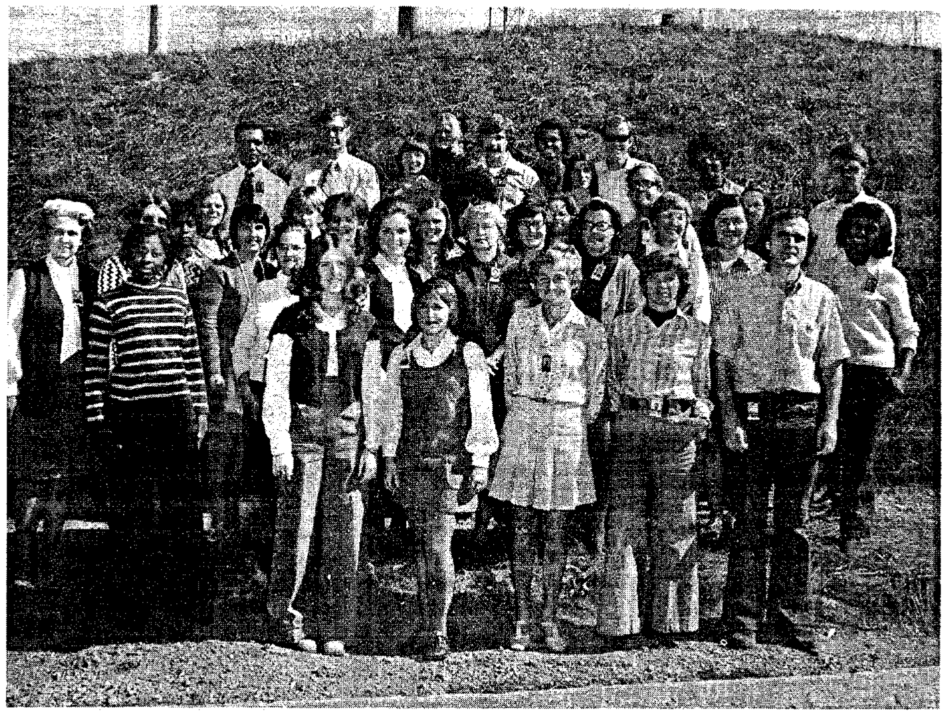


Fig. 31. Early 1970s photograph of staff members in the Environmental Information Systems Office of Oak Ridge National Laboratory.

Fig. 32. Photograph of staff members of the Toxicology Information Response Center in 1976. Pictured are (seated) Sharon Black, Eileen Waters, ***Blanca Ricci***, Susan Winslow; (standing) ***Helga Gerstner***, Regina Atwater, Jennetta Hutson, *Lois **Frogge*** (now *Lois **Floyd***).

Fig. 33. Photograph of staff members of both the Environmental Mutagen Information Center and the Environmental Teratology information Center in 1976. Pictured are (seated) Cynthia Schenley, Mike Shelby, John *Wassom, Jimmie Taylor;* (standing) Beth Owens, *Judy Adams* (now *Judy **Mynatt***), *Wilma Barnard, Liz Von **Halle**,* Marilyn Sheppard, Ida *Miller, Helen Morgan.*

Fig. 34. Photograph of staff members of the Biomedical Studies Group in 1976. Shown are (first row) *John Drury,* Lilabeth Cockrum, *Donna Stokes, Betty Galyan* (now *Betty Dagley*), Carol Shriner; (second row) *Eric Lewis,* Pat Hartman, Anna Hammons, Lee Towill, and *James Holleman.*

project funding, most of the Section's work during the latter part of the 1980s drifted away from those based solely on the technical information center concept. New work areas focusing on the Section's technical expertise in data analysis activities, computer applications, development of customized data bases and/or data management systems, technical information transfer, artificial intelligence, etc., were added. During this time, several new projects were inaugurated as part of this reorientation, such as the Human Genome Management Information System, the Chemical Unit Record Estimate data base, and the production of toxicology

Fig. 35. Staff members of the Biomedical and Environmental Information Analysis Section in May 1992.

profiles on select chemical agents for the U.S. Air Force, to name just a few. Other initiatives included **waste** management, environmental compliance, environmental restoration, and the preparation of health risk and. environmental assessment documents. As testimony to the caliber of work in the Section, the Environmental Mutagen Society awarded to EMIC in 1980 its recognition award for outstanding contributions to the field of genetic toxicology.

At present, the BEIA Section, under the direction of ***Po-Yung*** Lu and group leaders, John Wassom, Bob Ross, Mary W. Francis, and Gloria ***Caton,*** are continuing many of the programs that were in place at the end of the 1980s. In addition to these ongoing activities, the Section will be exploring new areas where the wealth of its resources and staff experience can be utilized (Fig. 35). It is expected that the Section will enter into a new phase as it expands into other areas of research such as predictive toxicology, expert systems development for personal computers, environmental safety and health compliance, and the origination and/or application of more novel techniques of information management (see Biomedical and Environmental Information Analysis in **THE NINETIES).**

THE SEVENTIES

Environmental Impacts Report Project

ORNL's entry into the environmental impacts business was a logical result and extension of activities already ongoing in the Health Physics Division (HPD). Two such activities prominent in the late 1960s were (1) Dose Estimation Related to Peaceful Uses of Nuclear Explosives and (2) Atlantic-Pacific Interoceanic Canal Study. Among the key participants in those activities were Ken Cowser, Don Jacobs, Steve Kaye, Paul Rohwer, Walter Snyder, and Ed Struxness. Innovative concepts and methodologies, developed in those activities provided tools needed to address tasks implicit in the development of the newly required environmental impact statements. For example, INREM and EXREM computer codes and data bases were developed to estimate radiation doses to individuals and populations through internal and external exposures. The doses resulted from environmental releases of radioactivity involving numerous radionuclides and exposure pathways (Fig. 36). Also well under way were detailed analysis of food-chain pathways leading to humans and early attempts at the development of radiation safety guidelines for transient exposures as contrasted with the more studied continuous exposures typically assumed in estimating potential doses for radiation workers.

In 1969 the U.S. Congress enacted the National Environmental Policy Act (NEPA). NEPA created a new requirement for federal agencies to thoroughly review the impact of all projects, to weigh the costs and benefits of such projects, and to examine alternative projects, thus the need for environmental impact statements. An immediate focus was on the Atomic Energy Commission (AEC) nuclear power stations showcased by a Federal Appeals Court ruling on July 23,197 1, relative to the Calvert Cliffs Station. In the earliest of these environmental impact evaluations, characterization and assessment of potential radiological impacts were major considerations, and the work done in HPD set the mark on which all of the AEC's detailed environmental impact statements were subsequently patterned. Prominent contributors to this early environmental impact statement work under Ed Struxness were Harold *Abee*, Ray Booth, Tom Burnett, Tom Clark, Myron Fair, Steve Kaye, Minton Kelly, George Kerr, *DeVaughan* Nelson, and Paul Rohwer. In 1972 the Laboratory staff and resources dedicated to environmental impact statement preparation expanded greatly, and the entire activity was moved to the Environmental Sciences Division (ESD).

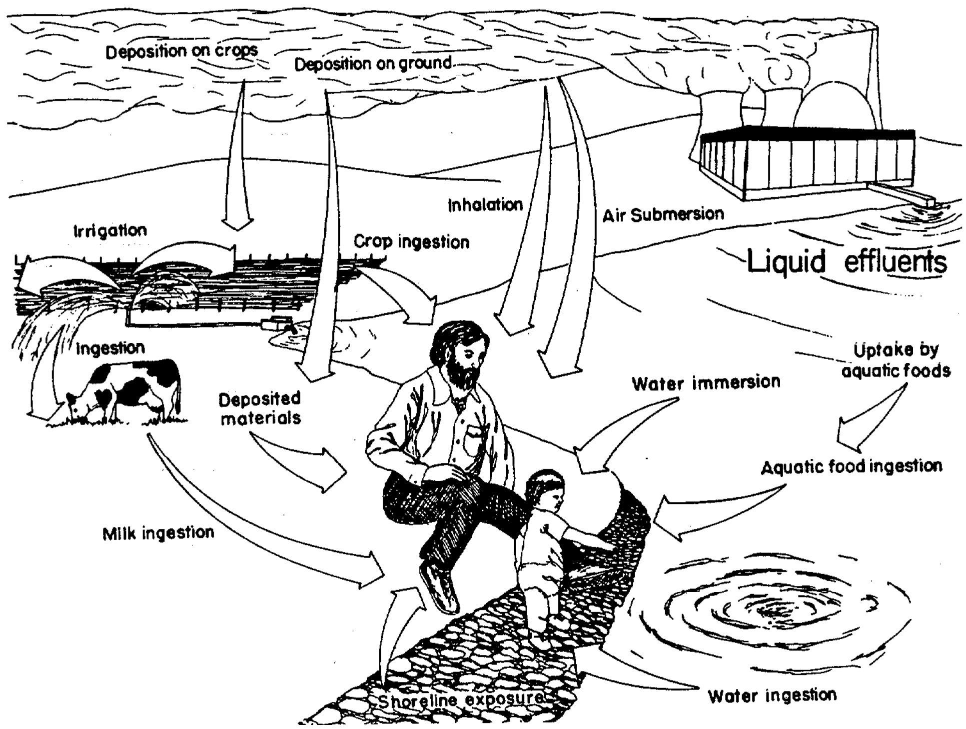


Fig. 36. illustration of the exposure pathways to humans for the gaseous and liquid effluents from a nuclear power station or other nuclear faciilty.

Uranium Mill Tailings Surveys

Today's extensive off-site characterizations of environmental contaminants began with involvement in the Grand Junction Remedial Action Project in 1972. From 1943 to 1970 most of the uranium in the United States was processed by private companies for delivery to AEC (and its precursor, the Manhattan Engineer

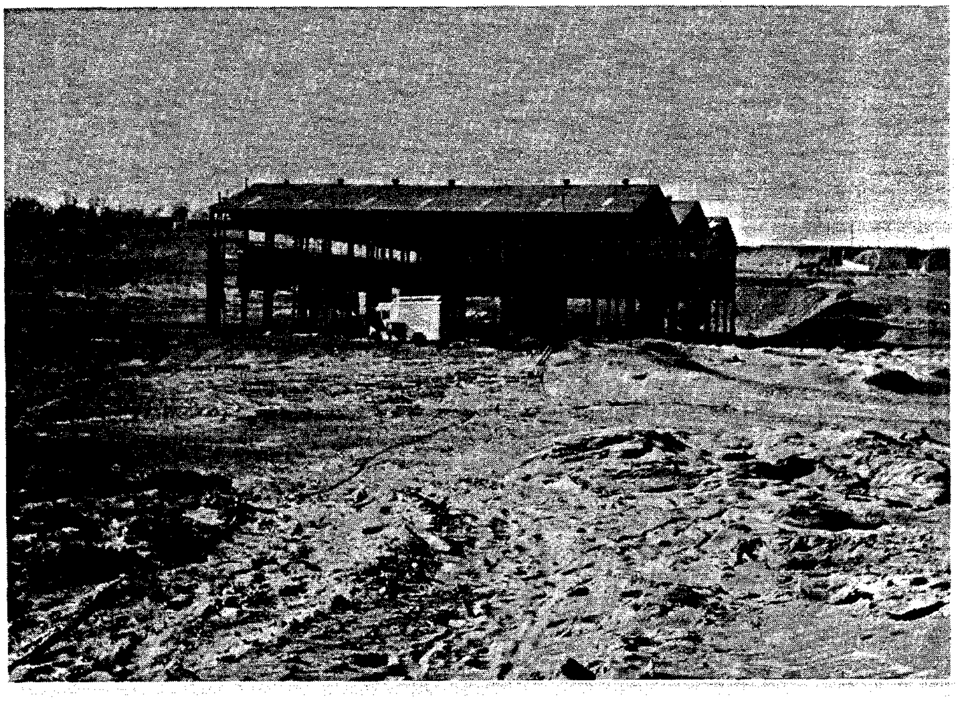


Fig. 37. Photograph of the "Gray Ghost," a delivery van used as a mobile laboratory, during an early survey at a site of abandoned uranium mill tailings in Tuba City, Arizona.

District). The uranium was extracted for use in nuclear weapons and in a developing nuclear energy program. Only the uranium was extracted from the uranium ore, leaving behind a residue called tailings, which is also radioactive. The greatest health concern associated with these tailings is the formation of radon gas and its radioactive byproducts, but no provisions were made by the government or these private companies to control and properly dispose of them. The tailings were used extensively in construction; therefore, numerous private, commercial, and federal properties became contaminated.

In 1973 ORNL was invited by AEC to make radon measurements in buildings in Grand Junction, Colorado, where tailings contamination was suspected. George Kerr, Phil *Perdue,* Bill Shinpaugh, Bill Fox, and Fred *Haywood* were involved in these early measurements using an old delivery truck called the "Grey Ghost" (Fig. 37). Beginning in 1973, various types of federal legislation were passed for funding and studies of the uranium mill tailings problems across the United States. These studies showed the tailings to be a potential health and environmental concern and culminated in the passage of the Uranium Mill Tailings Radiation Control Act of 1978 (PL 95-604), which mandated cleanup criteria from the U.S. Environmental Protection Agency (EPA) and remediation at affected sites by DOE with concurrence of the U.S. Nuclear Regulatory Commission. In 1976 ORNL began a preliminary site characterization of 24 inactive uranium mill sites with Ford, Bacon and Davis Utah (a western engineering firm). When HASRD was formed in April 1977, the work was performed under the leadership of Fred *Haywood* in the newly formed Offsite Pollutant Measurements Group (Fig. 38). In 1979

Fig. 39. Photograph of some of the original surveyors of the western mill tailings sites at a retirement party **for *Bill Shinpaugh* in 1985.** Shown from left to right are *Phil Purdue, Fred **Haywood,** Don Jacobs, George Kerr, Bill Shinpaugh, John Roberts, Ed* Loy, and *Troyce Jones.*

ORNL began to perform comprehensive radiological characterizations of properties in the vicinity of uranium mill sites for the U.S. Energy Research and Development Administration (ERDA, now DOE) that were identified as contaminated. In 1980 Tim ***Myrick,*** Mike Blair (Instrumentation and Controls Division), and Rick Doane began to develop a mobile vehicle that could be used to identify properties contaminated by uranium tailings from the streets or alleyways (mobile gamma scanning van). This van was used extensively to screen for radioactivity in the communities where the inactive mill sites are located. Often, 100% of all streets in those communities were scanned with the van (Fig. 39).

In 1983 ORNL was invited by DOE to become the "Inclusion Survey Contractor?' in the DOE Uranium Mill Tailings Remedial Action Program **(UMTRAP).** The mission of this new endeavor was to establish an office in Grand Junction, Colorado, and survey about 10,000 properties in the vicinity for radioactive tailings over a period of 4 years. The surveys were designed so that screening could be conducted quickly and at little. cost, but be sufficiently complex to ensure that tailings are or are not present in concentrations in excess of relevant EPA criteria. During October 1983 Craig Little and five other ORNL employees (Hal and Ogene Jennings, Tom Barclay, Dave ***Witt,*** and John Roberts) relocated to Grand Junction to undertake this daunting task (Fig. 40). Over the next 6 years the office grew **to** a staff of 65, and they completed over 14,000 surveys. During this time, annual milestones were met and the work was'performed below

Fig. 39. Mobile gamma scanning van during a 1992 survey. Shown **inside the van** from left to right are *Tim **Myrick,*** Rick Doane, and Mike Blair (instrumentation and Controls).

projected costs. This work has evolved into conducting surveys to verify that remedial actions taken at vicinity properties are successful in meeting EPA criteria. The ORNL Grand Junction Office continues to grow into new areas of environmental assessment in collaboration with ESD and Energy Systems' Hazardous Waste Remedial Action Program. Funding provided by DOE, the U.S. Department of Defense (DOD), and the U.S. Department of the Interior supports about 75% of the ongoing work and the 65 staff that remain at the ORNL Grand Junction Office (Fig. 41).

Fig. 40. Photograph of Oak Ridge National Laboratory personnel who relocated in 1993 to the ORNL Office in Grand Junction, Colorado. Front row (from left): *John Roberts, Ogene Jennings,* and *Craig Little.* Back row (from left): Tom Barclay (Instrumentation and Controls), Hal Jennings (Chemical Technology), and *Dave Witt.*

HEED Studies-Risk Analysis

In order to support the formulation and management of health and environmental research, DOE's Health and Environmental Risk Analysis Program (HERAP) provided quantitative analyses of the potential risks of emerging energy technologies. These analyses, known as health and environmental effects documents (HEEDs), provided a quantitative description of knowledge and uncertainties regarding potential health and environmental risks of various energy technologies. The HEEDs prepared by ORNL staff supplied a systematic approach to characterizing health and ecological risks for diit coal liquefaction. Literally thousands of chemicals, singly and in combination, are theoretically associated with coal-derived synfuels. It is neither economically nor scientifically practical to test all possibilities. Thus, prioritization of potential effects, uncertainties, and accompanying research efforts was necessary. The impacts (excess number of health effects) of fuel materials produced or released to the environment as byproducts of fuel production can be determined by combining an exposure assessment with a health effects assessment.

,&termination of the concentration of toxic materials in space and time at the interface with target populations is usually called exposure assessment, and estimation of exposure-response relationships is known as health effects assessment. The two components are combined to 'yield a risk assessment (in effect, the excess number of health effects due to releases of toxic materials from a particular component or all the components of a technology). Thus, the relative severity of health and environmental impacts can be established and prioritization of research needs can be accomplished through a comprehensive risk assessment activity that encompasses an assessment-oriented technology description, a chemically and physically characterized source term, environmental transport and fate analysis, and ecological and human health effects analysis.

The HEED analyses prepared by ORNL staff focused on formally

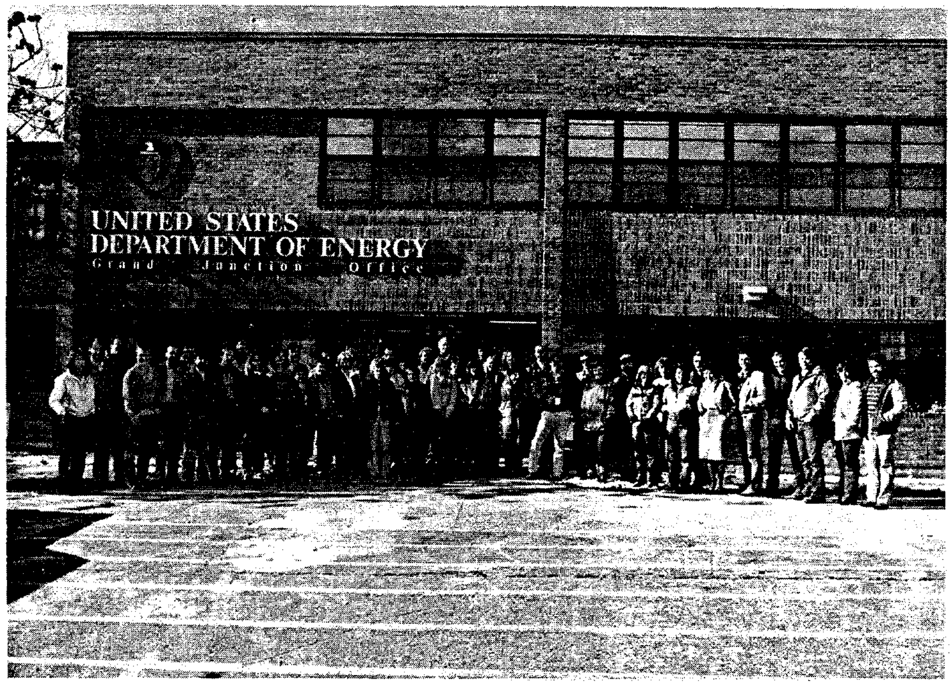


Fig. 41. "ORNL West" in Grand Junction, Colorado, is staffed by 65 Oak Ridge National Laboratory and subcontractor personnel who perform environmental measurements and assessments for the U.S. Department of Energy and other agencies of the U.S. Government.

integrating comprehensive human health and ecological studies on direct coal liquefaction to quantify risk as well as to identify research that would reduce uncertainty in critical areas. HEED analyses were directed at various times by Dennis *Parzyck* and Phil Walsh and were to be part of a continuing activity to provide more precise quantification and recommendations as data and research needs were met. It was also intended that the assessment expand to neglected areas as resources permitted. The overall process required close interaction with both technological and biomedical scientists to ensure a common view of problem areas, research designs compatible to resolution of the overall problems, and feedback of results. The interaction was one of the most important aspects of the ORNL assessment activity and was carried out primarily by HASRD staff in collaboration with ORNL's Life Sciences programs in synthetic fuels and fossil energy as well as through participation in HERAP workshops that covered numerous aspects of assessment and research in health and environmental effects of synfuels.

Synfuel Research Program

At the 1975 Division Information Meeting, several HPD staff were invited to tour the Tennessee Valley Authority's coal-fired steam plant at Bull Run with Robert W. Wood, Director of the Physical and Technological Research Division in the DOE Office of Health and Environmental Research (OHER), which was part of ERDA at that time. The tour marked the beginning of our research involvement on alternative energy systems, particularly synfuels. An early mission of this research, which was done under the diction of Dick Gammage, was to develop portable devices for measuring worker exposure to harmful fugitive emissions. New hirees into the fledgling occupatior.al health research program were *Alan* Hawthorne, *Tuan* Vo-Dinh, and Daniel Schuresko.

The focus of this research was on oil and tar products and the carcinogenic polycyclic aromatic hydrocarbons (PAHs) that they contain. A workshop, with 35 attendees, was convened at ORNL on February 6, 1976, with representatives from ERDA, the National Institute for Occupational Safety and Health (NIOSH), EPA, DOD, Environment Canada, industry, and universities.[39] The title was "PAH: Characterization and Measurement with a View Towards Personnel Protection." A second workshop, held in 1977 after the formation of HASRD, attracted 140 participants; the title was "Exposure to PAH in Coal Conversion Processes: I. Medical Surveillance, II. Industrial Experiences, Personnel Protection, and Monitoring."@'

To get a quick practical start, a bulky, derivative ultraviolet absorption spectrometer (DUVAS) that was designed for analysis of SO, and lower boiling point aromatics was purchased and adapted. Hawthorne and Gammage collaborated to develop a truly portable miniaturized DUVAS under microprocessor control (Fig. 42). The portable DWAS was first used to monitor fugitive emissions at our coal hydrocarbonization test facility. Interestingly, this DWAS has

Fig. 42. *Alan Hawthorne* and *Dick Gammage* in 1981 with a derivative ultraviolet absorption spectrometer that was designed for the analysis of sulfur dioxide and low boiling point aromatics.

undergone modem evolution into a fiber-optic device for directly measuring hydrocarbon fuel contaminants in groundwater.

Schuresko transferred to the group from ORNL's Chemical Technology Division, where he had developed a portable spill spotter. The spill spotter produced a chopped ultraviolet light beam that induced fluctuating fluorescence from oil spills that was detectable even in direct sunlight. *Vo-Dinh* and *Gammage* collaborated to produce a fiber-optic, fluorescence-inducing luminoscope. This highly portable device resembled a stethoscope and was designed to detect invisibly small traces of PAHs on the skin while using very low level ultraviolet illumination. The luminoscope was used to start studies on skin dosimetry and decontamination (Fig. 43). Another simple device was a passive PAH, vapor-and-liquid-aerosol exposure meter worn on a worker's lapel. This battery of devices was tested extensively at the low-Btu coal gasifier of the University of Minnesota, Duluth, and the Ashland Oil Company's H-Coal Liquification Plant at Catlettsburg, Kentucky. The spill spotter and PAH exposure meter each won an R&D- 100 award.

Another forte of what was the Monitoring Technology and Instrumentation Group was the development of quick screening methods for evaluating PAHs in oil and tar samples collected by industrial hygienists. Synchronized fluorescence, derivatized ultraviolet absorption or fluorescence, and room-temperature phosphorescence were the spectroscopic techniques that proved

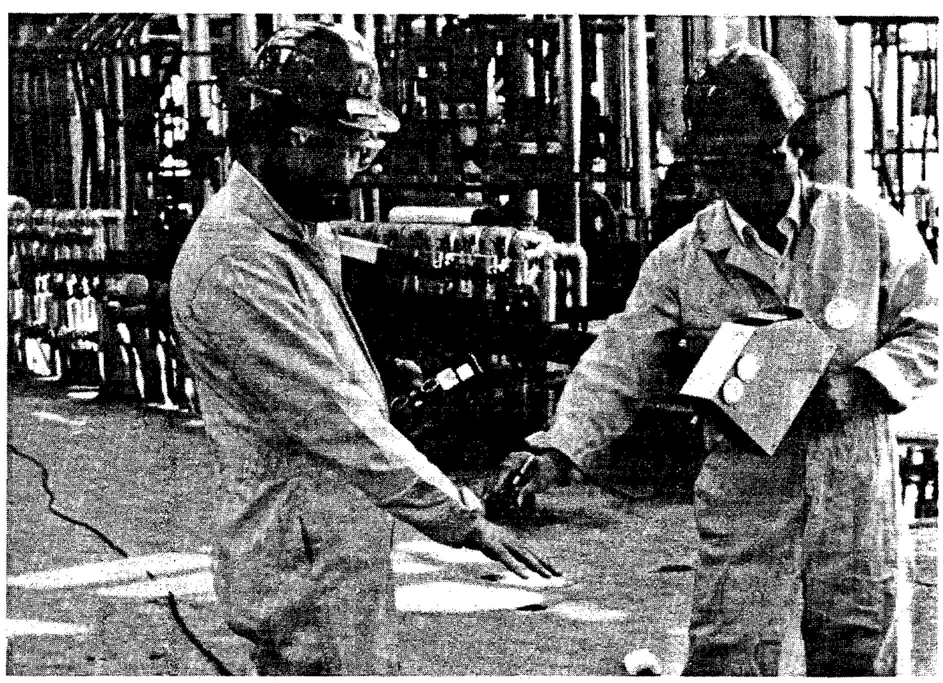


Fig. 43. *Tuan Vo-Dinh* checking *Dan Schuresko* for possible skin contamination at the H-Coal Pilot Plant in Cattletsburg, Kentucky.

most valuable and complementary to one another.

A watershed was reached in 1982. Following a retreat held at the Airlie House in Virginia, DOE OHER decided that the scientific understanding of the toxicity of synfuels was sufficient to begin focusing more strongly on the direct health protection of synfuel workers, the population deemed to be at highest risk. By 1983 HASRD had been given the task of drawing up a plan for DOE's national laboratories. A workshop on Monitoring and Dosimetry in an Occupational Health Research Program for Synfuel Technologies was held to identify key areas of research to improve occupational health protection for workers in a future synfuels industry. The proceedings were used in 1984 to produce the occupational health research plan for emerging energy technologies, which proved to be something of a swan song for the synfuel research program.

Coincident with these developments, the price of a barrel of oil crashed from over thirty dollars to the lower teens. With the availability of a cheap, temporarily plentiful supply of natural crude oil, the DOE OHER synfuel research and HEED programs came to an abrupt end in 1984.

Theoretical Radiation Physics Studies

The seventies were very eventful for radiation physics theory. In the basic study of charged-particle interactions with condensed matter, several important achievements may be noted. The theoretical group that was concerned with condensed matter physics consisted of Rufus Ritchie, Jim Ashley, Bob *Hamm*, and several graduate students, while Hamm, Jim Turner, and Harvel Wright dealt with particle transport theory.

Theoretical estimates made during this time of the probability of double-plasmon generation by swift electrons have spurred several different experimental studies of this phenomenon as well as many different theoretical estimates of the same quantity. The first theory of the simultaneous generation of transition radiation and bremsstrahlung by swift electrons was given, and a formulation of the quantized photon-plasmon system made it possible to solve a number of interesting problems in particle-solid interactions that until then could not be attempted by quantum-theoretic methods. A theory of the anomalous damping of plasmons in polycrystalline materials explained experimental results on this topic in a fully quantitative manner. An analytic solution was found for the low-energy end of the slowing-down cascade created in an electron gas by radiation. This has had many applications to the analysis of experimental data in radiation physics. The first theoretical study of high-order corrections to the well-known Bethe–Bloch formula for the stopping power of matter for charged particles was made. This has given rise to many subsequent experimental and theoretical investigations. A fundamental paper was written showing the connection between the image force near a metal surface and virtual excitation of the surface plasmon field at that surface. Stationary-state perturbation theory was used to analyze the ionization of inner shells of atoms by heavy ions and thereby rationalized an empirical procedure that was currently being used to analyze experimental data pertaining to this process. The interaction of swift ion clusters with condensed matter was studied using the theoretical concept of the charged-particle wake. This laid the groundwork for a new experimental method of establishing the steric (geometric) structure of ion clusters that has been pursued vigorously at Argonne National Laboratory. The theory of radiative electron capture by ions channeled in solids was elucidated. A theoretical procedure for estimating inelastic cross sections and energy loss rates of low-energy electrons in condensed matter was developed during this period. This has become a state-of-the-art method for obtaining theoretical data on many different materials that are difficult to study experimentally. Jim Ashley has applied this method systematically and energetically to many different materials.

In a collaboration between Ritchie and Archie Howie of the Cavendish Laboratory, problems of electron microscopy were addressed. A criterion for the maximum resolution attainable in energy loss transmission microscopy was established, and a statistical theory of the optical potential appropriate to such work was developed.

A major program of importance to basic radiation damage of biological matter was begun near the middle of this decade through the initiative of Wright, Turner, and Hamm. Using experimental data on the dielectric functions of liquid water obtained by Bob *Birkhoff*, Linda Painter, and coworkers, these workers, together with Rufus *Ritchie*, developed cross sections for the interaction of swift-charged particles with this substance. They used the Monte Carlo technique to produce a computerized simulation of the events that would occur as a charged particle passes through this material, which is of such basic importance to the living world (Fig. 44). Working in collaboration with John Magee and Aloke Chatterjee, they developed a model for determining the identity and position of each reactive chemical species (ion or radical) produced by each of the physical interactions. This theoretical approach has been applied to many different problems in microdosimetry with excellent results and may be said to represent the first realistic theoretical microdosimetry program.

During the later part of this decade, other gifted researchers, including Oakley *Crawford,* Tom Ferrell, and Bruce Wurmack, joined the Division and have added much to its programs. *Crawford* came from the Chemistry Division with a strong background in atomic collision theory. In the late 1970s and early **1980s,** he carried out an important **theoretical** study of the resonant coherent excitation of swift-channeled ions, subsequently developed the theory of **position-**dependent stopping of ions, and carried out theory for several other projects. *Ferrell* and Warmack took over the Submicron Physics program after Bob *Birkhoff's* retirement and have extended it with several outstanding developments in scanning microscopy (see Submicron and Liquid Physics in THE SEVENTIES and THE EIGHTIES). In 1979 Rufus Ritchie was designated a Corporate Research Fellow by the Union Carbide Corporation and later a Senior Research Fellow by Martin Marietta Energy Systems, Inc. (Fig. 26).

Fig. 44. Photograph of the developers of OREC, a Monte Carla transport code for low-energy electrons in liquid water. Shown from left to right are ***Harvel*** *Wright, Jim Turner,* Rufus ***Ritchie,*** and *Bob* ***Hamm.***

Experimental Radiation Physics Studies

This group, under the leadership of Ed Arakawa, Wendy England, and Tom *Callcott,* has pioneered in the development of techniques and instruments for measurement of the optical properties of materials in the vacuum ultraviolet and soft X-ray region of the spectrum. Over the years, with the help of many graduate students, the world's best and most comprehensive measurements of optical properties have been made of a wide variety of materials of biological importance such as DNA, chloroplasts, red blood cells, adenine, guanine, etc., over a wide energy range covering the whole oscillator strength of valence electrons. This work has now been summarized in an invited book chapter in the Handbook of ***Synchrotron Radiation*** Research, Vol. IV, coauthored by Arakawa, Wendy Williams (now Wendy England), and T. lnagaki from Osaka, **Japan.**[41]

Through a systematic study of the Wood's anomalies in grating diffraction, a Physical Review Letters paper was published that showed unexpected peaks in the diffraction spectra of continuum sources that could be ascribed to the grating rulings that furnish discrete amounts of momentum to the surface **plasmon.**[42] Energy gaps observed in the dispersion curves were shown to **be** analogous to energy gaps observed in single crystals in solid-state physics. This work illustrates the close collaboration that has existed over the years between the theoretical (Ritchie and Hamm) and experimental groups (***Arakawa*** and J. J. Cowan). Several thousand experiments have been carried out studying the various aspects of this phenomena, and several books have been written on the **subject.**[43] **Grating-**coupling is also now used in optical communication.

Submicron and Liquid Physics

The Submicron and Liquid Physics Group was born in 1975 under the leadership of Bob ***Birkhoff. Birkhoff*** discovered a nearly unexplored area of physics in the dielectric response of finely divided matter. He determined to study the unusual properties of particles with dimensions ranging from submicrometer down to the size scale where macroscopic dielectric responses begin to fail. Fundamental interactions between either charged particles or photons with such small particles would advance understanding in both theoretical and experimental areas. Others he enlisted in these efforts included Harry Hubbell and John Allen, David Spears as a postdoctoral fellow, and Russell Becker and Y. T. Chu as graduate students. Tom ***Ferrell*** came to ORNL and became a staff member in 1978.

Early experimental studies involved **the** scattering of light and electrons from known geometrical forms. A scanning electron microscope was acquired to help characterize **the** shape of these microscopic forms. Experimental stations were assembled to study the scattering of electrons and light by single cylindrical fibers. At the time, asbestos fiber characterization needed to be improved. Thus, fundamental studies could be of great benefit. Elastic and inelastic scattering of electrons by a formed cylindrical pore were also studied in a fundamental way. The application here was to ion transport in membranes. Although these were fundamental studies, they help exemplify the pattern followed by the group since then. Namely, broad, fundamental studies are undertaken with an eye toward applications to lithography, imaging, and spectroscopy.

Birkhoff **also** continued and expanded his collaboration with UT Professor Linda Painter. Their work involved the determination of optical properties of liquids from the infrared to the vacuum ultraviolet regions of the electromagnetic spectrum. Because of great experimental difficulties, this was the only group able to explore **the** vacuum ultraviolet region for liquids. Surface plasmons had been observed previously for solids but had not been experimentally verified in liquids until these studies. The dielectric properties of liquids **were** also of critical importance to dosimetric and track structure calculations that were being performed by the theory group headed by Rufus Ritchie.

Negative Ion Studies

In the past 20 years the physics of negative ions has been a cornerstone in the area of basic research in this Division. This work has included the attachment of slow electrons under high-pressure swarm conditions (***Loucas*** Christophorou) and in molecular beams (John ***Stockdale,*** Eph Klots, Bob Compton). The development of new laser techniques has allowed a myriad of new studies in photodetachment spectroscopy (Compton and Gerald ***Alton,*** who is now a staff member in the Physics Division) and in the area of Rydberg **charge-**exchange chemistry (Howard ***Carman*)**. Bob Compton's collaboration with ***Alton*** in the mid- 1980s led to a number of rather remarkable discoveries, among them the fact that Ca^- and He; formed bound states. They also measured **the** electron affinities for both of these species in addition to performing the first energy-level measurement for Be-. More recently, ***Lal*** Pinnaduwage and ***Loucas*** Christophorou have been successful at studying electron attachment to **laser-**excited molecules. These studies are important in pulsed-power applications and in radiation physics. As a result of earlier studies conducted by Sam Hurst and John Stockdale, the possibility of dipole-bound anions was suggested. Ray Garrett and Oakley Crawford, following previous work of Jim Turner, provided considerable theoretical guidance on this subject. Recently, such anions have been **well** studied.

There has been considerable interest in the possibilities of doubly charged negative ions in the physics and chemistry community. In this connection, collaborations between Bob Compton and other researchers at Arizona State University have resulted in very convincing evidence for doubly charged carbon clusters, C_n^{2-}, for $n \geq 7$. Compton and R. L. Hettich (Analytical Chemistry Division) have very recently reported the existence (possibly stable) of doubly charged Buckministerfullerene ions (C_{60}^{2-}). Calculations by Rufus Ritchie indicate that C_{60}^{2-} may be bound.

Negative ions are not only of intrinsic interest but also important because of the many possible applications to all phases of energy production, uses, and pollution abatement. It is certain that such research will be important in the future.

Gaseous Dielectrics

The energy crisis of the early seventies underlined the need for energy conservation and for efficient, safe, and environmentally acceptable **ways** to transmit and distribute electrical energy. For example, the development of insulating gases with electrical insulating properties superior to those of air would allow the use of more compact equipment, enclosed (underground) cables, and higher transmission voltages, which would result in enormous energy savings.

By the early seventies the Division had entered its second decade of fundamental studies on slow **electron–**molecule interactions, electron transport in gases, and negative ions. The results of these studies were reviewed, synthesized, and integrated with those of others in Christophorou's book **Atomic and Molecular Radiation Physics** and formed a sound basis for understanding the behavior of electrons and ions in gases that are electrically stressed.* In 1974 Christophorou proposed to the Laboratory Seed-Money Committee a program that would methodically use this basic knowledge to develop gaseous dielectric materials for the needs of the electrical industry. How the basic knowledge could be used for this purpose was first outlined by Christophorou in an invited paper at the 13thIntemational Conference on Ionization Phenomena in Gases, held in Berlin in 1977."

The ORNL Program on Gaseous Dielectrics that was triggered in 1974 with seed money was funded the following year by DOE's Electric Energy Systems. Randy James, Robert ***Pai,*** Richard ***Mathis,*** Isidor Sauers, and others soon joined the program in what quickly developed into a substantial activity that continued for over a decade. The gaseous dielectrics program in HASRD and a project on load management in the Energy Division (put in place by Hugh Long in 1976) led to the establishment in 1983 of the Laboratory's Power Systems Technology Program. Gaseous dielectrics research since the mid- 1980s has been and is still conducted in HASRD and elsewhere across the Laboratory, principally in connection with this program.

The Division's Gaseous Dielectrics Program contributed fundamentally and broadly to the development of the field of gaseous dielectrics and its uses; its impact has been worldwide. The systematic utilization of basic physical knowledge to understand, improve, and tailor gaseous dielectrics led to the formulation of basic criteria for optimizing gas-dielectric properties. Another basic contribution was the establishment of the concept of the multicomponent gaseous dielectric whereby one gas (or gases) slows down electrons and another gas (or gases) removes them by attachment. This concept allowed the "design" of **task-**specific dielectrics from basic knowledge. Thus, while sulfur hexafluoride (SF,) was, and still is, to date, the most widely used (and studied) insulating gas, fundamental research on this and other gases has provided knowledge on the basis of which it is now possible to choose and to tailor insulating gases to meet the various high-voltage insulating needs. Such gaseous media include mixtures of SF,, N,, and certain fluorinated hydrocarbon gases.

The Division's Gaseous Dielectrics Program was the first to address the issue of the bioenvironmental effects of gaseous dielectrics. Studies were begun **in** 1976 by Christophorou and his colleagues, who looked at the decomposition of gaseous dielectrics, short- and long-lived byproducts formation under application of high voltages or after breakdown, and toxicity of sparked dielectric gases. These studies were carried out by a number of researchers foremost among whom are Isidor Sauers, who joined the program in 1977, and Guy Griffin, who joined the program a little later and was the first to discover that sparked **SF_6** is cytotoxic. Unpopular as these studies were at the time, the electrical industry soon realized their significance and implications; work on the subject is continuing to date worldwide.

Two other research programs were spawned in the early eighties from the Division's Gaseous Dielectrics program: one on liquid dielectrics and. another on gaseous materials for **pulse-**power technologies. In the latter area, electrical energy gradually stored in large coils (inductive storage) or in capacitors could be released very suddenly (within microseconds or nanoseconds) if a switch were available that had sufficient speed and **current-**carrying capability. The successful operation of many advanced technologies (e.g., controlled fusion, laser and high-power microwave sources) relies on the availability of such switches, that is, on the conduction/insulation properties of gaseous media and on the rapid change (switching) of properties from an insulator to a conductor and vice versa. Through the decade of the **1980s,** ***Loucas*** Christophorou, Scott Hunter, Jim Carter, and their collaborators developed gaseous materials suitable for modulating/switching the impedance characteristics of gaseous matter down to nanosecond times through extensive experimental research of the electron transport and electron attachment and ionization properties of gases--especially on the temperature, applied electric field, and laser-irradiation dependence of these properties.

Landmarks established by the Gaseous Dielectrics Program include the series of **International** Symposia on Gaseous Dielectrics. Under the chairmanship of Loucas Christophorou, the Division has organized and hosted six such **international** meetings since 1978 (Fig. 45). The symposia served as the nation's premier forum for an international dialogue on worldwide activities in and uses of gaseous dielectrics. The breadth, cohesiveness, and truly international character of the "Knoxville" symposia (all six symposia were held in Knoxville) are amply documented in Gaseous **Dielectrics,** a six-volume set that describes the proceedings of these **meetings.**[46–51] Tbe latest (sixth) symposium was held in Knoxville, September 23-27, 1990.

Interphase and Liquid-State Studies

The most abundant and most reactive species produced when ionizing radiation interacts with matter is the slow electron, and a long-range program was initiated in the sixties to study comprehensively the interactions of slow electrons with atoms and especially molecules. The chasing of the electron by ***Loucas*** Christophorou has continued for over 20 years, and it is a story of many **research** accomplishments and an example of basic discoveries that led to novel applications. It is also the work of many people: Christophorou, Jim Carter, Scott Hunter, ***Lal*** Pinnaduwage, Dennis **McCorkle,** Homer Faidas, and others, including tens of graduate students, postdoctoral fellows, and guest scientists.

These studies helped unravel the intricate ways by which slow electrons interact with **and** affect matter, and they aided the elucidation of the complex sequences of events that accompany the interaction of ionizing radiation with matter. Of particular significance are the seminal contributions **on the** characterization and quantification of the mechanisms of electron attachment to molecules and the formation of negative ions; the elucidation and quantification of the fragmentation patterns of molecules by electron impact; the many discoveries on the 'negative ion states of polyatomic molecules (their autodetachment, energies, scattering, and structural properties): and the many and varied contributions on the motion, transport, and scattering of low-energy electrons in low- and high-pressure gases.

In the late sixties and early seventies the studies involved interactions of slow electrons with molecules that had little internal energy (vibrational/rotational) and were in their ground electronic state. It was soon discovered, however, that the interactions of slow electrons with molecules depend rather strongly and delicately on the internal energy of the molecule. Studies began in the early eighties on slow electron-"hot"

Fig. *45. Loucas Christophorou* and other members of an International Organizing Committee planning for the Sixth Symposium on Gaseous Dielectrics while attending an international conference at a former Benedictine Monastery on the Isle of San Giorgio Maggiore near Venice, Italy (photo by *Isidor* ***Sauers*** **).**

molecule interactions, which took us a step further in that they demonstrated the **significance** of molecular internal energy on basic electron-molecule interaction processes (e.g., scattering, molecular dissociation, radical/anion **formation,** and anion autodestruction). An account of these fundamental developments-and their contribution to many applied fields-can be found in the books by Christophorou on **Atomic and Molecular Radiation Physic@** and **Electron-Molecule Interactions and Their Applications."**

In 1981 Christophorou and his colleagues began exploring the use of lasers for the study of the interactions of slow electrons with electronically excited molecules; these studies opened up a field of enormous basic and applied research that remains important today. Five years later, in 1986, the first observation of optically enhanced electron attachment to electronically excited molecules was discovered.. A series of novel **techniques** was developed for the study of the interaction of slow electrons with excited electronic states of molecules using pulsed lasers to indirectly produce long-lived electronically excited molecules and to directly produce short-lived ones. Slow electrons colliding with such electronically excited molecules have been found **to** have electron attachment cross sections 10^5 to 10^6 times larger than those for the ground state (unexcited) molecules. More recent studies by Pinnaduwage and Christophorou involving **superexcited** states of molecules indicated even greater enhancements. This optical control of the **electron–molecule** collision cross sections has opened up the possibility of controlling the impedance characteristics of (gaseous) matter at times in the **microsecond-to-**nanosecond range.

The aforementioned studies led to two other significant research programs: interphase physics in the 1970s and liquid-state physics in the 1980s. The basic new knowledge and understanding has not only advanced the field and impacted research programs worldwide, but established physical techniques that have allowed such studies to be conducted over the 'entire density range from extremely low pressures to ultrahigh pressures (quasi-liquids) and to the liquid state itself. The development of these techniques enabled the acquisition of physical knowledge necessary for the understanding of radiobiological effects and **mechanisms.** The latter requires knowledge not only on the basic phenomena and processes involved in the interaction of radiation with matter, but also on the effect of density, nature, **and** state of **matter on** these phenomena and processes. Hence, these studies linked knowledge on the physical properties of isolated molecules and isolated molecule reactions to the properties and reactions of these same molecules when they are embedded in condensed media, and they helped 'interface" the gaseous and **the** condensed phases of matter. This interface was accomplished by studying the changes that occur in these properties and processes (principally those involving charge-separated and quasi-charge-separated states) as **the** density of a medium is increased from a low-pressure gas to a very high pressure gas **("quasi-liquid")** to a liquid. Of particular significance are the seminal contributions on negative ion formation and electron transport in quasi-liquids and on the laser multiphoton ionization of molecules (mechanisms and energetics) in dielectric fluids (high-pressure gases and liquids).

The liquid state is the least understood state of matter. In the early eighties, Christophorou initiated a program aimed at studies of laser, electron, and ion **interactions** in liquids and at the development of physical techniques to microprobe the electrical and structural properties of the liquid state. Two such novel techniques-the laser multiphoton ionization/ conductivity and the "fast drift" techniques-were developed, the former by Faidas, Christophorou, and Konstadinos Siomos, and the latter by Faidas and Christophorou; these techniques allowed quantitative studies of the nature of multiphoton ionization mechanisms in dielectric liquids and of, the energetics of charged-particle production and excess electron transport in dielectric liquids. These studies are continuing (Fig. 46) and **have** been expanded to include other basic physical processes such as **laser-**induced detachment from negative ions and transient photoionization of polar molecules. They are basic to the understanding of radiobiological mechanisms and for kindling new applications based on the liquid state of matter such as ultrafast and ultrasensitive dielectric liquids for advanced radiation detectors and **pulse-**power switches.

Resonance Ionization Spectroscopy

The idea of resonance ionization spectroscopy **(RIS)** was developed by Sam Hurst and Marvin Payne of the Photophysics Group in 1974. At that time, the primary goal was to use RIS to measure the population of excited

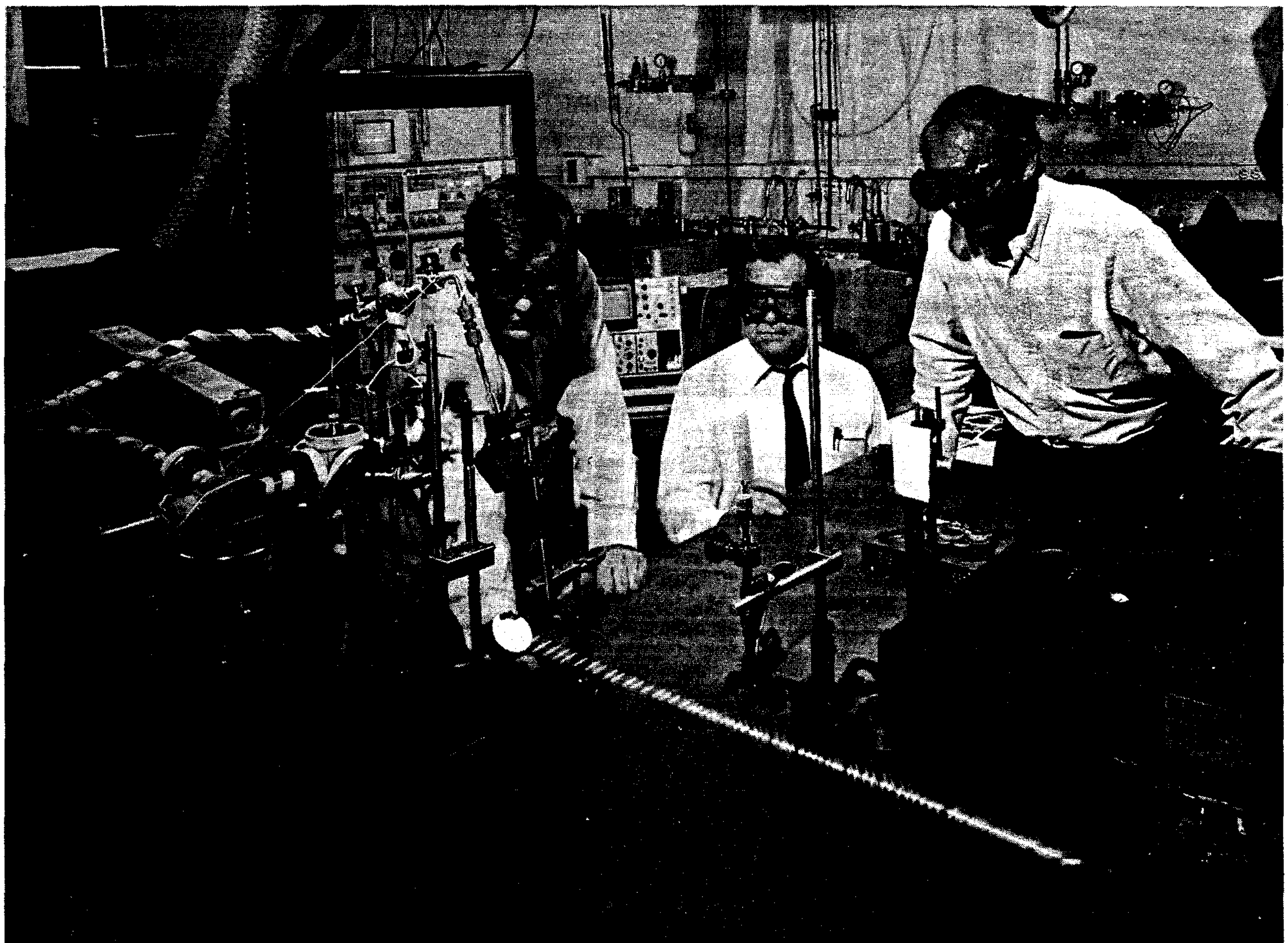


Fig. *46.* **Homer Faidas,** ***Loucas Christophorou,*** **and Dennis McCorkle (left to right) conducting an experiment on the electrical properties of dielectric liquids using pulsed lasers and fast conductivity techniques.**

atoms for gas media excited by fast-charged particles. Since then, many important theoretical developments and experimental applications have been developed in the 1970s and 1980s. The following discussion highlights some of the major contributions of the RIS program during the seventies.

Measurement of rare gas atoms in a medium excited by charged particles. The discovery of the "Jesse effect" has &en considered an important event in radiation research. The "W-value" (average energy deposition for each ion pair produced) of helium was found to be strongly dependent on very minor impurities in helium gas. It was quickly found that the effect of impurities on the W-value is mostly due to metastable helium. However, the absolute quantity of metastable helium compared to ions produced by fast-charged particles excitation could not be measured. The quantitative determination of metastable atoms from fast-charged particles in an excitation medium is a very critical factor in understanding radiation effects on biology. The Photophysics Group, led by Hurst at that time, developed RIS to accurately measure the quantity of metastable rare gas atoms in the medium excited by fast-charged particles. These important experimental results were published in two papers in **Physical Review Letters.**[53,54] The basic idea is to use a tunable laser to excite **He(2^1S)** to **He(3^1P)** with resonance excitation. Another photon was subsequently absorbed by He($3\,^1P$) to produce electron-ion pairs, which were collected by electrically charged parallel plates.

Single alkali atom detection. After the completion of the measurements of **metastable** rare gas atoms, Hurst and his colleagues in the Photophysics Group quickly realized that RIS could not only be a very powerful tool **with** which to study basic principles of physics and chemistry, but could also have very important applications as a supersensitive analytical tool. In 1976 Hurst, ***Munir Nayfeh,*** and Jack Young (Analytical Chemistry Division) demonstrated a single alkali metal atom detection in a medium of **10^{19}** of other molecules in a, proportional counter by RIS, the ultimate detection limit any analytical chemists ever dreamed of. This work was published **in Applied Physics Letters**[55] and the **Physical Review.**[56] Regular international symposia on RIS were held by DOE starting in 1978.

Applications in fundamental physics and statistical mechanics. With the capability of detecting single atoms, researchers in the Photophysics Group started to use RIS to prove the ergodic hypothesis. Also, RIS was immediately used to study the basic physics of laser interactions with matter, including pressure broadening, power broadening, multiphoton excitation, and mechanisms of production and ionization of highly excited atoms including Rydberg states. In 1979 Hurst and his colleagues in the Photophysics Group were invited to write a comprehensive review article for **Reviews of Modern Physics." In their** article, all aspects of theoretical and experimental approaches to RIS were discussed. Two important new ideas were also presented: (1) the use of a mass spectrometer as a detector and (2) the development of a method for detecting every desired atom with isotopic selectivity in the sample instead of just atoms that happened to be in an RIS laser beam.

Laser Studies

Research using lasers in HASRD began almost concurrently with the development of the pulsed-dye laser in the early 1970s. Previous to that time, conventional light sources had been employed by researchers like ***Ed Arakawa*** in order to study such phenomena as the optical properties of materials. The pulsed-dye laser in **particular** 'allowed for the study of nonlinear optical phenomena, those processes that involve the participation of many photons. Important applications of this research include RIS, multiphoton ionization spectrometry, and other nonlinear **spectroscopies** such as third-harmonic generation. Research in this area has been particularly fruitful and **continues** today. Notable accomplishments include the development of multiphoton ionization photoelectron spectroscopy by Bob Compton and John Miller. In the course of these studies, Miller and Compton also recognized a major new phenomenon in **nonlinear optics,** namely the possibility that interference effects exist in laser-excited media where secondary coherent beams are generated. These initial studies have been further elaborated upon both experimentally and theoretically at ORNL by Marvin Payne and Ray Garrett and others throughout the world.

For the past 10 years Howard ***Carman,*** Eph ***Klots,*** and Bob Compton have been using multiple laser beams to selectively excite atoms and molecules in order to study **state-to-**state chemical reactions. In one study these authors have discovered an enormous isotope effect on the reactions of excited alkali atoms with carbon disulphide leading to **CS^-_2** ions.

In more recent years Ed ***Arakawa,*** Winston ***Chen,*** and Bob Compton have individually begun studies of laser ablation. This research includes fundamental observations such as the role of **plasmon** resonances in laser ablation by Arakawa and Compton and more applied studies such as the examination of superconducting thin films by Winston Chen and of fish scales by Sam McKenzie and Ida Lee. Laser ablation is expected to be the **method** of choice for introducing large molecules (e.g., RNA and DNA) in the gas phase and will play an important role in the human genome studies.

Nuclear Medicine Program

The HASRD Nuclear Medicine Program **(NMP)** developed from programs started at Oak Ridge in the 1940s. In January 1946, Paul C. Aebersold moved from Los **Alamos** to assume the important responsibility of directing the isotopes program in Oak Ridge. The production of radioisotopes at ORNL and their distribution for a variety of industrial, agricultural, **and** medical applications rapidly became an important function at ORNL following the end of the war. The first radioisotope catalog was entitled "Availability of Radioactive Isotopes" and was published in the June 14, 1946, issue of **Science.**[58] The introduction to this catalog set the stage for the use of radioisotopes in medicine and stated that "production of tracer and therapeutic radioisotopes has been heralded as one of the great peacetime contributions of the uranium chain-reacting pile. This use of the pile will unquestionably be rich in scientific, medical, and technological applications." The X-10 pile soon became known as a "nuclear reactor" or more specifically as the "Graphite Reactor," and the important role that ORNL continues to play in medical radioisotope research had begun. Oak Ridge soon became the early mecca for nuclear medicine research, training, and meetings. The early workers in nuclear medicine still tell stories of rocking on the front porch of the Alexander Hotel during the 1950s and 1960s, when the first nuclear medicine meetings were held in Oak Ridge.

The Graphite Reactor was completed in 1943 as a prototype, and the first isolated plutonium was produced in this facility. It was recognized very early that reactor-produced radioisotopes would be very important in medical research and clinical applications, and the Graphite Reactor soon became the workhorse for the production of radioisotopes for use in nuclear medicine. In 1946 these early efforts at ORNL resulted in the shipment of ^{14}C, the first reactor-produced radioisotope, to the Barnard Free Skin and Cancer Hospital in St. Louis, Missouri. In the first year of the ORNL program, over 1100 shipments were made comprising about 60 different reactor-produced radioisotopes (primarily ^{131}I and ^{32}P). In this first year, over 90 shipments of ^{14}C were made with a total activity of only about 130 millicuries, a quantity quite low by the standards of today, but at that time a quantity millions of times greater than that available prior to 1946. The Graphite Reactor was permanently shut down in 1963 and was designated a National Historic Landmark in 1966. Al Callahan, a senior investigator of the NMP staff, was one of the last reactor operators during the final days of the Graphite Reactor prior to its shutdown (Fig. 47).

Fig. 47. Photograph of the Nuclear Medicine Program Group after it was incorporated into the new Health and Safety Research Division in 1977. Shown from left to right are Al Callahan, *Dave Woo, Tom Butler, Leigh Ann French, Clarence Guyer, Kathleen Ambrose, Robert Grigsby, Russ Knapp, Jim Hoeschele,* and *Ken Poggenburg.*

Following the shutdown of the Graphite Reactor, the ORNL Research Reactor and later the ORNL High Flux Isotope Reactor (HFIR) became important resources for the production of radioisotopes both for research and for distribution from ORNL. The HFIR is still an important resource for the preparation of radioisotopes for radionuclide generator research and other research projects in the current NMP. The 86-Inch Cyclotron was a complementary facility located at the Y-12 site. It became available in 1948 and provided a resource for the production of neutron-deficient nuclei. This facility, which was permanently shut down in 1980, was used for the development of the technology for production of ^{67}Ga in the late 1960s and early 1970s. Gallium-67 rapidly became the only widely available tumor imaging agent and is still available commercially for this purpose. The NMP staff was involved in a collaborative program with Oak Ridge Associated Universities (ORAU) for the preparation of ‘T-labeled amino acids for tumor imaging by positron emission tomography. The **NMP** staff used the 86-Inch Cyclotron as an important resource for the production of a variety of radioisotopes, and, during the 1972-1980 period, for preparation of the large amounts of ^{11}C required for these studies of patients at ORAU.

In 1946 all radioisotope production activities at ORNL were consolidated and transferred to the Reactor Operating Croup, a development group consisting of A. F. Rupp and E. E. Beauchamp, which quickly developed an organization to provide production, shipping, and developmental activities. Radioisotope research, including medical applications explored by our predecessor organizations, was then conducted in the ORNL Isotopes Division until a reorganization occurred in 1972. When the Isotopes Division was disbanded, the program elements from the Biomedical and Radioisotopes Croup were integrated into the ORNL Operations Division. In addition to many pioneering studies involving reactor and accelerator production of medical radioisotopes, many radioisotopes were distributed through the Isotopes Development Center, which established and maintained collaborative programs with institutions throughout the world. In fact, this center also published a journal at ORNL until the summer of 1972 entitled *Isotopes and Radiation Technology*. The Isotopes Development Center also formed the foundation for the current Medical Cooperative Programs, where collaborative programs with clinics and research institutions in the United States and abroad provide an important opportunity for further preclinical testing and clinical evaluation of new agents developed in the NMP studies.

The current NMP structure was established under Ken Poggenburg in 1975 to expand the extensive expertise in radiochemistry and radioisotope production by the addition of new expertise and capabilities in synthetic organic chemistry, radiopharmaceutical development, and biological evaluation of new agents. The important expansion of this program and the change in direction were made following the recommendations of the Nuclear Medicine Committee, which was formed in 1974 by ORNL Associate Laboratory Director Floyd Culler and which consisted of a group of widely recognized experts in the field of nuclear medicine. The committee was headed by Henry Wagner, M.D., Professor of Radiology and Chief of Nuclear Medicine at Johns Hopkins Medical Institutions, widely recognized as the father of nuclear medicine. The staff was expanded at that time to include biochemistry and synthetic organic chemistry (Russ Knapp) and expertise in the biological sciences (Kathleen Ambrose). In 1977 the NMP Croup was integrated into the newly formed Health and Safety Research Division (Fig. 47). The radioisotope production and processing and radiopharmaceutical development efforts were also complemented in the initial HASRD organizational structure with an instrumentation and computer software effort headed by P. R. Bell, widely recognized internationally as one of the developers of the early rectilinear scanning equipment and

Fig. 48. Photograph of P. R. Bell In 1966 during an experiment at the Oak Ridge National Laboratory Research Reactor.

associated data processing software (Fig. 48). In 1978 Russ Knapp became **NMP** Group Leader.

Since the **NMP** Group joined HASRD in 1977, their studies have focused on the development of new radiophatmaceuticals and radionuclide generator systems for diagnostic and therapeutic applications in cardiology, oncology, and brain physiology. The core funding for these studies has traditionally been provided through AEC and its successor organizations, and DOE OHER now funds most of the program. However, the Nuclear Medicine Program was the first research program at the ORNL site to obtain peer-reviewed research funds from **the** National Institutes of Health in 1979. A variety of guest researchers from throughout the world have worked with the NMP staff, including scientists, physicians, and students from Belgium, France, Germany, India, and Switzerland.

THE EIGHTIES

Health Risk Analysis

Health risk analysis had always been an integral part of HASRD work, but several early contributions, such as the development of codes for internal dosimetry under the diction of Keith *Eckerman* (see **THE FIFTIES)** and the HEED Studies under the direction of Phil Walsh (see **THE SEVENTIES),** established the basis for a more focused program in risk analysis and led to the creation in 1984 of the Office of Risk Analysis **(ORA).** Under the direction of Curtis Travis, ORA provided risk-related work for others and developed a sound funding base from various government agencies, including the Office of Science and Technology Policy, the National Science Foundation, the U.S. Environmental Protection Agency (EPA), and the Agency for Toxic Substances and Disease Registry. Major projects included evaluating the use of pharmacokinetic models to extrapolate between species to estimate human cancer risk, developing pharmacokinetic models in mice, rats, and humans for tetrachloroethylene, methylene chloride, methyl chloroform, and benzene; evaluating pharmacodynamic models to relate fundamental cellular processes to the epidemiology of cancer in animal and human populations; evaluating rapid methods for prioritizing chemicals with respect to their potential threat to human health; and performing health assessments at EPA's Superfund sites and U.S. Department of Defense (DOD) facilities throughout the United States. A laboratory research program to support field work in health assessments was also established.

At the close of the eighties, the focus of ORA's research was redirected to develop improved health risk analyses for cost-effective remediation of hazardous waste sites. Hazardous wastes associated with DOE facilities and other hazardous waste sources and the resources required to remediate past waste problems provide strong incentives for performing high-quality health risk assessments to ensure that the desired and appropriate risk reductions are achieved at minimum costs. In 1991 ORA became HASRD's Risk Analysis Section with Curtis Travis as its section head. Capping this accomplishment was the announcement later in 1991 of the establishment of a Center for Risk Management. The major mission of this interdisciplinary Center of Excellence is to focus the resources of ORNL even more strongly on evaluating risks to human health and on prioritizing and solving environmental problems related to energy production and consumption. Curtis Travis serves as its first director.

Site Characterization

The Health Physics Division (now HASRD) first became involved in environmental pollutant assessment and site characterization in 1972 with the Grand Junction (Colorado) Remedial Action Project uranium mill tailings work (see **THE SEVENTIES).** More extensive ORNL participation in environmental pollutant assessment work began in 1975 when the U.S. Energy Research and Development Administration [now the U.S. Department of Energy (DOE)] requested that Don Jacobs, Howard Dickson, and Woody Cottrell visit the Middlesex Sampling Plant in Middlesex, New Jersey, which was being used for sampling, weighing, and storing uranium and thorium ores. This visit led to ORNL's involvement in the Formerly Utilized Sites Remedial Action Program (FUSRAP), which has provided a firm basis for radiological pollutant characterization work by HASRD. FUSRAP was developed to identify, characterize, and remediate (if appropriate) sites where radioactive materials were used while under contract with the U.S. Atomic Energy Commission (AEC) or its predecessor, the Manhattan Engineer District (MED). Over 250 sites required some level of scrutiny to ensure that no residual radioactive materials from AEC or MED operations were present. Since 1977 ORNL has served in four primary roies for this project: (1) performing preliminary studies to determine if there is any indication of the presence of radioactive materials, (2) conducting comprehensive site assessments to fully characterize the magnitude and extent of radioactive pollutants, (3) verifying the adequacy of remedial action activities performed by private contractors, and (4) serving as an independent technical consultant for DOE on FUSRAP and health physics items. To support this work, two large recreational vehicles were procured and equipped by ORNL to serve as mobile field offices and laboratories.

When HASRD was formed in April of 1977, environmental assessment work (including FUSRAP) was consolidated in the Offsite Pollutant Measurements Group under

Fred *Haywood.* In the early eighties, under *Barry Berven,* most efforts of this group were aimed at conducting preliminary surveys and comprehensive site characterizations of radiological pollutants at many locations around the country. In 1988 HASRD environmental assessments programs were divided between the Grand Junction Office in Colorado (Fig. 41) and the Measurement Applications and Development (MAD) Group at ORNL (Fig. 49). The MAD Group, under the current leadership of Dick *Swaja,* is responsible for FUSRAP support, which mostly involves site characterizations, verification surveys, and technical consultation for DOE. Since 1988 this group has grown and diversified to include assessments of all types of chemical and radiological pollutants in support of environmental restoration efforts at Energy Systems locations (Fig. 50). In addition, computerized systems have been developed to improve efficiency and accuracy of data management and sample analysis, training programs have been developed and implemented for local and off-site personnel, and a new state-of-the-art mobile field laboratory has been procured and equipped for chemical and radiological field operations (Fig. 5 1). The primary mission of the HASRD environmental pollutant assessment activities continues to be the development of methods and equipment aimed at providing accurate, efficient, and cost-effective site characterizations.

Environmental Radiological Assessments

The earlier work on environmental radiological assessments described under Environmental Radiation

Fig. 49. Photograph of the Measurement Applications and Development Group in 1999. Shown **are** (kneeling from *left* to right) *Phil Purdue, Barry **Berven, Bill** Shinpaugh;* (standing from left to right) ***Betty** Ellis, A. C. Butler, Gwen **Yalcintas,** Sue Huckaba, Debbie Roberts, John Roberts, Ogene Jennings, Woody **Cottrell,*** Amhet Taner. *Rick Doane.*

Fig. 59. Staff members of the Measurement Applications and Development Group making high- pressure ionization measurements of radiation levels near the waste collection basin to the High Flux Isotope Reactor and Transuranium Processing Facility at Oak Ridge National Laboratory. Shown from left to right are *Peggy Tiner, Richard **Mathis,*** and *Debbie Roberts.*

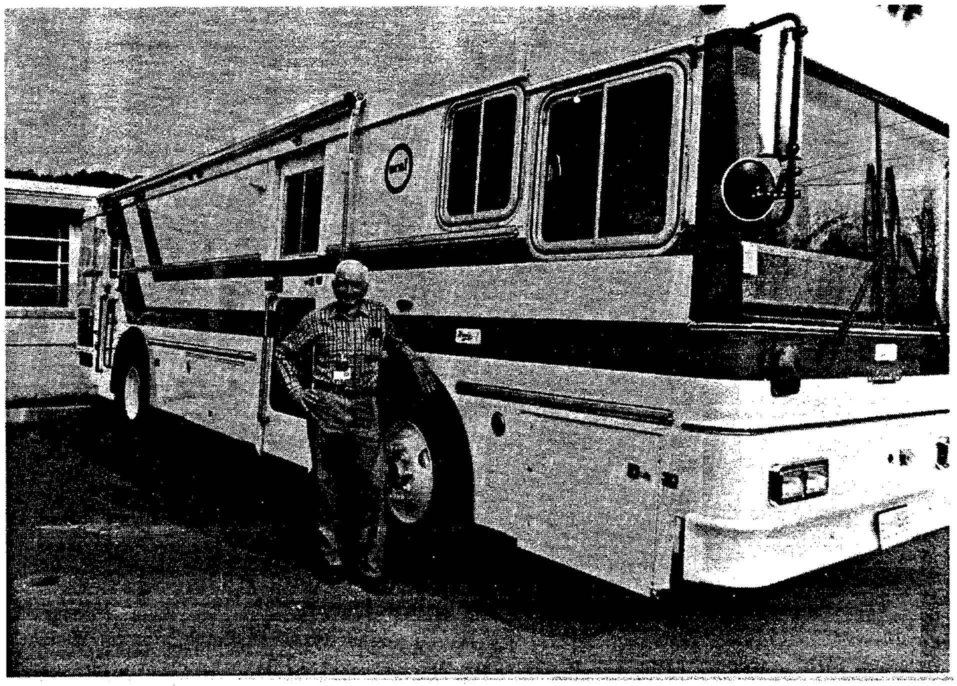


Fig. 51. Recent photograph of Woody *Cottrell* and new state-of-the-art mobile laboratory for chemical and radiological field operations of the Measurement Applications and Development Group.

Studies (see THE SIXTIES) and Environmental Impacts Report Project **(see THE SEVENTIES) was** expanded during the eighties. The basic focus of the work in HASRD was the development, evaluation, and implementation of models, methods, and data bases for the purpose of estimating radiological impacts on humans from exposure to radioactive materials released to the environment.

The work on environmental radiological assessments during this period was carried out by many individuals, including Fred Baes, Rowena Chester, ***Sherri*** Cotter, Mark ***Cristy,*** Don Dunning, Keith Eckerman, Elizabeth ***Etnier,*** David Fields, Gorman Hill, Goro Hiromoto, ***Lee*** Hively, Owen ***Hoffman,*** Greg Holton, George Killough, David Kocher, Rich ***Leggett,*** Craig Little, Laura ***McDowell-Boyer,*** Bob Meyer, Charles Miller, Bob Moore, Sue ***Niemczyk,*** John Nyquist, Frank O'Donnell, Jim Pleasant, Mac Randolph, Paul Rohwer, Betty ***Rupp,*** Mike Ryan, Gunter **Schwarz,** Lynn ***Shaeffer,*** Ron Sharp, Roberta ***Shor,*** Andrea Sjoreen, John Till, Curtis Travis, Phil Walsh, Richard Ward, Annetta Watson, John Witherspoon, and Guven Yalcintas. The great strength of this group was its ability to bring multidisciplinary approaches to bear on a wide variety of assessment problems.

The significant developments in environmental radiological assessments (key investigators are identified in parentheses) fell into three areas: (1) the development of new models and data bases, (2) the evaluation of models, and (3) the development of assessment applications for operating facilities and accidental releases. The **first** area included integrated assessment models and data bases packaged in forms readily accessible to outside users (Charles Miller and Bob Moore); models for estimating dose from use of contaminated consumer products (Frank ***O'Donnell*)**; models for disposal of low-level radioactive waste (David Fields); dynamic global transport models for **tritium,** ^{14}C, and ^{129}I (George Killough and David Kocher); and dynamic terrestrial food-chain transport models (George Kilfough). The second area included critical evaluations of model structure, **parameterization,** and application to regulatory and **decision-**making purposes (Owen ***Hoffman*** and David Kocher); model validation studies (Owen ***Hoffman*** and Charles Miller); and development and application of methods for evaluating model uncertainty and parameter sensitivity (Fred Baes, Owen ***Hoffman,*** and Lynn Shaeffer). The third area emphasized site-specific and realistic assessments (Charles Miller, Frank O'Donnell, and John Witherspoon) and development of screening models for purposes of demonstrating regulatory compliance (Owen ***Hoffman*** and Charles Miller).

The work in HASRD on environmental radiological assessments was widely recognized and used both nationally and internationally. Compilations of radioactive decay data (David Kocher), external dose-rate conversion factors and internal dose conversion factors for radionuclides (Keith Eckerman, George Killough, and David Kocher), agricultural and terrestrial food-chain data bases (Fred Baes), and human usage factors (Betty Rupp) have been widely used throughout the world. Assessment codes developed for the EPA have been used to support current and proposed standards for airborne emissions of radionuclides (Charles Miller and Bob Moore) and disposal of low-level radioactive waste (David Fields). The expertise of the HASRD staff in a wide variety of assessment activities is reflected in the significant contributions by such individuals as Keith Eckennan, Owen ***Hoffman,*** George Killough, David Kocher, Bob Meyer, Charles Miller, and John Till to several textbooks, review documents, and standard reference reports prepared for the U.S. Nuclear Regulatory Commission, DOE, the National

Council on Radiation Protection and Measurements, and the International Atomic Energy Agency. Several members of the Division, including Keith ***Eckerman,*** David ***Kocher,*** Charles Miller, and Frank 0 'Donnell, also made significant contributions to specific exposure situations, including the Three Mile Island and Chernobyl accidents, historical releases from the Femald Uranium Processing Facility, the Kerr-McGee uranium hexafluoride accident, liquid releases from the **Rancho Seco** Nuclear Power Plant, and routine releases from all DOE Oak Ridge Operations facilities.

Chemical Stockpile Disposal Program and Chemical Stockpile Emergency Preparedness Program

In 1985 Congress directed DOD to destroy the U.S. **stockpile** of lethal unitary weapons in such a manner as to provide (1) maximum protection of the environment, the general public, and the operations personnel involved in the destruction; (2) adequate and safe facilities designed solely for the destruction of the stockpile; and (3) cleanup, dismantlement, and disposal of the facilities on completion of the disposal program **(PL 99-** 145, DOD Authorization Act of 1986). This Act required that disposal of the entire unitary stockpile be completed by September 1994. (Unitary munitions contain a lethal chemical agent at the time the munition is loaded; binary munitions contain agent precursors that mix and react to form a lethal agent after the weapon is fired.) Later amendments to the Act have altered the completion date to **early** 1999 (as of September 1991).

Since December of 1985, HASRD staff members have collaborated with their colleagues in Energy Division and in the Environmental Sciences Division **(ESD)** to provide technical research and development to the U.S. Army in developing and implementing what became known as the Chemical Stockpile Disposal Program. Energy Division serves as the lead division for this activity. The disposal program is a major federal effort involving effects analysis for eight stockpile sites in the continental United States (Aberdeen Proving Ground, Maryland; Anniston Army Depot, Anniston, Alabama; Lexington-Blue Grass Army Depot, Richmond, Kentucky; Newport Army Ammunition Depot, Newport, Indiana; Pine Bluff Arsenal, Pine **Bluff,** Arkansas; Pueblo Depot Activity, Pueblo, Colorado; Umatilla Depot Activity, Umatilla, Oregon; and Tooele Army Ammunition Depot, Tooele, Utah). The unitary stockpile includes numerous munitions containing either organophosphate nerve agents or the vesicant agents, sulfur mustard and **Lewisite.** The initial task, therefore, was the preparation of an environmental impact statement (EIS).

Staff members of HASRD (Kathleen Ambrose, Guy ***Griffin,*** Nancy Munro, and Annetta Watson) and Analytical Chemistry Division **(Larry** Waters) were given the task of preparing an assessment of agent toxicity that could be used as a resource and decision document by the Army and cooperating agencies such as the U.S. Department of Health and Human Services, EPA, and state and local **regulatory** and planning agencies. This task grew to include presenting the analyses at numerous public hearings in 1986, addressing public health concerns raised during the hearings (such as an evaluation of antidote treatment protocols and their toxicity), and interacting with other EIS team members to ensure that an understanding of agent toxicology and physical characteristics was incorporated into pertinent aspects of the entire EIS. Following completion of public hearings on the draft EIS in the summer of 1986, all efforts were focused on completion of an expanded version of the EIS by the end of 1987. A three-volume Statement, which included an extensive analysis of agent toxicology, antidotes, breakdown products, and reentry issues, was published by the Army in January 1988. During this period of **EIS** analysis, the "Tox Team" was initially led by ***Griffin,*** who passed task leader responsibility to Watson in 1986.

A number of data gaps became apparent during preparation of the programmatic EIS. Information was needed to help determine the human carcinogenic potential of the persistent agent, sulfur mustard (i.e., mustard gas). Preparation of the EIS generated new insight into the potential long-term health effects of sulfur **mustard;** the result was a semiquantitative assessment of sulfur mustard carcinogenic potency. This assessment made use of the rapid screening of hazard (RASH) relative potency technique developed by Troyce Jones and colleagues; the analysis was later published in **Regulatory Toxicology and Pharmacology.**[59] **There was also** a notable absence of decision criteria for reentry/restoration of potentially contaminated areas outside U.S. Army installation boundaries. The Army concurred with this appraisal and began supporting follow-up research at ORNL in 1990 as part of the Chemical Stockpile Emergency Preparedness

Program (CSEPP). Funding is being supplied by the Office of the Assistant Secretary of the Army (Installations, Logistics, and Environment) through the office of the Program Manager for Chemical Demilitarization. Watson is now task leader of the Reentry Technical Support Analysis of CSEPP, which includes four research projects distributed among HASRD, Analytical Chemistry Division, and ESD.

Chemical Detection

The development of effective methods and instrumentation for trace detection of chemicals in the environment and the assessment of their potential impacts and human health risks is critical for the achievement of environmentally viable and safe technologies. Problem areas pertaining to identification of specific compounds or classes of compounds (i.e., analysis of complex mixtures, estimation of realistic dose regimes, and determination of biological effects) continue to create new challenges for chemical detection technologies. To address these problem areas, the Advanced Monitoring Development (AMD) Group led by Tuan Vo-Dinh is working to develop novel and unique monitoring technologies to measure chemical pollutants as well as related biological indicators of exposures associated with a variety of energy technologies.

Chemical Detection: The Pursuit of a Moving Target. Over the last decade the research focus in the AMD Group for chemical detection technologies has evolved from monitoring of the polyaromatic hydrocarbons (PAHs) produced by synfuel industries to the detection of a wide array of chemical pollutants. Some current projects, for example, involve research and development of screening techniques for polychlorinated biphenyls (PCBs), detection of chemical permeation through protective clothing materials, and development of advanced sensing technologies for application in arms control. PAHs have been a topic of great interest because they have been shown to be mutagens and/or potent carcinogens. Because combustion of organic materials is involved in countless natural processes or human activities, PAHs are omnipresent and abundant pollutants are present in air, soil, and water.

PAH toxicity in a wide variety of materials has been extensively investigated. More than two centuries ago skin cancer was observed in chimney sweeps and later in workers at tar factories. Frequent contact with soot and tar materials was correlated with the incidence of skin cancer, and the carcinogenic activity of these materials can be correlated with their content of PAHs, which are formed during incomplete combustion or pyrolysis of organic matter containing carbon and hydrogen. The emphasis has subsequently shifted from the basic PAHs to heterocyclic chemicals formed as combustion products because studies reveal that homocyclic PAH compounds cannot account for all the biological activities encountered in many environmental and biological samples. These biological results have spurred us to develop chemical detection techniques that must be able not only to differentiate compounds with different benzenoid ring sizes but also to identify specific substitute and/or derivative chemical groups attached to the basic structures.

Since the mid- 1980s there has been an evolution in research interest from single target compounds in the synfuel days to the more complex mixtures for hazardous waste applications. There is now an urgent need for improved or new chemical detection methods for the characterization of complex mixtures. Whereas the identification and quantification of a specific compound at trace levels continue to be important, the ability to analyze and/or screen complex mixtures has become a major focus of the group's research efforts. The importance of complex mixtures has arisen from the need to identify, monitor, and understand synergistic and/or antagonistic effects of multicomponent systems. Very often researchers have little or no unequivocal evidence that a specific chemical causes cancer in humans, but do have a wealth of evidence that many real-life mixtures do cause human and animal cancer. Therefore, an important mission of chemical detection technologies is to provide efficient tools to analyze complex mixtures.

A significant development in the early 1980s was a badge-type dosimeter for PAHs. This personal monitor, the PNA dosimeter, was developed by Tuan Vo-Dinh to detect airborne polyaromatic vapors and aerosols. The device was the recipient of an R&D-100 Award in 1981. Another successful device developed by the AMD Group was the luminoscope. This device, developed by Vo-Dinh and fabricated in the Instrumentation and Controls (I&C) Division, is a portable monitor that uses fiber-optic techniques to measure chemical contamination on skin and other surfaces. The luminoscope technology was licensed in 1987 to Environmental Systems Corporation as the first technology transfer of an ORNL-developed technology to an East Tennessee Company. Under current sponsorship of EPA, the luminoscope is being further developed for field screening of organic contamination at EPA's Superfund sites.

Current research and development efforts are also being aimed at the detection of many heterocyclic PAHs, which are produced in conjunction with their parent PAH compounds. For example, nitrogen-containing (nitro) PAHs are produced primarily as the result of incomplete combustion processes. Well-known sources of nitro-PAHs include exhaust emission from diesel engines, aluminum smelting effluent, and wood smoke and gasoline engine exhaust. Nitro-PAHs have also been identified in fly ash, soot from woodburning stoves, urban air, tobacco and tobacco smoke, and originally in xerographic toner. Nitro-PAHs have been recognized as one of the most important classes of PAH derivatives because they are highly suspect as etiologic agents in human cancer. Among the nitroarenes, nitropyrenes are of particular interest because they have been identified in microbial assays as primary mutagenic components of diesel emission particulates. In order to selectively detect pollutants with specific chemical groups such as nitro-PAHs, new spectrochemical detection methods were developed. A novel technique developed in the AMD Group and other research groups at ORNL is the surface-enhanced Raman scattering technique. This continuous monitor technology developed by *Vo-Dinh* has been licensed recently to Gamma-Metrics, Inc., a California-based company, through the technology transfer effort of DOE and Energy Systems.

Another new research initiative in the AMD Group is related to global atmospheric concerns such as the ozone depletion problem. In collaboration with research staff from ESD and I&C, AMD research staff members have developed a fiber-optic microprobe capable of measuring profiles of ultraviolet (UV-B) light within plant leaves in order to assess the effect of increased levels of W-B radiation on terrestrial plant life. W-B radiation, which has increased because of ozone depletion, could cause adverse ecological effects for this and future generations. The W-B microprobe system integrates state-of-the-art fiber-optic sensors, submicron piezoelectric micropositioning technology, and sensitive real-time microchannel detection techniques. A prototype instrument developed for measurements in the field is pictured in Fig. 52.

Fig. 52. Field testing of a fiber-optic microprobe instrument by *Tuan Vo-Dinh, Gordon Miller,* and Michelle Dial (left to right). This instrument was developed to assess the effects on terrestrial plant life of increased levels of ultraviolet radiation due to ozone depletion in the atmosphere.

Bioindicators of Exposure: The New Frontier in Chemical Detection. When the biomonitoring research program was first initiated in the mid-1980s, DNA damage was monitored using radiometric techniques. The interactions of chemicals **with** DNA were measured both at a gross level (i.e., total binding of compound) or at the molecular level (i.e., reactions formed with specific DNA products). Radiometric techniques generally suffer from several disadvantages: **(1)** radioisotopes have limited shelf life (e.g., ^{125}**I** has a half-life of only 60 days); (2) instruments for detection and reagents are relatively expensive; (3) special precautions are required for the shipping, handling, and waste disposal of radioactive materials; and (4) there is concern over the confounding deleterious biological effects that are due to the radioactive labels. These limitations motivated researchers to develop novel nonradioactive methods for detecting bioindicators of exposure using both environmental and human samples.

The initial approach was to develop widely used fluorometric methods for DNA **adducts** of **PAHs** because the polyaromatic structures are generally strongly fluorescent. An important development was the synchronous luminescence (SL) technique developed in the AMD Group. Conventional luminescence spectrometry uses either a fixed excitation or fixed emission wavelength. **With** SL, both excitation and emission wavelength are scanned synchronously, producing a spectrum with a more resolved structure and more readily identified peaks. Because of its simplicity, the SL technique has been successfully used in the United States and Europe to detect low levels of carcinogen-DNA **adducts** and **metabolites** of chemicals in human populations exposed to hazardous substances. Curtis Harris and coworkers at the National Cancer Institute have successfully applied **the** SL technique developed at ORNL to monitor DNA **adducts** of **BaP** in coke oven workers. The SL procedure is now incorporated as a standard feature in most modem commercial luminescence spectrometers.

The routine detection of DNA damage as fluorescent DNA **adducts** is limited by fluorescence quenching such that the PAH-DNA **adduct** must be cleaved before measurement. ***Mayo Uziel***, a long-time nucleic acid biochemist at ORNL, has investigated approaches that detect DNA **adducts** without prior cleavage. A laser-based technique using room-temperature phosphorescence was successfully applied by Vo-Dinh and Uziel to detect DNA **adducts** even when **PAHs** were bound to DNA. Surface-enhanced **Raman** spectrometry also was shown to selectively detect PAH **adducts** at the femtomole level. Another approach to measurement of DNA damage that can quantify the chemical functional groups introduced by **adduct** formation has also been used to investigate what appears to be nonrandom, radiation-induced chain cleavage of DNA. Uziel and Elaine ***Zeighami***, with the help of Nancy Munro, ***Tuan*** Vo-Dinh, and Sue Katz, collaborated with the EPA Health Effects Laboratory to examine the role of DNA **adducts** as a marker for epidemiologic studies. The review was cited as an Issues Document in the EPA Office of Research and Development Research Strategy Document for the Health **Biomarkers** Program (1991).

Fiber-optic antibody-based fluoroimmunosensors **(FISs)** have **also** been developed through collaborative studies between Vo-Dinh at ORNL and M. J. Sepaniak at The University of Tennessee (UT). This project has also involved Guy ***Griffin***, Kathleen Ambrose, and J. P. Alarie, as well as B. J. Tromberg and J. R. Bowyer at UT. In this technique, polyclonal or **monoclonal** antibodies produced against **BaP** are immobilized at the terminus of a fiber-optic probe or contained in a microsensing cavity within the FIS for use in both in vitro and in vivo fluorescence assays. High sensitivity is provided by laser excitation and optical detection. The FIS device utilizes the back-scattering light emitted at the remote sensor probe. A single fiber is used to transmit the excitation radiation into the sample and collect the fluorescence emission from the antigen. The laser radiation reaches the sensor probe and excites the **BaP** bound to the antibodies that are immobilized at the fiber-optic probe. Because of its excellent sensitivity, this technique has considerable potential to perform trace analyses of chemical and biological samples in complex matrices (i.e., it has been used recently to detect DNA **adducts** in human placenta samples). Measurements are simple and rapid (about 12 minutes per sample), and the technique is applicable to other compounds provided appropriate antibodies are used. The FIS instrument was **the** recipient of an R&D- 100 Award in 1987.

Indoor Air Pollution

The energy crises of the seventies resulted in many attempts to make. residences more energy efficient. DOE and other federal agencies promoting residential energy conservation were required by law to assess the environmental impacts of conservation measures. One prominent concern was the reduction of exchange of indoor and outdoor air, with the accompanying increases of indoor concentration of pollutants from indoor sources. Ted Lundy (Metals and Ceramics Division), ***Phil*** Walsh, and

Charles Dudney were members of an interagency group that was formed in 1979 to address this issue. This task force included representatives from EPA, the Consumer Product Safety Commission (CPSC), and the Formaldehyde Institute. The task force reviewed the available literature, found that there were very few data on pollutants in occupied homes, and called for more studies.

CPSC was concerned primarily about formaldehyde in homes because injecting hollow walls with urea–formaldehyde foam insulation (UFFI) had become a popular way of reducing home energy losses. Formaldehyde generation and release is an inherent property of UFFI; emission of formaldehyde can be especially troublesome if it is improperly installed or formulated. The CPSC was receiving large numbers of complaints about acute sensitivity problems from homeowners with UFFI in their houses. Through contacts on the task force, ORNL was asked to evaluate emissions from simulated UFFI wall panels. Results showed that even correctly formulated UFFI led to significant releases of formaldehyde; UFFI types that were commercially available in 1980 generated an average of 0.1 ppm formaldehyde indoors even 2 years after installation. This finding played a key role in the banning of UFFI in Canada and in a temporary ban in the united states.

Alan Hawthorne, Tom Matthews, and Dick Gammage were the early team members, and their studies expanded to include measurements of formaldehyde off-gassing of UF resin from bonded pressed-wood products used in conventional and mobile house construction and furnishing. Measurements were ma& both in test houses and in a large environmental chamber fitted with a variety of formaldehyde-emitting products. From the results, predictive models were formulated to understand performances under realistic indoor conditions. The findings helped industry develop product-testing procedures that are now standard for preventing the hitherto unhealthy indoor formaldehyde levels that were all too common in the seventies and early eighties.

In 198 1 multipollutant indoor air pollution studies were made for CPSC inside 40 houses in the Oak Ridge and Knoxville area. High indoor levels of volatile organic compounds were discovered compared with levels outside, and these results led to larger multi-federal agency studies for DOE, EPA, CPSC, and the Tennessee Valley Authority (TVA). Studies were made in 6, 70, and 300 homes; the latter study, in Kingston-Harriman, was one of those included in the Harvard-directed Six-City Study of air pollution. Emissions from carpets, space heaters, gas cookers, cigarettes, a variety of insulating materials, and personal and home-use products each received attention. Performances of heating, ventilation, and air conditioning systems (HVAC) were evaluated together with problems of pollutant entry and distribution by HVAC systems.

Naturally occurring radon was a concern of several original sponsors, mainly TVA, EPA, and DOE, and radon levels were measured in the initial 40-house study for the sake of completeness. Surprisingly, elevated indoor radon levels were discovered, especially among those houses built on the sides and ridges of limestone hills. More detailed studies of indoor radon commenced in 1984 when TVA requested a study of radon and its decay products in 70 houses distributed in six cities throughout the Tennessee Valley area. Seasonal measurements were made, and the results of these studies were the first to show summertime elevation of indoor levels in a large number of houses. The indoor air programs subsequently evolved in the later 1980s into radon detection and mitigation to reflect the shifting priorities of sponsors. The DOE-sponsored field work involves fundamental studies of radon availability, transport, and entry into houses. This work is carried out in Huntsville, Alabama, and Oak Ridge, Tennessee. An aerostatically driven radon transport mechanism appears to be operative in hilly karst terrains of the southern Appalachians. Air movements inside interconnected limestone solution. cavities can be communicated to some houses and cause elevation of indoor radon levels because of the large underground reservoirs of radon-bearing air that are being tapped. These phenomena are of consequence in DOE's current efforts to identify the 100,000 houses with the highest radon levels in the United States.

EPA has funded radon programs that identified high radon levels in houses and subsequently mitigated them to acceptable levels below 4 picocuries per liter (4 pCi/L). The first studies were conducted in collaboration with Princeton University. Houses with unfinished basements were diagnosed and mitigated in Clinton, New Jersey, an area of the country with some of the highest indoor levels of radon. Analogous studies and successful mitigations were later made using houses in Oak Ridge and Huntsville. Mitigation procedures, principally subslab depressurization, proved to be successful and economically acceptable for lowering indoor radon to less than 4 pCi/L, the EPA guidance level.

These programs have now been expanded worldwide with the inclusion of the Navy's radon assessment and mitigation programs. Screening and assessment measurements are being conducted in up to a total of 260 naval facilities, some of which are located in remote areas with climates ranging from tropical to arctic. This program is managed through the Hazardous Waste Remedial Action Program (HAZWRAP) organization. A base with a high-level reading above 70 pCi/L requires immediate visitation by a "swat team" to make confirmational measurements and effect on-site investigation.

Legislation requires all federal agencies to monitor their facilities for indoor radon. Numerous opportunities exist to help agencies, such as the U.S. Post Office, to meet their obligations. An environmental chamber is now being used full-time to conduct radon calibrations. Other pending legislation deals with more general indoor air quality issues, such as sick-building syndrome and chemical sensitivity. The future will call for increasing attention to indoor air quality with many challenging opportunities for research and development.

Three books on indoor air quality have been edited by members of the Division. In 1984 CRC Press published **Indoor Air Quality,** which was edited by Phil Walsh, Charles Dudney, and Emily Copenhaver.[60] This book contained ten chapters prepared by 20 experts on various topics, including specific pollutants, measurement techniques, and building-related illness. Dick Gammage and Steve Kaye edited **Indoor Air and Human Health, the** proceedings of the Seventh Life Science Symposium, held in Knoxville, Tennessee, in 1985.[61] Dick Gammage also edited **The Practitioner's Approach to Indoor Air Quality**,[62] the proceedings of an international symposium on air quality, held in St. Louis, Missouri, in 1989, in conjunction with the American Industrial Hygiene Annual Conference.

Theoretical Radiation Physics Studies

When the federal government changed its emphasis in the 1980s to include broader aspects of energy production and conservation, the Theoretical Radiation Physics Group was asked to shift its research directions correspondingly, building on a basic understanding of radiation interactions with condensed matter. Study of the physics underlying basic aerosol interactions was begun and included frictional forces on an atom near a surface, ripplon effects (the interaction of atoms with quantized surface waves on liquids), and aspects of physisorption (the adsorption of atoms on surfaces by van der Waals forces).

A new and powerful technique for treating the self energy of atoms or charged particles (the energy of interaction with the polarization they create) located in or near condensed matter was devised and applied to analyze quantal effects in a number of important systems. Work in electron microscopy theory continued, resulting in a general theorem about energy loss spectroscopy using electron microprobes (as in scanning transmission electron microscopy). A new approach to the theory of the stopping power of slow ions was achieved through the use of density-functional results for the phase shift of electrons at the Fermi surface of a metal. A quantal generalization of the Landau distribution of energy losses by swift electrons in matter was devised, and a new approach to the theory of the stopping power of relativistic charged particles was made. The first theoretical evaluation of high-order corrections to the image potential of an electron at a metallic surface was given. The theory of the solvated electron has been addressed through study of dynamical corrections to the binding energy of this entity in the volume of a liquid and that of an electron bound to the surface of a dielectric sphere. A comprehensive review paper on the dynamic screening of ions in condensed matter was published in the prestigious **Solid-State Physics series.**[63]

Extensive collaboration on projects of mutual interest with active and talented people at other institutions has been very beneficial for our research program through the years. These people have included Archie Howie (Cavendish Laboratory), Pedro Echenique (Universidad Pais Vasco, Spain), Fernando Flores (Universidad Autonoma de Madrid), and Jens Lindhard (Aarhus University). Other gifted colleagues include the late Werner Brandt (New York University), Dick Manson (Clemson University), C. C. Sung (University of Alabama), and Alberto Gras-Marti (University of Alicante, Spain).

Experimental Radiation Physics Studies

In 1980 this group showed that the very powerful techniques of resonance ionization spectroscopy (RIS, see THE **SEVENTIES)** could be combined with mass spectroscopy to make an even more versatile instrument. The RIS process is used to perform the chemical separation in order to produce a simple mass spectrum that is uncomplicated with impurities. A simple quadruple mass spectrometer was used by Tom Callcott and Ed Arakawa to obtain a very clear mass spectrum showing the proper $^{40}K/^{41}K$ isotopic ratio. The combination of RIS and mass spectrometry is now being used in many applications for studies when accurate isotopic ratios are required.

A holographic technique to produce free-standing, soft X-ray transmission diffraction gratings for use in the extreme UV and soft X-ray regions of the spectrum was developed in 1980 by Arakawa and Paul Caldwell, an undergraduate student with the Southern College and University Union Program (Fig. 53). A spectrometer employing these unique transmission gratings for use in the extreme UV region of the electromagnetic spectrum was then designed and constructed. The instrument is compact, lightweight, virtually aberration free, and ideally suited for use with multichannel detectors. Instruments similar to this have been incorporated with space telescopes in orbiting laboratories and can also be used to identify impurities in fusion plasmas. This instrument was selected for an R&D-100 Award in 1981.

In 1982 Arakawa, in collaboration with George Begun (Chemistry Division) and visiting French scientist J. P. Goudonnet, showed that microspheres of polystyrene deposited on glass and coated with silver were very efficient, simple, and practical substrates for use in surface-enhanced Raman spectroscopy.* Signal enhancements of approximately 10^6 were obtained, which made possible the use of these microspheres on other backing materials such as filter paper for the development of several practical instruments for field use in the detection of low-level organic contaminants. This has resulted in a significant advance in technology for detection of organic pollutants in the environment and promises to have a major impact on environmental protection from such pollutants (see Chemical Detection in THE EIGHTIES).

In collaboration with Tom Callcott and Dave Ederer of the National Bureau of Standards, a soft X-ray emission spectrometer (SXES) was designed and constructed that has been shown to be about 1000 times more efficient than any similar instrument in existence. This instrument, which incorporated several unique features, won an R&D- 100 Award in 1986. The spectrometer was installed as a national user facility at the National Synchrotron Light Source in Brookhaven as the only one of its kind and has already proven its versatility and worth. It has been convincingly demonstrated that SXES is a very powerful instrument for the study of complex advanced materials such as the high-T_c superconductors, semiconductor superlattices used in optoelectronic applications, refractory alloys, etc. This power derives from the fact that SXES provides electronic density of states and bonding information independently for each element of the material, even when present in small amounts.

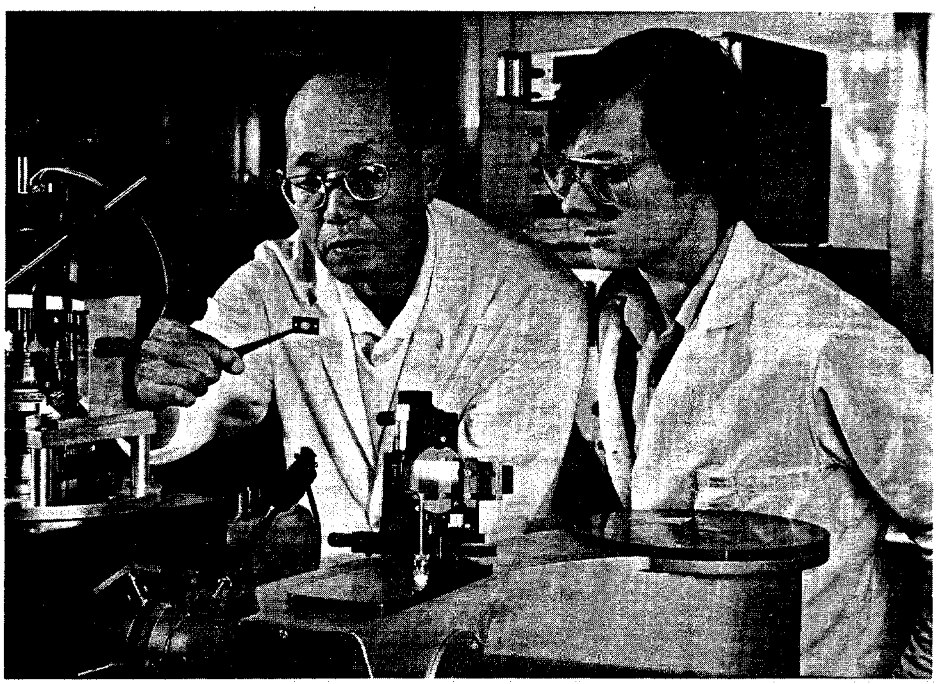


Fig. 53. Photograph of Ed Arakawa and Paul Caldwell examining one of their soft X-ray transmission gratings. These gratings are more easily fabricated and are considerably smaller and lighter than the conventional reflection-type grating as shown in the foreground.

Submicron and Liquid Physics

The Submicron and Liquid Physics Group has retained its fundamental character since its inception in 1975 but took on new perspectives in the eighties.

The concept of sample characterization at subwavelength resolution, either by direct imaging or inference from macroscopic properties, was successfully tested. Surface plasmons localized on small particles and cavities of various shapes were predicted theoretically and observed experimentally. The spectra of these plasmons were found to depend upon the specific dielectric properties, shapes, and sizes. New imaging techniques advanced **direct** views of the scattering structures. These techniques promoted new directions for applications of fundamental studies.

Major personnel changes within the group also occurred. Bob ***Birkhoff*** **took** an early retirement in 198 1. Bruce ***Warmack*** joined the group to help supervise experimental activities in Birkoff ***'s*** absence. Harry Hubbell continued as a part-time consultant. Dave Allison became the principal biological microscopist in the late eighties. Randy James was supported part-time to help with **Raman** spectroscopy. The number of graduate students fostered by the staffs affiliation with UT also grew in numbers. These included Russell Becker, Milan Buncick, Steve Kennerly, Brenna Russell, Sherrie Humphrey ***Sharp***, Mark Bloemer, and Robin **Reddick.** Postdoctoral fellows that worked in the group included John Little, Y. T. Chu, Jim Mantovani, John Todd, and Eric Lesniewska. Many collaborations with outside institutions were established. The meager funding in the early eighties grew more than tenfold during the decade.

Fundamental Studies. Responses were calculated and measured for both electromagnetic and charged-particle interactions on a number of different structures: hyperboloids, cylinders, spheres, spheroids, ellipsoids. Techniques for producing these structures had to be developed; these included optical holography, **electron**-beam lithography, and reactive-ion etching. Strong resonances due to localized surface plasmons were observed, especially for low-damping metals like silver.

Surface-Enhanced Raman Scattering. An important application directed toward trace chemical analysis was seen to depend heavily upon localized surface plasmons. The Laboratory, the Army, and the Bureau of Printing and Engraving helped support both fundamental and applied research in this field. Certain structures such as silver-coated spheres and needles were found to enhance the ordinary **Raman** effect by as much as 10^8.

Scanning Tunneling Microscopy. A very good state-of-the-art electron microscope was acquired in 1983, which improved resolution over the older microscope by an order of magnitude. Structures that had been predicted from optical measurements could now be imaged directly. Still, direct imaging of the smallest produced structures remained indistinct, and height information was difficult to quantify. Seeded by a grant from the Laboratory Directors in 1985, the group moved into the newly developing field of scanning tunneling microscopy (STM). Collaborating with colleagues from AT&T Bell Labs and a former student, Russell Becker, atomic resolution on semiconductor surfaces was achieved within a year. At the time only a few laboratories in the world could claim this distinction. Not only was the STM extremely useful in characterizing samples with features too small to be observed by other microscopes, but it had the potential to operate in high vacuum or under fluids. Biological imaging was of immediate and direct interest to program directors in DOE's Office of Health and Environmental Research (OHER). The group made and operated its own **fluid**-based **STMs** until commercial units began to appear in 1987. Since then collaborations were established with a number of different divisions throughout the Laboratory and with outside institutions as well.

An outgrowth of fundamental studies and the STM program was the invention of the optical analogue of the STM, the photon STM (PSTM). Operating by the tunneling of photons rather than electrons, the PSTM was able to image optical (insulating) surfaces that were impossible for the STM because of charging (Fig. 54). An R&D- 100 Award recognized the development of the PSTM in 1989. Both instruments operate with subwavelength resolutions and helped realize a fundamental goal of the group. Though the use of these novel microscopes has focused on imaging applications, they are used for fundamental research as well, of which they are simply an outgrowth.

Nuclear Medicine Program

The Nuclear Medicine Program (NMP) was the first to develop and demonstrate the concept of metabolic trapping of radiolabeled fatty acids for cardiac imaging. This NMP work, which began in 1977, represented the foundation on which similar research has been conducted at many institutions worldwide, and the NMP Croup continues to receive international recognition for its leadership role in this area. The NMP studies with the cardiac imaging agents evolved through the eighties and have now culminated in the clinical application of the ^{123}**I**-labeled "BMIPP" agent at several institutions in the United States, Europe, and Japan using single photon computed tomography. Commercial development of this BMIPP agent is now under way in Japan by Nihon

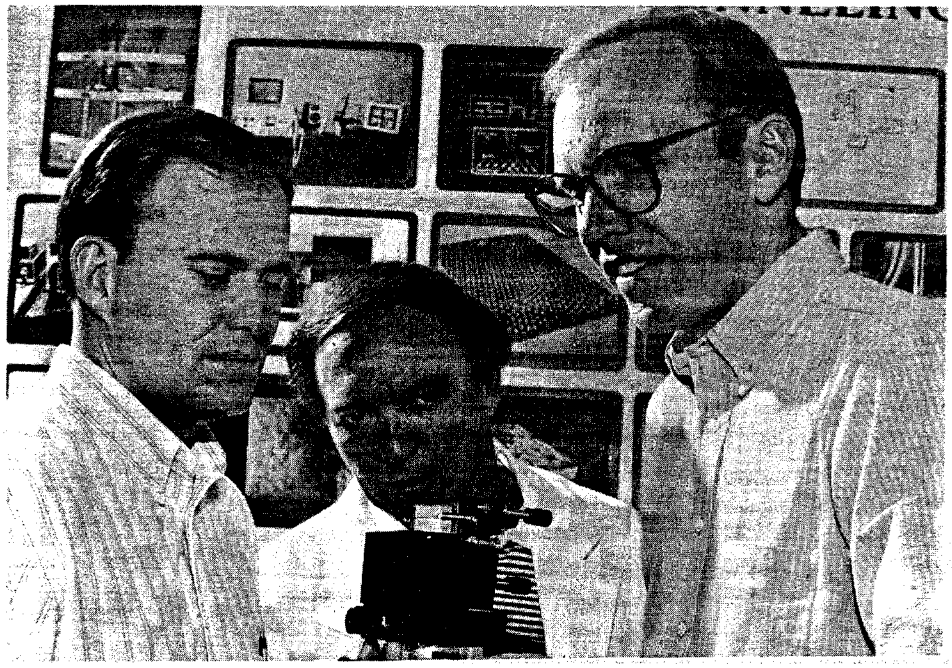


Fig. 54. Photograph of an experimental version of the photon scanning tunneling microscope held by its inventors, Robin Reddick, Tom *Ferrell,* and *Bruce Warmack*

Medi-Physics, Inc., a major radiopharmaceutical **manufacturer.** Mark Goodman joined the NMP Group in 1980 and Prem Srivastava in 198 1 (Fig. 55).

In the area of new agents for the evaluation of cardiac disease, the NMP Group began early in 1985 to develop a new ^{191}**Os/**^{191m}**Ir** generator system to provide the **4.96-second, ultrashort-**lived ^{191m}**Ir** daughter radioisotope for the **first-pass** evaluation by radionuclide angiocardiography (RNA) of the geometry and volume differences of the cardiac ventricles during contraction. By late 1985 the NMP Group had coordinated the first patient studies with collaborators in Belgium, who demonstrated the clinical usefulness of ^{191m}**Ir** for RNA. This system has now been used in over 600 patient studies **in** Europe, a patent has been granted, and a license has been developed with Scintillation Technologies, Inc., in Maryville, Tennessee.

Beginning in 1985, the NMP Group developed an improved protein radiolabeling agent named p-iodophenyhnaleimide for the stable attachment of radioiodine to antibodies for potential human applications in radioimmunodiagnosis with ^{123}**I** or radioimmunotherapy with ^{131}**I.** It was demonstrated in NMP studies with laboratory animals that administration of antibodies radiolabeled in this manner resulted in only very low loss of radioiodine. This technology has thus overcome a'major problem previously encountered involving loss of radioiodine from antibodies radioiodinated by traditional methods. This technology became the first commercial license for the NMP with E. I. DuPont and Co. in 1988. The developers of maleimide radiolabeling technology (Prem Srivastava, assisted by John ***Allred***) won an R&D- 100 Award in 1990.

In the area of radionuclide generator research, the NMP Group began in 1987 to develop a new ^{188}**W/**^{188}**Re** generator system, which provides the **16.9-hour** half-life ^{188}**Re** daughter for attachment to therapeutic agents, primarily for potential tumor therapy and other therapeutic applications. In 1991 the NMP Group prepared large-scale clinical prototype generators for the **first** time. In addition to the long shelf life and consistent performance of this generator, ^{188}**Re** has chemical and radionuclidic properties that make it far superior to many other radioisotopes currently being explored for therapeutic applications. During 1991 the NMP Group also developed an improved synthesis of ^{188}**Re-labeled** dimercaptosuccinic acid **(DMSA),** an agent that shows promise for the treatment of nonresectable thyroid **medullary** carcinoma, and the group expects initial patient studies with the DMSA agent to begin in collaboration with the Nuclear Medicine Department at Guy's Hospital in London. The **NMP** Group is also collaborating on further work with this generator with several other key research groups internationally and expects initial patient studies to begin soon with ^{188}**Re-labeled** tumor therapy agents. Other current generator research focuses on optimizing the reactor preparation and chemical processing of the parent **radionuclides.** In addition, the ^{194}**Os/**^{194}**Ir** generator system to

Fig. 55. Photograph of the Nuclear Medicine Program Group in 1982. Standing from *left* to right): *Prem Srivastava, Mark Goodman, James Hoeschele, Clarence Guyer, John Roberts, Tom Butler, Al Callahan, Russ Knapp,* seated from left to right: *Kathleen Ambrose, Evelyn Cunningham, Linda **Ailey.***

provide the ^{194}Ir daughter for potential therapeutic applications has been developed for the first time.

At present, the NMP staff is also actively engaged in the molecular design, synthesis, and animal testing of potential new radiopharmaceuticals for a broad range of potential clinical applications. **Dan McPherson** is an organic chemist and joined the NMP Group in 1988, and in 1989 **Saed Mirgaceh** joined the NMP Group to provide additional radiochemistry expertise. The radiolabeled nucleoside project, represents the most recently funded project by OHER. This research involves the synthesis of various radiolabeled nucleosides as metabolic markers of tumor nucleic acids. Since nucleosides are building blocks of RNA and DNA, these molecular nuclear medicine tools could potentially be targeted to tumor nucleic acids or tumor genes for diagnosis and therapy of cancer.

A new area of research initiated in 1991, which has already culminated in initial tests in humans, involves the development of a new radiopharmaceutical for the evaluation of pancreatic insufficiency. The results of testing in normal patients and volunteers with this new agent indicate that it may be a useful tool for the evaluation of the inability to digest fatty acids by way of a simple urine analysis. Low levels of the ^{131}I-labeled test agent are taken orally, and urine is collected at 24-hour intervals. In initial tests in 12 patients and volunteers at the Clinic for Nuclear Medicine in Bonn, Germany, greater than half of the administered activity was excreted in the urine in 24 hours, demonstrating the expected metabolism of the agent in individuals with normal functioning pancreas excreting the pancreatic lipase enzyme. If future evaluation in patients with pancreatic insufficiency resulting from pancreatitis, pancreatic carcinoma, or other gastrointestinal disorders that compromise the excretion of pancreatic digestive enzymes show only low levels of urinary radioactivity, then this may represent a new, simple test that could be used widely.

Finally, as noted earlier, the Medical Cooperative Programs represent an important activity that complements the NMP research and not only serves as an important link with other researchers, but also represents an important opportunity to evaluate the clinical feasibility of new agents designed and developed in the ORNL NMP. These programs represent the link between basic research by the NMP Group at ORNL and clinical evaluation.

Radiation Calibration Laboratory

The Dosimetry Applications Research (DOSAR) Group built the Radiation Calibration Laboratory (RADCAL) in the late 1980s with General Plant Project funds to supplement dosimetry research capabilities of the Health Physics Research Reactor (HPRR). After the shutdown of HPRR in 1987, RADCAL became the primary research tool of the DOSAR Group. The dedication of the facility took place on June 21, 1989 (Fig. 56). Some activities that had traditionally been accomplished using HPRR as the radiation source were continued at RADCAL; examples include Personnel Dosimetry

Intercomparison Studies (PDIS), neutron dosimeter development, and low-level radiobiology experiments. New areas of DOSAR Group activity opened up with the acquisition of RADCAL; examples include detailed characterization of dosimeter response to a variety of radiation sources and energies as well as routine calibration of dosimeters and operational instruments for applied health physics use. Highlights of three areas of DOSAR Group activity that utilize RADCAL are presented in the following text.

Fig. 56. Photograph made during the dedication of the Radiation Calibration (RADCAL) facility at the Oak Ridge National Laboratory. Shown in the foreground from left to right are ***Steve*** *Kaye,* Elmer Eisenhower (National Instiiute for Standards and Technology), and *Steve Sims.*

PDIS. The PDIS were started in 1974 using HPRR as the radiation source. Participants mailed dosimeters to DOSAR where they were exposed to various mixed fields of neutron-gamma radiation and returned to the participant for evaluation. The results provided a snapshot of the abilities of dosimeter processors to perform accurate dosimetry under controlled conditions. The results also suggested needed improvements and research dictions. The first 12 of these **annual** studies were conducted using HPRR. The average number of participant organizations in one of these HPRR studies (i.e., PDIS 1 through PDIS 12) was 3 1. A total of about 8000 dosimeters were processed during these 12 studies. PDIS 13 was performed using ^{252}**Cf** and ^{238}**PuBe** radioisotopic neutron sources, but not at RADCAL. PDIS 14-16 were performed at RADCAL and were expanded beyond mixed sources of neutron and gamma rays by also including irradiations with mixed **sources** of beta particles and gamma rays. The PDIS are currently more popular and valuable than ever as evidenced by the fact that the average number of participants in PDIS 13-16 was 54 and that about 5600 personnel dosimeters were irradiated during these four studies. Overall, about 67% of the 13,600 dosimeters tested in the 16 PDIS have yielded measured dose equivalents within 50% of reference values.

Neutron Dosimetry Using Bubble Detectors. In the late 1980s and early 1990s DOSAR again became heavily involved with university students as Steve Sims and Bill ***Casson*** directed the activities of several graduate students. As an adjunct professor at Texas A&M, Sims directed the 1989 Ph.D. research of James Liu in the area of neutron dosimetry using bubble detector technology. Liu used the Energy Systems thermoluminescent albedo neutron dosimeter in conjunction with two bubble detectors with differing neutron energy thresholds and essentially divided up the neutron spectrum into four components in the same manner that Sam ***Hurst*** did three decades ago with the threshold detector unit **(TDU).** The difference is that the TDU was applicable only to high doses associated with accident dosimetry, but Liu's combination personnel neutron dosimeter (CPND) is useful in routine personnel neutron monitoring. The CPND demonstrated a remarkable ability to measure neutrons in an unknown field. In acontinuation of associated work, Mark Buckner received his M.S. at UT in 1991 for improvements in the dosimetry accuracy and spectral resolution of the CPND. Buckner also added much to the literature on the theory and mechanisms associated with bubble dosimeters as well as on additional applications for bubble detectors, for example, area spectrometers and extremity dosimeters.

Support of Applied Health Physics. A dramatic reemphasis on issues of environment, safety, and health in the late 1980s within the DOE community redirected efforts of many research organizations; the DOSAR Group was one of those. Technical expertise within the group was brought to bear on problems previously associated with operational and applied health physics. Understanding the importance assigned to these efforts, the researchers provided assistance in a number of areas. Steve Sims headed a project that revamped the methodology associated with radiation source control at all five Energy Systems plants. Bill *Casson* designed and implemented a nuclear accident dosimetry system using the Energy Systems personnel dosimetry badge. Mark *Buckner* provided technical assistance in bringing the Energy Systems automatic reader for thermoluminescence dosimeters on line and shared in an R&D-100 Award. The DOSAR Group used RADCAL to provide quality assurance and quality control for the calibration of operational radiation monitoring instruments and personnel dosimetry systems in use at Energy Systems.

Technology Transfer

Technology has been effectively transferred over the years by several different processes. In the earliest years it was done through publications and presentations; later that was followed by a few outside business starts, and most recently by licensing our products to U.S. industry. Sam *Hurst* probably enjoyed more early successes than anyone else. His neutron dosimeter was the world's de facto neutron dosimeter for three decades starting in the late 1950s. His spectacular success working with lasers in the mid- 1970s led to the demonstration of single-atom detection using resonance ionization spectroscopy (RIS). Hurst obtained the U.S. patent for this technology and started the commercial firm Atom Sciences, which was based on this concept, in 198 1. Single-atom detection technology revolutionized the level at which chemicals could be detected and stimulated worldwide work in RIS.

Comstock, a commercial firm founded by Bob Compton and John *Stockdale* in 1979, continues to enjoy success as a supplier of specialized experimental equipment. In the past several years Energy Systems and DOE have collaborated to facilitate licensing technologies developed at ORNL. HASRD has five licensing agreements with private industry for different technologies, and the Office of Technology Applications is negotiating with industry for several more. On the basis of the large number of patents that are now being awarded to staff annually, it is expected that this activity will continue to grow in the 1990s (Fig. 57). In 1992, for example, *Tuan Vo-Dinh* was selected as Energy Systems' Inventor of the Year for inventing the Surface-Enhanced Raman Optical Data Storage System that offers 100 times greater storage density than current compact disk technology and has wide-ranging applications in the fields of computing, health care, government, banking, finances, and entertainment.

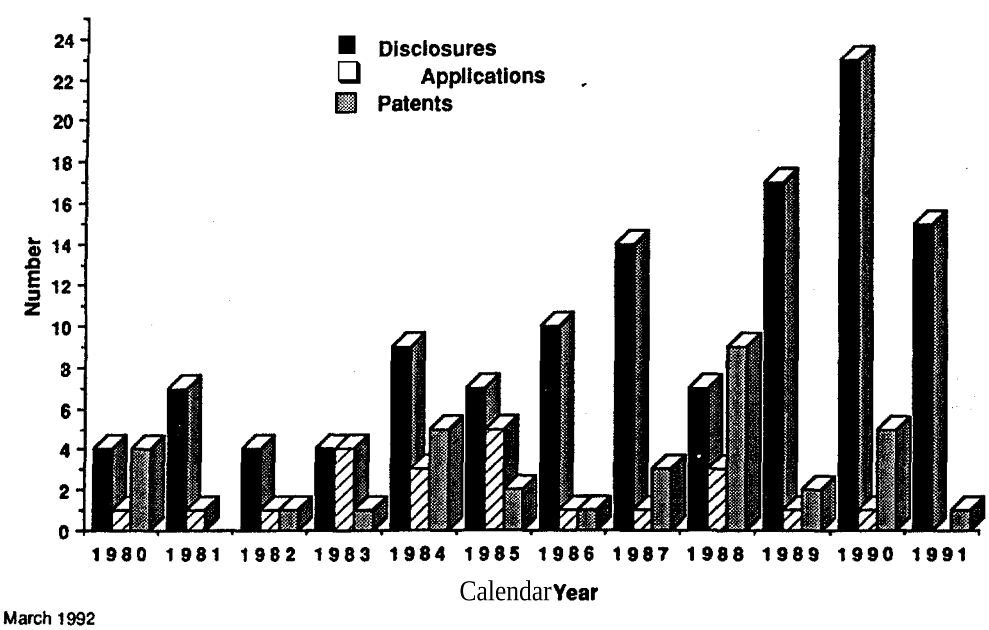


Fig. 57. Number of patent disclosures, patent applications, and patents granted to staff members of the Health and Safety Research Division since 1980.

The Nineties

The excellent people who have joined HASRD over the years, together with their outstanding accomplishments, continue to make the Division one of the most creative and productive at ORNL. This is seen in statistics for patents, licenses, publications, presentations, R&D-100 Awards, and other forms of recognition. Our initial roster in 1977 included 110 permanent staff members and 65 guests. Today we have about 150 guests per year and over 200 permanent staff members (Appendixes A and B). We have increased in diversity and complexity through expansions of our funding base to include a variety of non-DOE sponsors such as the U.S. Environmental Protection Agency, National Institutes of Health, U.S. Department of Defense, and U.S. Nuclear Regulatory Commission.

HASRD conducts a large laboratory and field research program that is concerned with human health and safety impacts of energy technologies (Fig. 58). This work includes both nuclear and nonnuclear technologies from the standpoint of potential impacts on the worker and the general population. Descriptions of work currently conducted in the five sections of the Division are briefly summarized in the following sections. The 1990s will be a time of change in program emphasis. Environmental restoration is a large and important activity both locally and nationally, and HASRD is carrying on research and development in areas of waste disposal, instrumentation development, site characterization, and risk analysis.

Biomedical and Environmental Information Analysis

The end products of scientific research and development are new data and information, the ultimate usefulness of which is dependent on accessibility. Much of the vast array of scientific information resources and data management capabilities associated with the research and development activities at ORNL have been developed by the Biomedical and Environmental Information Analysis (BEIA) Section. Since the late 1960s, BEIA has specialized in the development of "value added' information products on health and environmental effects of hazardous substances and on waste management/ remedial actions for contaminated ecosystems and facilities. BEIA's work takes many forms, including the following: the development of both mainframe and PC-based computerized data bases and expert systems; quality assurance for existing data sets; compilation of bibliographies and regulatory reference handbooks; and evaluation and analysis of data to prepare concise chemical profiles and health risk assessments reports. The assessments cover a variety of topics ranging from potential effects of toxic/ hazardous materials to studies of research and regulatory methodologies. As a spinoff of extensive efforts in data base and data systems development, the Section has also become involved in studies of new and better methods for information management and dissemination and of rapid communication tools such as technical newsletters and electronic conferencing. The information products developed are used to help inform the public of potential health risks of toxic/hazardous substances, reduce environmental risks of manufacturing processes, regulate exposure to toxic/hazardous materials, assist in the organization and dissemination of data for national research programs, and facilitate the process of environmental hazard control. The continuation of this type of work will be emphasized during the 1990s. The Section will always he mindful of the need to keep abreast of new research developments and the need to adapt to new situations.

Chemical Physics

Many of the health and environmental problems posed by present and future energy sources cannot be adequately assessed or ultimately solved until we have increased our understanding at the molecular level of a variety of pollutants and of their effects on humans and the environment. In the Chemical Physics Section, studies are being made of basic chemical and physical processes that characterize pollutants and their interactions with other chemical species. Novel physical principles are often combined with state-of-the-art lasers, mass spectrometers, and chemical sensors to yield prototype instruments capable of unprecedented sensitivity and selectivity.

HEALTH AND SAFETY RESEARCH DIVISION

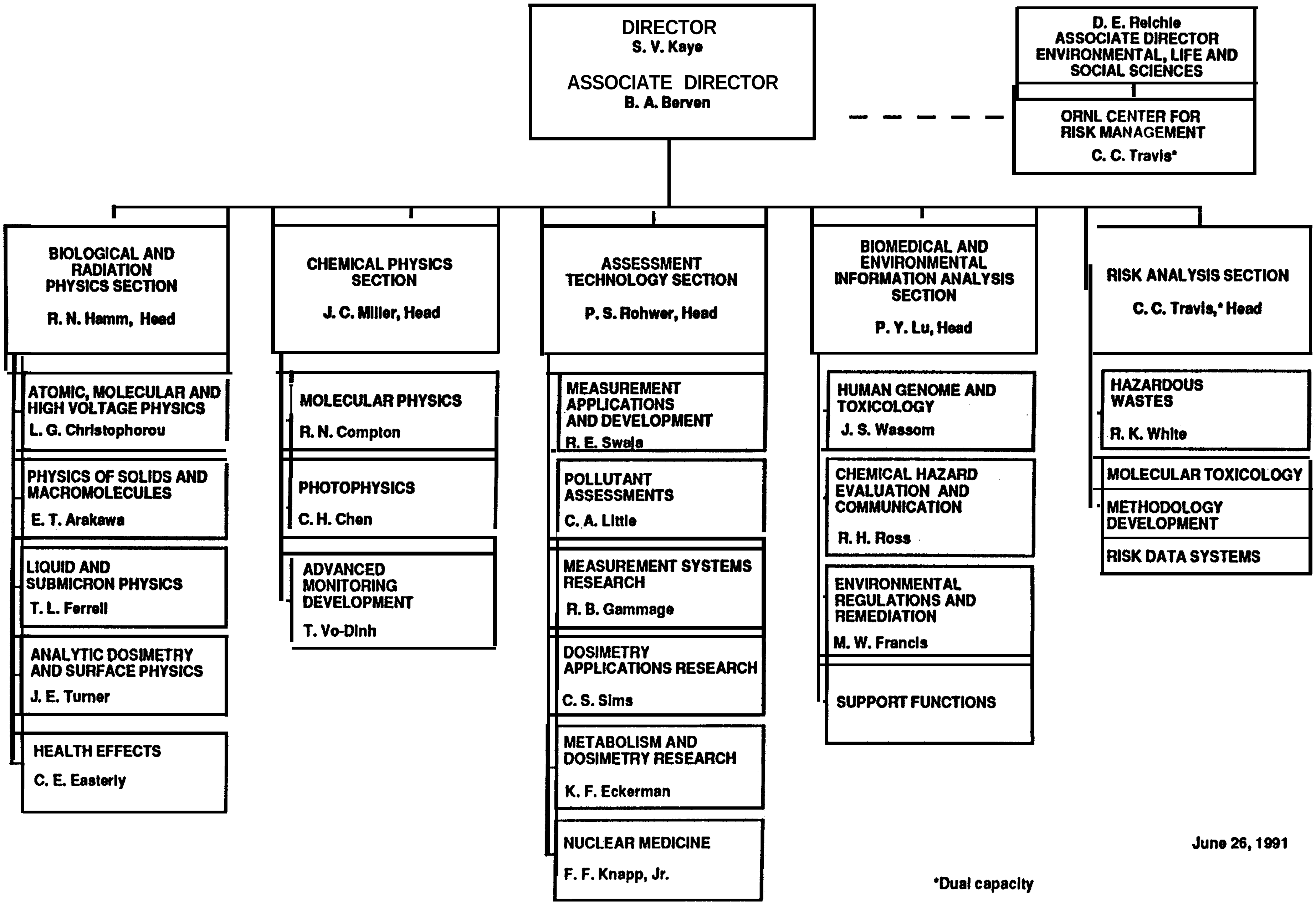


Fig. 58. Current organizational chart for the Health and Safety Research Division.

Topics of particular interest to the Molecular Physics and Photophysics groups include investigations of molecular clustering phenomena, ion molecular reactions, molecular negative ion formations, and photo-induced chemical reactions. These studies are related to problems in atmospheric chemistry and physics and to radiation chemistry. In these research areas, extensive use is made of lasers in studies of multiphoton excitation and ionization, laser fluorescence, resonance ionization spectroscopy of atoms and molecules, and nonlinear optical phenomena that extend the useful range of laser frequencies. These studies are aimed at the development of advanced analytical instrumentation for very low level environmental pollutant detection. A new picosecond laser facility provides very short time, high-intensity tunable laser pulses for studies of very fast chemical reactions and other phenomena that are accessible on picosecond time scales.

Development of improved instruments and methods for assessing human exposures to low levels of chemical pollutants as well as for measuring early health effects produced by these chemical exposures is the focus of the Advanced Monitoring Development Group. An emphasis is placed on spectrochemical techniques with potential field applications. Examples of instrumentation developed involved laser-based techniques for detecting DNA adduct products and microsensors that integrate fiber optics, spectrometric detectors, and bioreceptors.

Assessment Technology

The Assessment Technology Section focuses on the development and application of state-of-the-art technologies that identify and quantify parameters of demonstrated importance in assessing human health. The research and applications activities are numerous and wide ranging. Section personnel develop, calibrate, and use instrumentation to measure radiological and chemical environmental contaminants. Integral research and development includes new photonics to detect a variety of chemicals in the environment, new chemical and radiological survey methodologies, and field testing of newly developed instrumentation. The expertise exists to measure or sample virtually any radiological or chemical contaminant in the environment, determine the magnitude and extent of that contaminant, model the movement of that contaminant through the environment, and estimate potential human exposure. This Section also has nationally and internationally recognized capabilities in measurement and calibration of instrumentation and dosimeters in radiation detection, development of radionuclide generator systems and highly specialized radiopharmaceuticals for disease diagnosis and therapy, and dosimetry for internal and external radiation exposures including development of increasingly realistic anatomic and biokinetic models that allow consideration of special characteristics of exposed individuals of various ages.

The Assessment Technology Section has unique resources to enhance its research and development initiatives: (1) The Radiation Calibration Laboratory is a facility with well-characterized radiation sources suitable for use in performing international personnel radiation dosimetry intercomparison study programs as well as for testing dosimeters to the requirements of national accreditation programs. (2) The Indoor Air Program is a nationally recognized effort that primarily involves radon screening, assessment, and mitigation of DOD facilities worldwide. (3) A compilation of five high-purity germanium detectors are used for gamma spectroscopy of environmental samples. (4) Four large mobile laboratories are used for extended survey support at off-site locations. (5) A facility with laboratories and technical staff is operated in Grand Junction, Colorado, for the more cost-effective response to environmental assessments at federal facilities. (6) The Section is actively involved in the development and implementation of in situ fiber-optic devices for groundwater monitoring. (7) A large data base of anatomical, metabolic, and radionuclide data is maintained for dosimetric calculations for internal and external exposure to radiation sources. (8) Laboratories facilitate development, characterization, and preclinical testing of new radiolabeled agents in laboratory animals and in vitro systems.

These resources enable the Section to be a center of excellence in radiation measurement and calibration, internal and external radiation dosimetry, nuclear medicine research, development and application of chemical monitoring techniques, assessment of contaminants in the environment, and the collective determination of the impacts to human health from these physical and chemical agents. Education, training, licensure of newly developed products, and university interactions arc major avenues of technology transfer.

Biological and Radiation Physics

Activities in the Biological and Radiation Physics Section range from such basic research as measurements of the optical and electrical properties of liquids and solids to such applied research as the development of a new type of microscope. Research activities consist of basic studies of matter in all phases (gas, liquid, and solid), directed toward providing information on topics such as the structure and properties of materials of biological importance, the physical processes that are important in the transport of pollutants through the environment, and the interactions of pollutants with biological materials. We are also developing and improving methodologies to assess the impact and risk of various technologies on human health.

Specific activities include studies of (1) the interaction of radiation (photons, electrons, nucleons, and heavy charged particles) with matter, (2) photophysical and photochemical properties of chemical pollutants, (3) physical properties of submicron, structures using state-of-the-art technology such as scanning tunneling microscopes capable of single-atom resolution, (4) electron motion and attachment in low- and high-pressure gases and liquids, (5) forces that influence particulate accretion to surfaces, (6) the structure of charged particle tracks in liquids and solids, (7) the fundamental mechanisms of radiation or chemically produced damage to biological molecules, (8) the models for predicting biological response to radiation and development of a common risk scale for radiological and chemical agents, and (9) improved methods to assist the decision-making process in regulatory toxicology.

The primary objective of the research activities is to provide basic information needed to protect humans and the environment from harmful effects related to energy and associated technologies. Yet the research has such varied applications as developing detectors for use at the proposed Superconducting Super Collider Facility, understanding the properties of high-temperature superconductors, studying planetary atmospheres, assessing human health risks associated with disposal of the U.S. chemical weapons stockpile, and sequencing the human genome.

Risk Analysis

The Risk Analysis Section is involved in development and application of new methodologies in risk assessment and in characterization of uncertainties in the risk assessment process. Emphasis is placed on evaluating the scientific basis for assumptions used in risk assessment and for improving current methodologies when necessary.

The Section is active in the area of biologically based pharmacokinetic models. Relying on actual physiological parameters to describe the metabolic process, pharmacokinetic models can predict chemical transport and metabolism across routes of administration, across species, and through temporal variation in exposure. Biologically based pharmacodynamic models relate fundamental cellular processes to the epidemiology of cancer in animal and human populations. A program to identify the proper experimental research necessary to understand chemical pharmacodynamics and to perform such research in collaboration with the Biology Division has begun.

In the hazardous waste area, the Section is involved with development, evaluation, and application of decision methodologies for use in remedial activities associated with chemical waste at Superfund and DOE facilities. Involvement with on-site health evaluations at Superfund sites and with the use of risk data systems, including geographic information systems, to assist in the production of risk and health assessments and related demographic studies conducted around hazardous waste sites is also under way.

List of References

1. A. C. Brown and C. B. MacDonald, eds., **The Secret History** of the **Atomic Bomb,** Dial Press/James Wade, New York, 1977.

2. P. Vlajcic, "Oak Ridge National Laboratory: Supporting American Science," **Nuclear News 34 (8),** 63-69 (June 1991).

3. *G. S. Hurst* and *R. H. Ritchie,* "Application to Radiation Dosimetry," pp. 367–90 in **Nuclear Instruments and Their Uses,** Vol. 1, ed. A. H. Snell, John Wiley and Sons, New York, 1962.

4. *R. D. Birkhoff,* "The Passage of Fast Electrons Through Matter," pp. 53–138 in **Handbuch der Physik,** Vol. XXXIV, ed. S. Flugge, Springer-Verlag, Berlin, 1958.

5. *R. H. Rirchie,* "A Classic Citation-Plasma Losses by Fast Electrons in Thin Films," **Current Contents (Physical, Chemical, and Earth Sciences) 25 (3),** 18 (1985).

6. *J. A. Auxier, W. S. Snyder,* and *T. D. Jones,* "'Neutron Interactions and Penetration in Tissue," pp. 275-3 16 in **Radiation Dosimetry,** 2nd ed., Vol. 1, ed. F. H. Attix and W. C. Roesch, Academic Press, New York, 1968.

7. National Council on Radiation Protection, **Protection Against Neutron Radiation,** NCRP Report 38, National Council on Radiation Protection Publications, Washington, D.C., 1971.

8. R. L. Kathren, H. W. Patterson, J. N. Stannard, and P. L. Ziemer, eds., **"25th** Anniversary Issue," **Health Physics 38, 883–1212** (1980).

9. "Recommendations of the International Commission on Radiological Protection," Rev. **Dec. 1, 1954, British Journal of Radiology, Supplement 6 (1955).**

10. National Bureau of Standards, **Maximum Permissible Body Burdens and Maximum Permissible Concentrations of Radionuclides in Air and in Water for Occupational Exposure,** NBS Handbook 69, U.S. Government Printing Office, Washington, D.C., 1959.

11. *W. S. Snyder, M. R. Ford,* G. G. Warner, and H. L. Fisher, Jr., "Estimates of Absorbed Fractions for Monoenergetic Photon Sources Uniformly Distributed in Various Organs of a Heterogenous Phantom, MIRD Pamphlet No. 5," **Journal of Nuclear Medicine, Supplement 3 (1969).**

12. *W.* S. *Snyder, M. J. Cook,* L. R. Karhausen, E. S. Nassett, G. P. Howells, and I. H. Tipton, **Report of the Task Group on Reference Man,** A Report Prepared

by a Task Group of Committee 2 of the International Commission on Radiological Protection, ICRP Publication 23, Pergamon Press, Oxford, 1975.

13. ***K. F. Eckeman,*** A. B. Wolbarst, and A. C. B. Richardson, **Limiting Values of Radionuclide Intake and Air Concentrations and Dose Conversion Factors for Inhalation, Submersion, and Ingestion,** Federal Guidance Report 11, EPA-520/l-88-020, U.S. Environmental Protection Agency, Washington, D.C., 1988.

14. D. A. Weber, ***K. F. Eckeman,*** L. T. Dillman, and J. C. Ryman, **MIRD: Radionuclide Data and Decay Schemes,** Society of Nuclear Medicine, New York, 1989.

15. G. ***D. Kerr,*** T. Hashizume, and C. W. Edington, "Historical Review," pp. 1-13 in **Reassessment of Atomic Bomb Radiation Dosimetry in Hiroshima and Nagasaki, Final Report,** Vol. 1, ed. W. C. Roesch, Radiation Effects Research Foundation, Hiroshima, Japan, 1987.

16. ***J. A. Auxier,*** **Ichiban: Radiation Dosimetry for the Survivors of the Bombings of Hiroshima and Nagasaki,** TID-27080, ERDA Technical Information Center, Oak **Ridge, Tenn.**, 1977.

17. ***R. H. Rirchie*** and ***G. S. Hurst,*** "Penetration of Weapon Radiation: Application to Hiroshima-Nagasaki **Studies," Health Physics 1, 390–404 (1959).**

18. ***E. T. Arakawa***, "Radiation Dosimetry in Hiroshima and Nagasaki Atomic Bomb Survivors," **New England Journal of Medicine 263, 488–93 (1960).**

19. ***J. S. Cheka, F. W. Sanders, T. D. Jones,*** and ***W. H. Shinpaugh,*** **Distribution of Weapons Radiation in Japanese Residential Structures,** CEX-62.11, U.S. Atomic Energy Commission, Oak Ridge, **Tenn.**, 1965.

20. J. A. Auxier, J. S. Cheka, F. F. Haywood, T. D. Jones, and ***J. H. Thorngare,*** "Free-Field Radiation-Dose Distributions for the Hiroshima and Nagasaki Bombings," **Health Physics 12, 425–29 (1966).**

21. ***T. D. Jones, J. A. Auxier, J. S. Cheka,*** and ***G. D. Kerr,*** "In Vivo Dose Estimates for A-Bomb Survivors Shielded by Typical Japanese Houses," **Health Physics 28, 367–8 1 (1975).**

22. G. D. Kerr, **"Organ** Dose Estimates for the Japanese Atomic Bomb Survivors," **Health Physics 37, 487–508 (1979).**

23. H. H. **Rossi** and C. W. Mays, "Leukemia Risk from Neutrons," **Health Physics 34, 353–60 (1978).**

24. National Council on Radiation Protection and Measurements, "Statement on Dose Limit for Neutrons," **Health Physics 39, 84344 (1980).**

25. W. C. Roesch, "Historical Perspectives," pp. 14-22 in **New Dosimetry at Hiroshima and Nagasaki and Its Implications for Risk Estimates, NCRP**

Proceedings 9, National Council on Radiation Protection Publications, Washington, D.C., 1988.

26. V. P. Bond and J. W. Thiessen, eds., **Reevaluations of Dosimetric Factors: Hiroshima and Nagasaki,** DE81026279 (CONF-810928), Technical Information Center, U.S. Department of Energy, Oak Ridge, Tenn., 1982.

27. D. J. Thompson, ed., **Reassessment of Atomic Bomb Radiation Doshnetry in** Hiroshima **and Nagasaki,** Radiation Effects Research Foundation, Hiroshima, Japan, 1983.

28. **Reassessment of Atomic Bomb Radiation Dosimetry in Hiroshima and Nagasaki with Special Reference to Shielding and Organ** Dose, Radiation Effects Research Foundation, Hiroshima, Japan, 1984.

29. W. C. Roesch, ed., **Reassessment of Atomic Bomb Radiation Dosimetry in Hiroshima and Nagasaki, Final Report,** Radiation Effects Research Foundation, Hiroshima, Japan, 1987.

30. **New Dosimetry at Hiroshima and Nagasaki and Its Implications for Risk Estimates,** NCRP Proceedings 9, pp. 14-22, National Council on Radiation Protection Publications, Washington, D.C., 1988.

31. K. L. Mossman, *G. D. Kerr,* C. B. Meinhold, M. R. Sikov, J. B. Smathers, and R. L. Ulhich, **A Technical Review and Assessment of the BEIR V Report, DOE/EH-0149T,** U.S. Department of Energy, Washington, DC., 1990.

32. American National Standards Institute, **American National Standard: Dosimetry for Criticality Accidents,** ANSI Report N13.3, American National Standards Institute, New York, 1969.

33. K. Z. Morgan and *J. E. Turner,* eds., **Principles of Radiation Protection: A Textbook of Health Physics,** John Wiley and Sons, New York, 1967.

34. E. T. Arakawa, R. J. Herickhoff, and *R. D. Birkhoff*, "Detection of Plasma Radiation for Electron-Bombarded Al and Mg Foils," **Physical Review Letters 12,** 319-20 (1964).

35. C. Kittel, **Introduction to Solid-State Physics,** John Wiley and Sons, New York, 1966.

36. R. C. Vehse, J. L. Stanford, and *E. T. Arakawa,* "Discrete Energy Losses by Photoexcited Electrons in Silver and Palladium," **Physical Review Letters 19,** 1041-43 (1967).

37. W. *D. Cottrell*, **Radioactivity in Silt of the Clinch and Tennessee** Rivers, ORNL-2847, Oak Ridge National Laboratory, Oak Ridge, Tenn., 1960.

38. President's Science Advisory Committee, **Science, Government** and **Information: The Responsibilities of the Technical Community and the Government in the Transfer of Information; A Report,** U.S. Government Printing Office, Washington, DC., 1963.

39. *R. B. Gammage*, ed., **Abstracts of the First ORNL Workshop on Polycyclic Aromatic Hydrocarbons: Characterization and Measurement with a View Toward Personnel Protection, ORNL/TM-5598,** Oak Ridge National Laboratory, Oak Ridge, **Tenn.,** 1976.

40. *R. B. Gammage*, ed., **Proceedings of the Second ORNL Workshop on Exposure to Polynuclear Aromatic Hydrocarbons in Coal Conversion Processes, CONF-770361,** U.S. Department of Energy, Oak Ridge, Term., **1977.**

41. ***M. W. Williams, E. T. Arakuwa,*** and I. Inagaki, "Optical and Dielectric Properties of Materials Relevant to Biological Research," pp. 95-145 in **Handbook on Synchrotron Radiation Research,** Vol. 4, North Holland, New York, 199 1.

42. R. H. Ritchie, E. T. Arakawa, J. J. Cowan, and ***R. N. Hamm,*** "Surface **Plasmon** Resonance Effect in Grating **Diffraction," Physical Review Letters 21,** 1530-33 (1968).

43. A. D. Boardman, **ed., Electromagnetic Surface Modes,** John Wiley and Sons, New York, 1982.

44. L. G. Christophorou, **Atomic and Molecular Radiation Physics,** Wiley-Interscience, New York, 197 1.

45. L. G. Christophorou, "Elementary Electron-Molecule Interactions and Negative Ion Resonances at Subexcitation Energies and Their Significance in Gaseous Dielectrics," pp. 5 l-72 in Proceedings **of the XIIIth International Conference on Phenomena in Ionized** Gases **1977,** VEB-Buch-Export-Import, Leipzig, Germany, 1977.

46. L. G. Christophorou, ed., **Gaseous Dielectrics, CONF-780301,** National Technical Information Center, Springfield, Va., 1978.

47. L. G. Christophorou, **ed., Gaseous Dielectrics** II, Pergamon Press, New York, 1980.

48. L. G. Christophorou, ed., Gaseous **Dielectrics** III, Pergamon Press, New York, 1982.

49. L. G. Christophorou and M. 0. Pace, eds., Gaseous **Dielectrics IV,** Pergamon Press, New York, 1984.

50. L. G. Christophorou and B. W. **Bouldin,** eds., Gaseous **Dielectrics V,** Pergamon Press, New York, 1987.

5 1. ***L. G. Christophorou*** and ***I. Sauers***, eds., Gaseous **Dielectrics VI,** Plenum Press, New York, 1990.

52. L. G. Christophorou, **Electron-Molecule Interactions and Their Application,** Academic Press, New York, 1984.

53. G. S. Hurst, M. G. Payne, M. H. Nayfeh, J. P. Judish, and ***E. B. Wagner,*** "Saturated Two-Photon Resonance Ionization of **He(2[1]S)," Physical Review Letters 35, 82–85** (1975).

54. M. G. Payne, G. S. Hurst, M. H. Nayfeh, J. P. Judish, C. H. Chen, E. B. Wagner, and J. P. Young, "Kinetics of **He(2[1]S)** Using Resonance Ionization Spectroscopy," **Physical Review Letters 35, 1154–56** (1975).

55. G. S. Hurst, M. H. Nayfeh, and J. P. Young, "A Demonstration of One-Atom Detection," **Applied Physics Letters 30, 229–31** (1977).

56. G. S. Hurst, M. H. Nayfeh, and J. P. Young, "One-Atom Detection Using Resonance Ionization Spectroscopy, **Physics Review 15, 2283–92** (1977).

57. G. S. Hurst, M. G. Payne, S. D. Kramer, and J. P. Young, "Resonance Ionization Spectroscopy and One-Atom Detection," **Reviews of Modern Physics 57,** 767-819 (1979).

58. "Availability of Radioactive Isotopes," **Science 103, 697–705, June 14,** 1946.

59. A. P. Watson, T. D. Jones, and G. ***D. Griffin,*** "Sulfur Mustard as a Carcinogen: Application of Relative Potency Analysis to the Chemical Warfare Agents H, **HD** and **HT," Regulatory Toxicology and Pharmacology 10, l-25** (1989).

60. P. J. Walsh, C. S. Dudney, and ***E. D. Copenhaver,*** eds., **Indoor Air Quality,** CRC Press, **Boca Raton,** Fla., 1984.

61. ***R. B. Gammage*** and ***S. V. Kaye,*** eds., **Indoor Air and Human Health,** Lewis Publishers, Inc., Chelsea, **Mich.,** 1985.

62. D. M. **Weekes** and ***R. B. Gammage,*** **eds., The Practitioner's Approach to Indoor Air Quality Investigations,** American Industrial Hygiene Association, Akron, Ohio, 1990.

63. P. M. Echenique, F. **Flores,** and ***R. H. Ritchie,*** "'Dynamic Screening of Ions in Condensed **Matter," Solid-State Physics 43, 229–300** (1990).

64. J. P. Goudonnet, G. M. Begun, and ***E. T. Arakawa,*** "Surface Enchanced **Raman** Scattering on Silver-Coated Teflon Sphere Substrates, **Chemical Physics** Letters **92, 197–201** (1982).

Appendix A

SUPERVISORY AND SECRETARIAL STAFF MEMBERS HEALTH AND SAFETY RESEARCH DIVISION

June 1992

S. V. Kaye, Director
B. A. Berven, Associate Director

Susan Masingo
Pam Groves
Denise Henderson*

ASSESSMENT TECHNOLOGY SECTION

Paul Rohwer
- Sue Huckaba
- Annie Brown
- Linda White

Keith Eckerman
- Sonia Rogers

Dick Gammage
- Debbie Dickerson

Russ Knapp
- Linda Ailey

Craig Little (Grand Junction Office)
- Timi Holmes
- Heather Tochtrop

Dick Swaja
- Evelyn Collins
- Linda Pyles

BIOLOGICAL AND RADIATION PHYSICS SECTION

Bob Hamm
- Doris Crowell

Ed Arakawa
- Jo Ann Cripps*

Loucas Christophorou
- Joan Carrington

Clay Easterly
- Shirley Huling

Tom Ferrell
- Jo Ann Cripps*

Jim Turner
- Brenda Kimmel

BIOMEDICAL AND ENVIRONMENTAL INFORMATION ANALYSIS SECTION

Po-Y ung Lu
- Teya DuArt

Mary W. Francis
- Dorla Arnwine

Bob Ross
- Glenda Johnson

John Wassom
- Wilma Barnard

CHEMICAL PHYSICS SECTION

John Miller
- Nancy Currence*
- Denise Henderson*

Winston Chen
- Darlene Holt

Bob Compton
- Nancy Currence*

Tuan Vo-Dinh
- Julia Cooper

RISK ANALYSIS SECTION

Curtis Travis
- Lois Thurston
- Robin Self

Robin White
- Alane Evers

***Dual Capacity**

Appendix B

TECHNICAL AND TECHNICAL SUPPORT STAFF MEMBERS
HEALTH AND SAFETY RESEARCH DIVISION

(Listed in Alphabetical Order)

June 1992

J. P. ABSTON (Paul)
A.A.S., Environmental Health Technology (Waste Management), 1990, Roane State Community College
ASSESSMENT TECHNOLOGY SECTION: Measurement Applications and Development Group

J. P. ALARIE (Jean Pierre)
M.S., Chemistry, 1990, University of Tennessee
CHEMICAL PHYSICS SECTION: Advanced Monitoring Development Group

W. J. ALLEN (Willie)
B.S., Biology, 1975, Tougaloo College; specialized training in Biomedical Sciences, 1976-1980, University of Tennessee
BIOMEDICAL AND ENVIRONMENTAL INFORMATION ANALYSIS SECTION: Human Genome and Toxicology Group

D. P. ALLISON (Dave)
M.S., Microbiology, 1970, University of Tennessee
BIOLOGICAL AND RADIATION PHYSICS SECTION: Liquid and Submicron Physics Group

S. L. ALLMAN (Steve)
A.A.S., Electronics Engineering, 1975, Asheville-Buncombe Technical Institute
CHEMICAL PHYSICS SECTION: Photophysics Group

J. F. ALLRED (John)
A.S., Mechanical Engineering Technology, 1982, Roane State Community College
ASSESSMENT TECHNOLOGY SECTION: Measurement Applications and Development Group

K. R. AMBROSE (Kathleen)
M.S., Microbiology, 1970, University of Tennessee
ASSESSMENT TECHNOLOGY SECTION: Nuclear Medicine Group

E. T. ARAKAWA (Ed)
Ph.D., Physics, 1957, University of Tennessee
BIOLOGICAL AND RADIATION PHYSICS SECTION: Physics of Solids and Macromolecules Group Leader

A. Q. ARMSTRONG (Anthony)
M.S., Microbiology, 1989, University of Georgia
RISK ANALYSIS SECTION: Hazardous Waste Group

J. C. ASHLEY (Jim)
Ph.D., Theoretical Physics, 1963, University of Tennessee
BIOLOGICAL AND RADIATION PHYSICS SECTION: Analytic Dosimetry and Surface Physics Group

D. K. BARSLUND (Debbie)
ASSESSMENT TECHNOLOGY SECTION: Administrative, Grand Junction Office

C. B. BAST (Cheryl)
Ph.D., Biomedical Science, 1989, University of Tennessee-Oak Ridge Graduate School of Biomedical Sciences
BIOLOGICAL AND ENVIRONMENTAL INFORMATION ANALYSIS SECTION: Chemical Hazard Evaluation and Communication Group

B. A. BERVEN (Barry)
Ph.D., Radiology and Radiation Biology, 1979, Colorado State University
ASSOCIATE DIVISION DIRECTOR

B. P. BLAYLOCK (Bonnie)
M.A., English, 1990, University of Tennessee
RISK ANALYSIS SECTION: Methodology Development Group

H. T. BORGES (Tim)
Ph.D., Toxicology, 1990, University of Kentucky
BIOLOGICAL AND ENVIRONMENTAL INFORMATION ANALYSIS SECTION: Chemical Hazard Evaluation and Communication Group

P. A. BRIMER (Pat)
B. S., Medical Technology, 1962, University of Tennessee College of Medicine at Memphis; board-certified, American Society of Clinical Pathologist Medical Technology, 1962
ASSESSMENT TECHNOLOGY SECTION: Measurement Applications and Development Group

K. J. BROWN (Kathy)
M.S.L.S., Library and Information Science, 1980, University of Tennessee
ASSESSMENT TBCHNOLOGY SECTION: Measurement Applications and Development Group

M. M. BROWN (Mary)
Ph.D., Microbiology, 1954, University of Pennsylvania
BIOMEDICAL AND ENVIRONMENTAL INFORMATION ANALYSIS SECTION: Human Genome and Toxicology Group

M. A. BUCKNER (Mark)
M.S., Nuclear Engineering, 1991, University of Tennessee
ASSESSMENT TECHNOLOGY SECTION: Dosimetry Applications Research Group

S. **N. BURMAN (Steve)**
M.P.H., Environmental and Occupational Health and Safety, 1991, University of Tennessee
ASSESSMENT TECHNOLOGY SECTION: Measurement Applications and Development Group

A. P. CALLAHAN (Al)
First Division of Chemical Engineering from International Correspondence School, Elements of Nuclear Energy from International Correspondence School
ASSESSMENT TECHNOLOGY SECTION: Nuclear Medicine Group

T. A. CALLCOTT (Tom)
Ph.D., Physics, 1965, Purdue University
BIOLOGICAL AND RADIATION PHYSICS SECTION: Physics of Solids and Macromolecules Group

S. J. CAMPBELL (Sherry)
BIOMEDICAL AND ENVIRONMENTAL INFORMATION ANALYSIS SECTION: Information Management Technology

H. S. CARMAN, JR (Howard)
Ph.D., Chemistry, 1986, Rice University
CHEMICAL PHYSICS GROUP: Molecular Physics Group

R. F. CARRIER (Romance)
B.A., Botany, 1957, University of Michigan; coursework toward M.S., Botany, 1957-1958, University of Tennessee
ASSESSMENT TECHNOLOGY SECTION: Measurement Applications and Development Group

J. G. CARTER (Jii)
MS., Physics, 1960, Vanderbilt University
BIOLOGICAL AND RADIATION PHYSICS SECTION: Atomic, Molecular, and High Voltage Physics Group

W. H. CASSON (Bill)
Ph.D., Physics, 1985, University of Tennessee
ASSESSMENT TECHNOLOGY SECTION: Dosimetry Applications Research Group

G. M. CATON (Gloria)
Ph.D., Analytical Chemistry, 1968, Iowa State University
BIOMEDICAL AND ENVIRONMENTAL INFORMATION ANALYSIS SECTION: Information Management Technology Coordinator

S. S. CHANG (Susan)
M.S., Nutritional Biochemistry, 1968, Oregon State University
BIOMEDICAL AND ENVIRONMENTAL INFORMATION ANALYSIS SECTION: Chemical Hazard Evaluation and Communication Group

D. E. CHAVARRJA (Darlene)
ASSESSMENT TECHNOLOGY SECTION: Pollutant Assessments Group, Grand Junction Office

C. H. CHEN (Winston)
Ph.D., Chemical Physics, 1974, University of Chicago
CHEMICAL PHYSICS SECTION: Photophysics Group Leader

L. G. CHRISTOPHOROU (Loucas)
Ph.D., Physics, 1963, University of Manchester, England
BIOLOGICAL AND RADIATION PHYSICS SECTION: Atomic, Molecular, and High Voltage Physics Group Leader, Senior Corporate Fellow

G. H. COFER (Glen)
A.A.S., Environmental Health Technology (Waste Management), 1990, Roane State Community College
ASSESSMENT TECHNOLOGY SECTION: Measurement Applications and Development Group

R. L. COLEMAN (Bobby)
B.S., Physics, 1988, University of Tennessee, Chattanooga
ASSESSMENT TECHNOLOGY SECTION: Measurement Applications and Development Group

R. N. COMPTON (Bob)
Ph.D., Physics, 1964, University of Tennessee
CHEMICAL PHYSICS SECTION: Molecular Physics Group Leader, Corporate Fellow

W. D. COTTRELL (Woody)
B.A., Mathematics, 1942, Lincoln Memorial University
ASSESSMENT TECHNOLOGY SECTION: Measurement Applications and Development Group

0. H. CRAWFORD (Oakley)
Ph.D., Chemistry, 1966, University of Illinois
BIOLOGICAL AND RADIATION PHYSICS SECTION: Analytic Dosimetry and Surface Physics Group

M. CRISTY (Mark)
Ph.D., Biology, 1976, University of Oregon
ASSESSMENT TECHNOLOGY SECTION: Metabolism and Dosimetry Research Group

T. A. CRONK (Tom)
B.S., Physics, 1987, Mesa College, Grand Junction, Colorado
ASSESSMENT TECHNOLOGY SECTION Pollutant Assessments Group, Grand Junction Office

G. S. DANFORD (Gerry)
B.A., Chemistry, 1953, University of Southern Mississippi
BIOMEDICAL AND ENVIRONMENTAL INFORMATION ANALYSIS SECTION: Environmental Regulations and Remediation Group

M. W. DAUGHERTY (Mary Lou)
M.S., Zoology, 1973, University of Tennessee
BIOMEDICAL AND ENVIRONMENTAL INFORMATION ANALYSIS SECTION: Chemical Hazard Evaluation and Communication Group

J. R. DAVIDSON (Jim)
A.S., Nuclear Technology, 1985, Chattanooga State Technical Community College
ASSESSMENT TECHNOLOGY SECTION: Pollutant Assessments Group, Grand Junction Office

K. A. DAVIDSON (Kowetha)
Ph.D., Zoology, 1973, University of Tennessee
BIOMEDICAL AND ENVIRONMENTAL INFORMATION ANALYSIS SECTION: Chemical Hazard Evaluation and Communication Group

H. C. DEES (Craig)
Ph.D., Molecular Virology, 1984, University Wisconsin-Madison
RISK ANALYSIS SECTION: Molecular Toxicology Group

K. S. DICKERSON (Kathy)
B.S., Geology, 1982, Mesa College, Grand Junction, Colorado
ASSESSMENT TECHNOLOGY SECTION: Pollutant Assessments Group, Grand Junction Office

D. M. DOUTHAT (Doug)
M.S., Business Administration, 1991, University of Tennessee
RISK ANALYSIS SECTION: Hazardous Waste Group

C. S. DUDNEY (Charles)
Ph.D., Biophysics, 1978, Massachusetts Institute of Technology
ASSESSMENT TECHNOLOGY SECTION: Measurement Systems Research Group

M. D. DYKES (Marsha)
B.S., Management and Data Processing, 1984, Carson-Newman College
RISK ANALYSIS SECTION: Risk Data Systems Group

C. E. EASTERLY (Clay)
Ph.D., Physics, 1972, University of Tennessee
BIOLOGICAL AND RADIATION PHYSICS SECTION: Health Effects Group Leader

K. F. ECKERMAN (Keith)
Ph.D., Environmental Health Engineering, 1972, Northwestern University
ASSESSMENT TECHNOLOGY SECTION: Metabolism and Dosimetry Research Group Leader

A. R. EHRENSHAFT (Anne)
B.A., 1966, Brooklyn College
BIOMEDICAL AND ENVIRONMENTAL INFORMATION ANALYSIS SECTION: Environmental Regulations and Remediation Group

J. R. ELLIS (Jewell)
DIVISION OFFICE: Administrative Assistant

M. W. ENGLAND (Wendy)
Ph.D., Solid-State Physics, 1960, University of London
BIOLOGICAL AND RADIATION PHYSICS SECTION: Analytic Dosimetry and Surface Physics Group

M. **L. ESPEGREN (Marcy)**
B.S., Geology, 1977, Colorado State University
ASSESSMENT TECHNOLOGY SECTION: Pollutant Assessments Group, Grand Junction Office

E. L. ETNIER (Liz)
M.A., Zoology, 1965, University of Minnesota
BIOMEDICAL AND ENVIRONMENTAL INFORMATION ANALYSIS SECTION: Chemical Hazard Evaluation and Communication Group

R. A. FAUST (Rosmarie)
Ph.D., Pharmacy, 1966, University of North Carolina
BIOMEDICAL AND ENVIRONMENTAL INFORMATION ANALYSIS SECTION: Chemical Hazard Evaluation and Communication Group

T. L. FERRELL (Tom)
Ph.D., Physics, 1969, Clemson University
BIOLOGICAL AND RADIATION PHYSICS SECTION: Liquid and Submicron Physics Group Leader

D. E. FIELDS (David)
Ph.D., Solid-State Physics, 1972, University of Wisconsin
ASSESSMENT TECHNOLOGY SECTION: Pollutant Assessments Group

L. M. FLOYD (Lois)
B.S.A., Zoology and Microbiology, 1966, Colorado State University
BIOMEDICAL AND ENVIRONMENTAL INFORMATION ANALYSIS SECTION: Environmental Regulations and Remediations Group

R D. FOLEY (Ray)
M.P.H., Environmental and Occupational Health and Safety, 1981, University of Tennessee
ASSESSMENT TECHNOLOGY SECTION: Measurement Applications and Development Group

A. A. FRANCIS (Andy)
M.S., Biochemistry, 1961, University of Arkansas Medical Center, Little Rock
BIOMEDICAL AND ENVIRONMENTAL INFORMATION ANALYSIS SECTION: Chemical Hazard Evaluation and Communication Group

M. W. FRANCIS (Mary)
M.S., Physiology, 1966, Florida State University
BIOMEDICAL AND ENVIRONMENTAL INFORMATION ANALYSIS SECTION: Environmental Regulation and Remediation Group Leader

R. B. GAMMAGE (Dick)
D.Sc., 1984, Exeter University, England; Ph.D., Physical Chemistry, 1964, Exeter University, England
ASSESSMENT TECHNOLOGY SECTION: Measurement Systems Research Group Leader

F. G. GARDNER (Frank)
B.S., Geology, 1980, Eastern Michigan University
ASSESSMENT TECHNOLOGY SECTION: Pollutant Assessments Group, Grand Junction Office

W. R. GARRETT (Ray)
Ph.D., Theoretical Atomic Physics, 1963, University of Alabama
CHEMICAL PHYSICS SECTION: Photophysics Group

R. C. GOSSLEE (Bob)
A.S., Health Physics (in progress), Roane State Community College
ASSESSMENT TECHNOLOGY SECTION: Measurement Applications and Development Group

T. J. GRAVES (Tina)
ASSESSMENT TBCHNOLOGY SECTION: Administrative

D. W. GREENE (Dennis)
M.S., Environmental Health, 1992, East Tennessee State University
ASSESSMENT TECHNOLOGY SECTION: Measurement Applications and Development Group

G. D. GRIFFIN (Guy)
Ph.D., Biochemistry, 197 1, University of Nebraska College of Medicine
CHEMICAL PHYSICS SECTION: Advanced Monitoring Development Group

G. E. GROOVER (Gerry)
BIOMEDICAL AND ENVIRONMENTAL INFORMATION ANALYSIS SECTION: Environmental Regulations and Remediations Group

J. W. HAAS (John)
Ph.D., Chemistry, 1986, University of Massachusetts
ASSESSMENT TECHNOLOGY SECTION: Measurement Systems Research Group

R. T. HAAS (Rose)
MS., Computer Science, 1986, University of Tennessee; Ph.D., Organic Chemistry, 1960, University of **Münster,** Germany
BIOMEDICAL AND ENVIRONMENTAL INFORMATION ANALYSIS SECTION: Human Genome and Toxicology Group

D. K. HALFORD (Doug)
M.S., Radiation Biology, 1975, Colorado State University; M.S., Pathology, 1974, Colorado State University
ASSESSMENT TECHNOLOGY SECTION: Pollutant Assessments Group, Grand Junction Office

S. C. HALL (Steve)
B.A., Biology, 1979, Western State College of Colorado
ASSESSMENT TECHNOLOGY SECTION: Pollutant Assessments Group, Grand Junction Office

R. N. HAMM (Bob)
Ph.D., Physics, 1967, University of Tennessee
BIOLOGICAL AND RADIATION PHYSICS SECTION: Head

U. F. HARRIS (Ursula)
DIVISION **OFFICE:** Administrative

T. L. HATMAKER (Terry)
M.S. Chemistry, 1988, University of Tennessee
ASSESSMENT TECHNOLOGY SECTION: Measurement Applications and Development Group

G.T. HAWKINS (Todd)
B.A., Psychology, 1985, University of Tennessee
BIOMEDICAL AND ENVIRONMENTAL INFORMATION ANALYSIS SECTION: Environmental Regulations and Remediation Group

C. L. HECKMAN (Cindy)
M.S., Biology, 1985, University of Kentucky
BIOMEDICAL AND ENVIRONMENTAL INFORMATION ANALYSIS SECTION: Environmental Regulations and Remediation Group

B. E. HINGERTY (Brian)
Ph.D., Physics, 1974, Princeton University
BIOLOGICAL AND RADIATION PHYSICS SECTION: Analytic Dosimetry and Surface Physics Group

L. M. HOULBERG (Linda)
B.S., Nursing, 1970, University of Wisconsin
BIOMBDICAL AND ENVIRONMENTAL INFORMATION ANALYSIS SECTION: Environmental Regulations and Remecliation Group

P. S. HOVATTER (Patti)
M.S., **Wildlife** Biology, 1976, Tennessee Technological University
BIOMEDICAL AND ENVIRONMENTAL INFORMATION ANALYSIS SECTION: Chemical Hazard Evaluation and **Communication** Group

S. M. HUBNER (Sibyll)
B.S., Medical Technology, 1954, University of Tubingen, Germany
BIOMEDICAL AND **ENVIRONMENTAL** INFORMATION ANALYSIS SECTION: Chemical Hazard Evaluation and Communication Group

D. R. JAMES (Randy)
Ph.D., Physics, 1975, Georgia Institute of Technology
BIOLOGICAL AND RADIATION PHYSICS SECTION: Liquid and Submicron Physics Group

M. K. JENSEN (Melissa)
B.A., Biology, 1979, University of Northern Colorado
ASSESSMENT TECHNOLOGY SECTION: Pollutant Assessments Group, Grand Junction Office

C. A. **JOHNSON (Carol)**
B.S., Botany, 1975, University of Tennessee; coursework toward M.S., Microbiology, 1975-1977, University of Tennessee
ASSESSMENT TECHNOLOGY SECTION Measurement Applications and Development Group

T. D. JONES (Troyce)
M.S., Applied Mathematics, 1963, Missouri School of Mines and **Metallurgy**
BIOLOGICAL AND RADIATION PHYSICS SECTION: Health Effects Group

S. V. KAYE (Steve)
Ph.D., Radiation Biology, 1966, University **of** Rochester
DIVISION DIRECTOR

G. D. KERR (George)
Ph.D., Physics, 1971, University of Tennessee
ASSESSMBNT TBCHNOLOGY SECTION: Metabolism and Dosimetry Research Group

B. W. KLINE (Betty)
B.S., Chemistry, 1964, Knoxville College
BIOMEDICAL AND ENVIRONMENTAL **INFORMATION** ANALYSIS SECTION: Environmental Regulations and Remediation Group

C. E. KLOTS (Eph)
Ph.D., Physical Chemistry, 1960, Harvard University
CHEMICAL PHYSICS SECTION: Molecular Physics Group.

F. F. KNAPP (Russ)
Ph.D., Biochemistry, 1970, St. Louis University School of Medicine
ASSESSMENT TBCHNOLOGY **SECTION:** Nuclear Medicine Group Leader

R R. KNOTT (Richard)
B.S., Geology, 1981, Mesa College, Grand Junction, Colorado
ASSESSMENT TBCHNOLOGY SECTION Pollutant Assessments Group, Grand Junction Office

D. C. KOCHER (David)
Ph.D., Nuclear **Physics, 1970, University of** Wisconsin
ASSESSMENT TECHNOLOGY SECTION Metabolism **and Dosimetry Research Group**

B. J. KRALL (Joella)
B.S., Chemistry, 1976, Metropolitan State College, Denver, Colorado
ASSESSMENT TECHNOLOGY SECTION: Pollutant Assessments Group, Grand Junction Office

C. R LAMBERT (Carla)
A.S., Biology, 1983, Roane State Community College
ASSESSMENT TECHNOLOGY SECTION: Nuclear Medicine Group

M. L. LAND (Miriam)
M.S., Statistics, 1986, Kansas State University; M.B.A., 1982, Kansas State University
RISK ANALYSIS SECTION: Risk Data Systems Group

D. C. LANDGUTH (David)
M.S., Environmental and Occupational Health and Safety, 1990, University of Tennessee
ASSESSMENT TECHNOLOGY SECTION: Measurement Applications and Development Group

M. E. LANGSTON (Marilyn)
B. S., Computer Science, 1991, Bristol University
BIOMEDICAL AND ENVIRONMENTAL INFORMATION ANALYSIS SECTION: Information Management Technology

R. W. LEGGETT (Rich)
Ph.D., Mathematics, 1972, University of Kentucky
ASSESSMENT TECHNOLOGY SECTION: Metabolism and Dosimetry Research Group

R. P. LENC (Bob)
B.S., Geology, 1983, Mesa College, Grand Junction, Colorado
ASSESSMENT TECHNOLOGY SECTION: Pollutant Assessments Group, Grand Junction Office

E. B. LEWIS (Eric)
M.S., Forestry, 1974, Virginia Polytechnic Institute and State University
BIOMEDICAL AND ENVIRONMENTAL INFORMATION ANALYSIS SECTION: Environmental Regulations and Remediation Group

C. A. LITTLE (Craig)
Ph.D., Radiation Ecology, 1976, Colorado State University
ASSESSMENT TECHNOLOGY SECTION: Pollutant Assessments Group Leader, Grand Junction Office

P. Y. LU (Po-Yung)
Ph.D., Environmental Toxicology, 1974, University of Illinois
BIOMEDICAL AND ENVIRONMENTAL INFORMATION ANALYSIS SECTION: Head

J. M. MacINNIS (Jean)
Ph.D., Molecular Biophysics, 1987, Florida State University
RISK ANALYSIS SECTION: Molecular Toxicology Group

B. K. MANSFIELD (Betty)
MS., Biology, 1986, James Madison University
BIOMEDICAL AND ENVIRONMENTAL INFORMATION ANALYSIS SECTION: Human Genome and Toxicology Group

R. A. MATHIS (Richard)
A.D., 1976, Knoxville Business College; Certified Senior Engineering Technician: 1976, Institute for the Certification of Engineering Technicians, N.S.P.E.; Radiotelephone First Class, 1976, USFCC; attended the University of Tennessee
ASSESSMENT TECHNOLOGY SECTION: Measurement Applications and Development Group

K. I-I. MAVOURNIN (Kathy)
Ph.D., Microbial Genetics, 1979, University of Tennessee
BIOMEDICAL AND ENVIRONMENTAL INFORMATION ANALYSIS SECTION: Environmental Regulations and Remediations Group

L. M. McDOWELL-BOYER (Laura)
Ph.D., Civil Engineering, 1989, University of California, Berkeley
ASSESSMENT TECHNOLOGY SECTION: Pollutant Assessments Group, Grand Junction Office

C. W. McGINN (Wilson)
M.S., Geology, 1988, University of Tennessee
RISK ANALYSIS SECTION: Hazardous Waste Group

S. P. McKENZIE (Sam)
M.S., Physics, 1989, Memphis State University
BIOLOGICAL AND RADIATION PHYSICS SECTION: Physics of Solids and Macromolecules Group

D. W. McPHERSON (Dan)
Ph.D., Chemistry, 1984, Auburn University
ASSESSMENT TECHNOLOGY SECTION: Nuclear Medicine Group

D. B. MILLER (Dennis)
M.S., Environmental Sciences, 1987, Institute of Environmental Sciences, Miami University, Ohio
RISK ANALYSIS SECTION: Hazardous Waste Group, Work-for-Others Team Leader

I. C. MILLER (Ida)
B.S., Biology, 1959, Carson-Newman College
BIOMEDICAL AND ENVIRONMENTAL INFORMATION ANALYSIS SECTION: Human Genome and Toxicology Group

J. C. MILLER (John)
Ph.D., Physical Chemistry, 1975, University of Colorado
CHEMICAL PHYSICS SECTION: Head

P. D. MILLER (Denise)
B.S., Geology, 1988, University of Tennessee
RISK ANALYSIS SECTION: Hazardous Waste Group

S. MIRZADEH (Saed)
Ph.D., Chemistry, 1978, University of New Mexico
ASSESSMENT TECHNOLOGY SECTION: Nuclear Medicine Group

J. M. MORRIS (Jill)
B.S., Biology, 1991, University of Tennessee
RISK ANALYSIS SECTION: Methodology Development Group

C. A. MUHR (Chris)
B.S., Geology, 1982, Mesa College, Grand Junction, Colorado
ASSESSMENT TECHNOLOGY SECTION: Pollutant Assessments Group, Grand Junction Office

N. B. MUNRO (Nancy)
Ph.D., Mammalian Physiology, 1971, University of Kentucky
ASSESSMENT TECHNOLOGY SECTION: Metabolism and Dosimetry Research Group

M. E. MURRAY (Michael)
B.S., Chemical Engineering, 1978, Tennessee Technological University
ASSESSMENT TECHNOLOGY SECTION: Measurement Applications and Development Group

J. 0. MYNATT (Judy)
Knoxville Business College, 1969
BIOMEDICAL AND ENVIRONMENTAL INFORMATION ANALYSIS SECTION: Environmental Regulations and Remediation Group

D. M. OPRESKO (Dennis)
Ph.D., Biological Oceanography, 1974, University of Miami, Florida
BIOMEDICAL AND ENVIRONMENTAL INFORMATION ANALYSIS SECTION: Chemical Hazard Evaluation and Communication Group

E. T. OWENS (Beth)
B.A., Zoology, 1975, University of Tennessee
BIOMEDICAL AND ENVIRONMENTAL INFORMATION ANALYSIS SECTION: Human Genome and Toxicology Group

V. P. PATANIA (Vaughn)
B.A., Physics, 1988, University of Tennessee
ASSESSMENT TECHNOLOGY SECTION: Measurement Applications and Development Group

J. E. PETERSON (Pete)
B. A., Geology, 1984, University of Colorado
ASSESSMENT TECHNOLOGY SECTION: Pollutant Assessments Group, Grand Junction Office

R C. PHILLIPS (Ron)
A.A.S., Electronics Technology, 1978, Richmond Technical Institute
CHEMICAL PHYSICS SECTION: Photophysics Group

D. A. PICKERING (Douglas)
B.S., Geology, 1978, Mesa College, Grand Junction, Colorado
ASSESSMENT TECHNOLOGY SECTION: Pollutant Assessments Group, Grand Junction Office

G. A. PIERCE (Gretchen)
B.S., Environmental Biology, 1979, Eastern Illinois University
ASSESSMENT TECHNOLOGY SECTION: Pollutant Assessments Group, Grand Junction Office

E. M. PILZ (Elaine)
B.S., Nursing, 1976, Montana State University; B.A., Art, 1969, University of Colorado
ASSESSMENT TECHNOLOGY SECTION: Pollutant Assessments Group, Grand Junction Office

L. A. PINNADUWAGE (Lal)
Ph.D., Physics, 1986, University of Pittsburgh
BIOLOGICAL AND RADIATION PHYSICS SECTION: Atomic, Molecular, and High Voltage Physics Group

B. L. **RAMSEY (Brenda)**
RISK ANALYSIS SECTION: Administrative

C. D. RETOLAZA (Caroline)
ASSESSMENT TECHNOLOGY SECTION: Pollutant Assessments Group, Grand Junction Office

D. E. RICE (Dennis)
Attended Roane State Community College and Asheville-Buncombe Technical Institute; Certified Welder of Reactor Targets
ASSESSMENT TECHNOLOGY SECTION: Nuclear Medicine Group

R. H. RITCHIE (Rufus)
Doctor **Honoris Causa,** 1992, Universidad **del Pais** Vasco, Spain; Ph.D., Physics, 1959, University of Tennessee
BIOLOGICAL AND RADIATION PHYSICS SECTION: Analytic Dosimetry and Surface Physics Group, Senior Corporate Fellow

D. A. ROBERTS (Debbie)
Attended Roane State Community College; attended University of Tennessee
ASSESSMENT TECHNOLOGY SECTION: Measurement Applications and Development Group

R E. **RODRIGUEZ (Rick)**
B.S., Health Physics, 1986, Georgia Institute of Technology
ASSESSMENT TECHNOLOGY SECTION: Measurement Applications and Development Group

P. S. ROHWER (Paul)
Ph.D., Radiation Biology, 1966, University of Rochester
ASSESSMENT TECHNOLOGY SECTION: Head

D. A. ROSE (Doug)
A.S., Mini/Microcomputer Technology, 1988, Roane State Community College
ASSESSMENT TECHNOLOGY SECTION: Measurement Applications and Development Group

R. H. ROSS (Bob)
M.S., Biology, 1974, East Tennessee State University
BIOMEDICAL AND ENVIRONMENTAL INFORMATION ANALYSIS SECTION: Chemical Hazard Evaluation and Communication Group Leader

I. **SAUERS (Isidor)**
Ph.D., Physics, 1974, Georgia Institute of Technology
BIOLOGICAL AND RADIATION PHYSICS SECTION: Physics of Solids and Macromolecules Group

G. G. SHEARIN (Georgi)
ASSESSMENT TECHNOLOGY SECTION: Administrative

J. L. SKILES (Joni)
M.S., Mathematics, 1990, Clemson University
RISK ANALYSIS **SECTION:** Hazardous Waste Group

K. G. SLUSHER (Kim)
M.S., Plant Pathology, 1989, University of Tennessee
BIOMEDICAL AND ENVIRONMENTAL INFORMATION ANALYSIS SECTION: Human Genome and Toxicology Group

D. R. SMUIN (David)
B.S., Geology, 1976, Mesa College, Grand Junction, Colorado
ASSESSMENT TECHNOLOGY SECTION: Pollutant Assessments Group, Grand Junction Office

P. C. SRIVASTAVA (Prem)
Ph.D., Organic-Medicinal Chemistry, 1970, Lucknow University, Central Drug Research Institute, India
ASSESSMENT TECHNOLOGY SECTION: Nuclear Medicine Group

M. E. STACK (Mark)
B.S. Botany, 1990, University of Tennessee
RISK ANALYSIS SECTION: Hazardous Waste Group

R. S. STAFFORD (Bob)
B.S., Mathematics, 1960, Emory and Henry College
BIOMEDICAL AND ENVIRONMENTAL INFORMATION ANALYSIS SECTION: Human Genome and Toxicology Group

G. H. STEVENS (Gloria)
B.S., Geology, 1981, Mesa College, Grand Junction, Colorado; B.S., Secondary Education, Science, 1968, University of North Carolina
ASSESSMENT TECHNOLOGY SECTION: Pollutant Assessments Group, Grand Junction Office

T. R. STEWART (Tony)
A.S., 1976, Southwestern Technical Institute
ASSESSMENT TECHNOLOGY SECTION: Measurement Applications and Development Group

D. B. STINNETT (Donna)
BIOMEDICAL AND ENVIRONMENTAL INFORMATION ANALYSIS SECTION: Administrative

J. M. STOCKSTILL (Julia)
BFA, Liberal Arts, 1964, Wittenberg University
BIOMEDICAL AND ENVIRONMENTAL INFORMATION ANALYSIS SECTION: Environmental Regulations and Remediation Group

R. E. SWAJA (Dick)
Ph.D., Nuclear Science, 1973, Carnegie-Mellon University
ASSESSMENT TECHNOLOGY SECTION: Measurement Applications and Development Group Leader

J. H. SWENSON (Janet)
A.S., Medical Records Technology, 1976, Roane State Community College
BIOMEDICAL AND ENVIRONMENTAL INFORMATION ANALYSIS SECTION: Chemical Hazard Evaluation and Communication Group

S. S. TALMAGE (Sylvia)
Ph.D., Environmental Toxicology, 1989, University of Tennessee
BIOMEDICAL AND ENVIRONMENTAL INFORMATION ANALYSIS SECTION: Chemical Hazard Evaluation and Communication Group

J. W. TAYLOR (Jimmie)
B.S., Business Education, 1950, Tennessee State University
BIOMEDICAL AND ENVIRONMENTAL INFORMATION ANALYSIS SECTION: Environmental Regulations and Remediation Group

J. E. THATE (Jim)
A.S., Mining Technology; A.S., Mining Safety, 1983, College of Eastern Utah
ASSESSMENT TECHNOLOGY SECTION: Pollutant Assessments Group, Grand Junction Office

J. K. THOMAS (Janice)
M. S., Human Ecology, 1972, University of Tennessee
RISK ANALYSIS SECTION: Risk Data Systems Group

D. J. THORNE (David)
M.S., Health Physics, 1988, Colorado State University
ASSESSMENT TECHNOLOGY SECTION: Pollutant Assessments Group, Grand Junction Office

P. F. TINER (Peggy)
B.A., Botany, 1982, University of Tennessee
ASSESSMENT TECHNOLOGY SECTION: Measurement Applications and Development Group

C. C. TRAVIS (Curtis)
Ph.D., Mathematics, 197 1, University of California, Davis
RISK ANALYSIS SECTION: Head; CENTER FOR RISK MANAGEMENT: Director

J. E. TURNER (Jii)
Ph.D., Physics, 1956, Vanderbilt University
BIOLOGICAL AND RADIATION PHYSICS SECTION: Analytic Dosimetry and Surface Physics Group Leader, Corporate Fellow

R. L. TYNDALL (Dick)
Ph.D., Microbiology, 1961, Pennsylvania State University
BIOLOGICAL AND RADIATION PHYSICS SECTION: Health Effects Group

S. Y. UPPULURI (Shigeko)
M.A. (incomplete), 198 1, Anthropology, University of Tennessee
BIOMEDICAL AND ENVIRONMENTAL INFORMATION ANALYSIS SECTION: Human Genome and Toxicology Group

M. UZIEL (Mayo)
Ph.D., Biochemistry, 1955, University of Washington
CHEMICAL PHYSICS SECTION: Advanced Monitoring Development Group

M. S. UZIEL (Mary)
M.S., Zoology, 1962, University of Wisconsin
. ASSESSMENT TECHNOLOGY SECTION: Measurement Applications and Development Group

A. A. VASS (Anpad)
BIOLOGICAL AND RADIATION PHYSICS SECTION: Health Effects Group

V. L. VEST (Vicki)
B.A., English, 1989, Carson-Newman College
RISK ANALYSIS SECTION: Hazardous Waste Group

T. VO-DINH (Tuan)
Ph.D., Physical Chemistry, 1975, Eidgenossische Tecbnische Hochschule (Swiss Federal Institute of Technology), Switzerland
CHEMICAL PHYSICS SECTION: Advanced Monitoring Development Group Leader

E. A. WACHTER (Eric)
Ph.D., Chemistry, 1988, University of Wisconsin-Madison
ASSESSMENT TECHNOLOGY SECTION: Measurement Systems Research Group

S. J. WALLACE (Shawn)
B.S., Physics, 1986, Mesa College, Grand Junction, Colorado
ASSESSMENT TECHNOLOGY SECTION: Pollutant Assessments Group, Grand Junction Office

R J. WARMACK (Bruce)
Ph.D., Physics, 1975, University of Tennessee
BIOLOGICAL AND RADIATION PHYSICS SECTION: Liquid and Submicron Physics Group

J. S. WASSOM (John)
B.S., Biology, 1963, Tennessee Technological University
BIOMEDICAL AND ENVIRONMENTAL INFORMATION ANALYSIS SECTION: Human Genome and Toxicology Group Leader

A. P. WATSON (Annetta)
Ph.D., Agriculture, 1976, University of Kentucky
BIOLOGICAL AND RADIATION PHYSICS SECTION: Health Effects Group

K. A. WEAVER (Karen)
BIOMEDICAL AND ENVIRONMENTAL INFORMATION ANALYSIS SECTION: Environmental Regulations and Remediation Group

R K. WHITE (Robin)
Ph.D., English, 1985, University of Tennessee
RISK ANALYSIS SECTION: Hazardous Wastes Group Leader

B. L. WHITFIELD (Brad)
Ph.D., Molecular Biology, Immunology and Medical Microbiology, 197 1, University of Florida
BIOMEDICAL AND ENVIRONMENTAL INFORMATION ANALYSIS SECTION: Human Genome and Toxicology Group

J. K. WILLIAMS (John)
M.S., Science Education, 1977, University of Tennessee
ASSESSMENT TECHNOLOGY SECTION: Measurement Applications and Development Group

D. L. WILSON (David)
M.S., B.A., Chemistry, University of Tennessee
ASSESSMENT TECHNOLOGY SECTION: Measurement Systems Research Group

J. E. WILSON (John)
A.A.S., Computer Information Systems, 1987, Mesa College, Grand Junction, Colorado
ASSESSMENT TECHNOLOGY SECTION: Pollutant Assessments Group, Grand Junction Office

L. A. WILSON (Lee Ann)
M.A., Anthropology, 1989, University of Tennessee
BIOMEDICAL AND ENVIRONMENTAL INFORMATION ANALYSIS SECTION: Chemical Hazard Evaluation and Communication Group

M. J. WILSON (Mary)
M.A., Public Administration-Environmental Affairs (in progress), University of Colorado; B.S., Geology, 1984, Mesa College, Grand Junction, Colorado
ASSESSMENT TECHNOLOGY SECTION: Pollutant Assessments Group, Grand Junction Office

W. WINTON (Bill)
ASSESSMENT TECHNOLOGY SECTION: Measurement Applications and Development Group

K. M. WOYNOWSKIE (Kim)
B.S., Geology, 1976, Mesa College, Grand Junction, Colorado
ASSESSMENT TECHNOLOGY SECTION: Pollutant Assessments Group, Grand Junction Office

J. M. WYRICK (Judy)
BIOMEDICAL AND ENVIRONMENTAL INFORMATION ANALYSIS SECTION: Information Management Technology

H. YOSHIDA (Hiroko)
Ph.D., Physical Chemistry, 1984, New York University
BIOLOGICAL AND RADIATION PHYSICS SECTION: Analytic Dosimetry and Surface Physics Group

R A. YOUNG (Bob)
Ph.D., Physiology, 1983, Southern Illinois University
BIOMEDICAL AND ENVIRONMENTAL INFORMATION ANALYSIS SECTION: Chemical Hazard Evaluation and Communication Group

E. A. ZEIGHAMI (Elaine)
Ph.D., Epidemiology and Biostatistics, 1974, University of Oklahoma
ASSESSMENT TECHNOLOGY SECTION: Measurement Applications and Development Group