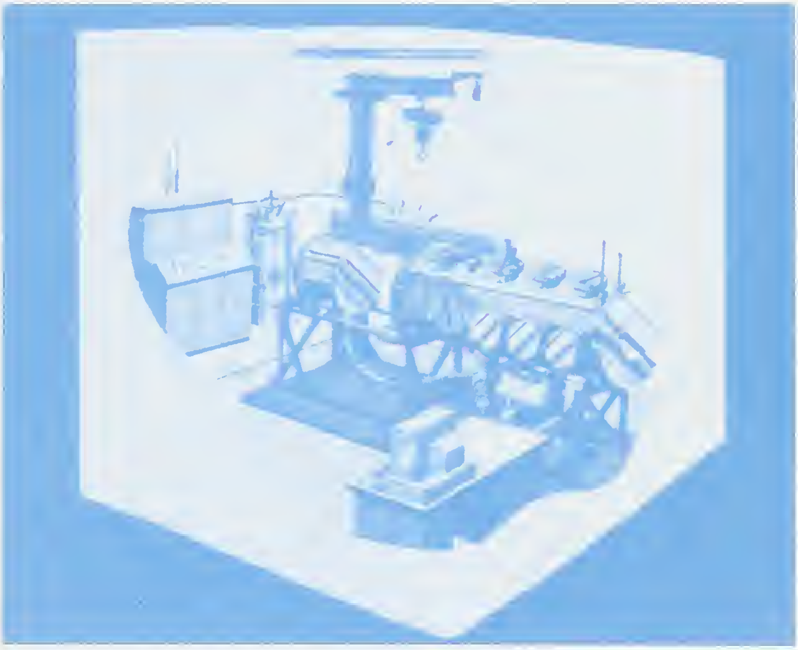
NISTIR 89-4183

Center for Radiation Research



U.S. DEPARTMENT OF COMMERCE
National Institute of Standards and Technology

1989 Technical Activities

The cover illustration shows a facility for the calibration of infrared sources in a low background cryogenic environment which has recently been completed in the Radiometric Physics Division of the Center for Radiation Research. It is capable of measuring the total radiant power from a blackbody with future improvements planned for the measurement of the spectral and angular distributions of the emitted radiation. The new facility is available for calibrations of user devices and for collaborative projects.

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1989 Technical Activities

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ABSTRACT

This report summarizes research projects, measurement method development, calibration and testing, and data evaluation activities that were carried out during Fiscal Year 1989 in the NIST Center for Radiation Research. These activities fall in the areas of radiometric physics, radiation sources and instrumentation, ionizing radiation, and nuclear physics.

Key Words: Ionizing radiation; measurement support; nuclear radiation; radiation instrumentation; radiation measurements; radiation sources; radiometric physics.

INTRODUCTION

This report is a summary of the technical activities of the NIST Center for Radiation Research (CRR) for the period October 1, 1988 to September 30, 1989. The Center is one of four Centers in the National Measurement Laboratory.

The Center for Radiation Research develops and maintains the scientific competences and experimental facilities necessary to provide the Nation with a central basis for uniform physical measurements, measurement methodology, and measurement services in the areas of near infra-red radiation, optical (visible) radiation, ultraviolet radiation, and ionizing radiation (x rays, gamma rays, electrons, neutrons, radioactivity, etc.); provides government, industry, and the academic community with essential calibrations for field radiation measurements needed in such applied areas as nuclear power, lighting, solar measurements, aerospace, defense, color and appearance, health care, radiation processing, advanced laser development, and radiation protection for public safety; carries out research in order to develop improved radiation standards, new radiation measurement technology, and improved understanding of atomic, molecular, and ionizing radiation processes, and to elucidate the interaction of radiation and particles (electrons, neutrons, and ions) with inanimate and biological materials; and participates in collaborative efforts with other NIST centers in the interdisciplinary applications of radiation.

This report summarizes the activities that were carried out by the three divisions and one group that comprised the Center for Radiation Research (CRR) for fiscal year 1989. Specifically the four CRR units included the Radiometric Physics Division, the Radiation Source and Instrumentation Division, the Ionizing Radiation Division, and the Nuclear Physics Group. Each organizational unit tells its own story in its own way. In general there is an introduction followed by a series of short reports on current activities, publications during the year, talks given, committee participation, and professional interactions.

A detailed table of contents has been provided to permit the reader to find those activities of greatest interest. To obtain more information about particular work, the reader should address the individual scientists or their division, c/o Center for Radiation Research, Radiation Physics Building, C229, National Institute of Standards and Technology, Gaithersburg, MD 20899.

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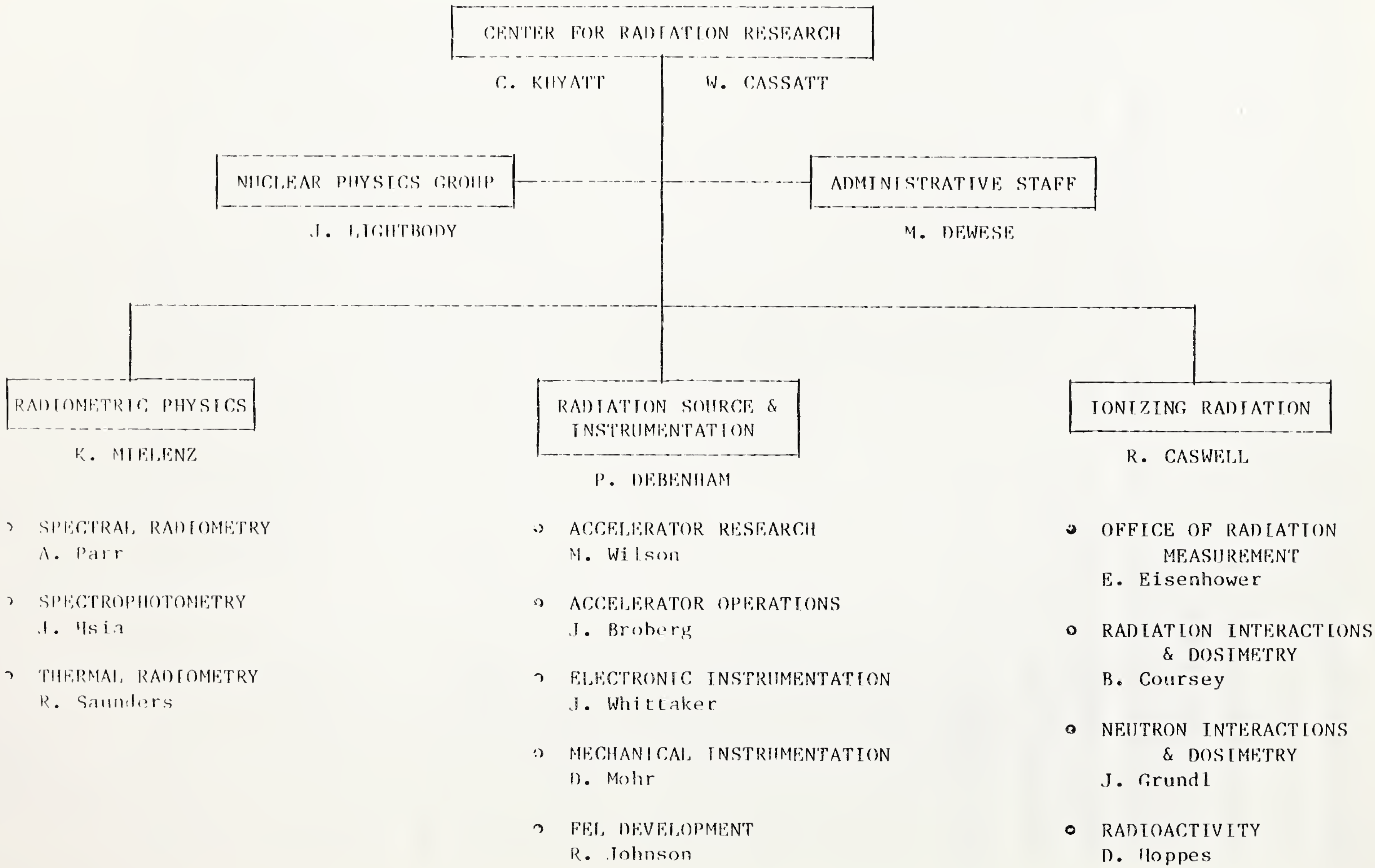
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TECHNICAL ACTIVITIES

Division 534, Radiometric Physics

Introduction

The Radiometric Physics Division (534) of the Center for Radiation Research is the primary unit within NIST for carrying out the core mission of promoting accurate, meaningful, and compatible optical radiation measurements in the uv, visible, and ir spectral regions. The Division:

- develops, improves, and maintains the national standards for radiation thermometry, spectroradiometry, photometry, and spectrophotometry;
- disseminates these standards by providing measurement services to customers requiring calibrations of the highest accuracy;
- conducts fundamental and applied research to develop the scientific basis for future measurement services in optical radiometry.

In pursuing these goals, the Division is actively engaged in collaborative efforts with industry, other government agencies, universities, professional societies, and standards organizations at the national and international levels.

Barry Hillard, Steve Southworth, and Edward Zalewski have left the Division during Fiscal Year 1989. Dr. Raju Datla, formerly with the Atomic and Plasma Radiation Division of NIST, has joined the Division and is now heading the Low-Background Infrared (LBIR) Project. Mr. Thomas Larason, formerly with the Naval Weapons Station at Corona, California, has been hired to work in the Detector Applications Project. Mr. Robert D. Saunders has completed his first year as Leader of the newly formed Thermal Radiometry Group. Drs. Chris Cromer and Jonathan Hardis have assumed leadership of the Photodetector Metrology and Detector Applications Projects, and Dr. Ambler Thompson heads the Biological Radiometry Project.

The Division has again made important progress during the year. For example:

The LBIR calibration chamber has been installed and tested. A calibration users' group has been formed, and routine calibrations of LBIR blackbody sources will commence during FY 1990.

A high-gain, low-noise amplifier and a silicon photodiode have been combined to form a detector capable of measuring optical radiant power over 13 orders of magnitude. This detector/amplifier package can replace photomultiplier tubes in applications where wide dynamic range, stability, and absolute calibration are important.

The Munsell Color Laboratory of the Rochester Institute of Technology has been established as a secondary calibration laboratory providing diffuse reflectance factor calibrations. The Division will continue to provide this laboratory with measurement assurance services.

A new method for measuring infrared specular reflectance was developed. The method employs a grating spectrophotometer with a modified reflectance attachment which reduces the systematic errors of this type of measurement and has commercial potential.

A definitive report on the gold-point measurement was prepared and submitted as an official NIST input to the proposed International Temperature Scale of 1990. The result obtained is 0.25K below the gold-point assignment in the International Practical Temperature Scale of 1968.

. The first round of an international solar uv measurement intercomparison has been completed and the second round is underway. The intercomparison is sponsored by NOAA, and Division 534 is the reference laboratory.

The progress reports for the Spectral Radiometry, Spectrophotometry, and Thermal Radiometry Groups of the Division appear below, followed by an outline of future program directions.

Spectral Radiometry (A. C. Parr, Group Leader)

This group is divided into five projects,

Low Background Infrared Calilbrations (LBIR)
Facilities Development
Detector Applications
Detector Metrology
Advanced Radiometry

The project structure has undergone some changes in the last year with the formation of the LBIR project now that the facility is complete. Additionally, the group has assumed the responsibilty for photometry in the overall group reorganization that transpired last October. There is a sharing of purpose in some cases, e.g., the two detector projects, with a resultant close cooperation by the staff involved. Each of the projects has a project leader who is responsible for the technical direction and technical accomplishments of the project. This person is the first listed in the brackets after the project names and is reported to reflect the organization as it was during later part of the year and as is expected for the next fiscal year.

Low Background Infrared (LBIR) Calibration (Datla, Ebner, Proctor)

The construction of the LBIR calibration facility is complete and the facility is undergoing final tests before the start of user cryogenic blackbody calibrations. The facility is located in the basement of the Physics building at NIST. This location provides optimal isolation from vibration and adequate space for a clean room environment as well as affording clearance for cryogenic lines and connections.

The apparatus is shown in Figure 1. The closed cycle helium refrigerator expansion unit (refrig.) is situated on the left side of the apparatus. The compressor which drives the expansion unit is located in a special equipment room and is not shown. The vacuum shell housing the source and detector is constructed of type 304 stainless steel, 152cm long and 60cm in diameter. The flange connections associated with the chamber use all-metal seals. The absolute cryogenic radiometer (ACR) is shown mounted into the port closest to the blackbody (BB) source to be calibrated. Two additional ports are available for mounting the ACR farther from the source to allow for more intense sources. Initial pump-down of the chamber to approximately $1x10^{-8}$ torr is accomplished with the combination of a 500 l/sec turbopump and a 2000 l/sec cryopump (not shown). A 60 l/sec ion pump is available as a holding pump when the other pumps are offline. When the front flange of the main chamber is rolled back on its linear bearing assemblies, the auxiliary vacuum chamber can be put into position with an overhead crane (not shown) and joined to the flange. With the blackbody mounted to an actively cooled plate cantilevered from the front flange, preconditioning of the blackbody can now be accomplished independent of the main chamber. The helium refrigerator is used to circulate cooled helium gas (15K) through a series of copper lines vacuum brazed to the outside of the inner and outer shields, also made of copper (shown in the cutaway portion of fig. 1). The shields are connected in series and separated by a 2.54 cm gap with the inner shield operating at 20K and the outer one at 80K. The inner surface of the inner shield has a highly absorbing black coating of 3M's ECP 2200 paint to cut down on scattered radiation. The refrigerator has a design cooling capacity of approximately 200 watts at 10K.

The chamber was evacuated and cooled down several times from ambient room conditions and found to be within specifications each time for temperature and pressure.

The ACR was constructed by Cambridge Research and Instrumentation, Inc. (CRI) on contract from NIST for the LBIR facility. It is currently installed and is undergoing final characterization.

The ACR is an electrical substitution radiometer (ESR) operated in the "active cavity" mode where the temperature of the blackened cavity receiver is controlled continuously. The temperature is sensed with germanium resistance thermometers (GRT's) and heat is applied with resistive coils mounted on the receiver. With "non-equivalence" errors being negligible at the 1.0% level, absorbed radiation is equal in magnitude to the decrease in electrical power applied by the controller when the shutter is opened, and the same temperature is maintained at the receiver.

The overall design objective is to provide an accuracy of approximately 1.0% for flux levels as small as 20nW for wavelengths from the visible out to 30 micrometers.

The ACR data acquisition electronics consist of two digital controllers that maintain constant temperatures at the receiver and the receiver mounting plate, which serves as the heat sink. In addition to controlling temperatures, the controllers provide accurate heater power information which is used for the radiometric measurement. The electronics are interfaced to an IBM-AT via an IEEE-488 bus. Each temperature controller uses an AC-bridge to sense the temperature. The output of the AC bridge is demodulated and sent to a microprocessor which applies appropriate electrical power to the heaters mounted on the receiver.

The data collection is performed through a menu-driven computer program. The program provides fully documented data files, data reduction functions, and plotting routines.

The ACR is installed in the LBIR chamber and various tests for acceptance from the contractor have been performed. The non-equivalence errors measured to be less than .06% and the responsivity was within specifications. Further characterization of the ACR in terms of comparison with another absolute detector, QED-200, is in progress.

Facilities Development (Fowler, Tobin)

The Low Background Infrared (LBIR) calibration facility (see Fig. 1, page 18) has been assembled and is currently being tested along with the absolute radiometer produced by Cambridge Research Instrumentation. The facility should be performing the first calibration in the next month or two.

A third water bath black body has been constructed and is being fitted to extend the range from the current 5 to 60°C range to 5 to 80°C. The third bath is being characterized for water temperature uniformity currently and will be then characterized radiometrically. The first two baths have been retro-fitted mechanically to permit 80 deg. operation if desired. A new cone made of gold plated copper was designed and fitted to all three baths to eliminate a corrosion problem under certain conditions.

Various detector packages have been assembled along with their respective ancillary accessories along with many special circuits and instruments in support of the various projects in the division. The re-designed spectral flux lamp alignment fixture is being produced for delivery. A machine vision lab has been established for the purpose of determining the feasibility, methodology and implementation of an augmentation to the Test set for the Army ANVIS/NVIS Night Vision Goggles. Work is now ongoing to determine the best approach to this endeavor.

Detector Applications (Hardis, Houston, Wilkinson, Lusk, Eppeldauer)

High Sensitivity Detectors

The improvements in commercial silicon photodiodes and operational amplifiers over the last several years allow a corresponding increase in the performance of optical radiation measurements. The photodiodes are becoming available with larger shunt resistances and the amplifiers are becoming available with lower noise specifications, which combined give detectors with noise equivalent powers on the order of a fW. We have studied these devices in complete electrical circuit packages and are finding applications for them for contemporary measurement problems. For example, we are working with the Army Night Vision Laboratory, which is concerned with the performance of aviator night vision goggles. Using their specifications, we designed, built, and calibrated high sensitivity detectors which they, in turn, are evaluating for field use for certifying the performance of the goggles.

Photometry

The Division is committed to changing the candela measurement scale from one based on light sources (lamps) to one based on silicon photodiodes. This goal is based on the advent both of better technology and of the difficulty of maintaining the old scale. Our traditional lamp supplier is no longer interested in continuing the service. We have taken action on several fronts to provide for an orderly and accurate changeover. Eppeldauer has worked closely with suppliers of V(lambda) filters, such as NRC (Canada) and PRC Krochmann (Berlin) to develop filters that fit our needs. McSparron has sought alternate sources of lamps and has mapped out a strategy to provide calibration services for our customers. We continue to analyze and to develop a new, automated calibration bench for photometry in order to improve the accuracy and reproducibility of our photometric calibration services.

High Accuracy Cryogenic Radiometer

A Cooperative Agreement is in force between NIST and NPL (our counterpart agency in the UK) that provides for an exchange of technology concerning absolute radiometric (light measurement) standards. NIST is providing expertise in the operation of advanced silicon photodiode detectors and NPL is providing expertise in the operation of cryogenic radiometers. Under the agreement, a new cryogenic radiometer is being built in England which will be delivered to NIST at the conclusion of research specified in the Agreement. A cryogenic radiometer measures optical power by finding the balance with an equal amount of electrical power, under especially favorable conditions. We expect that this device will improve our absolute measurement base by reducing the measurement uncertainty by an order of magnitude. Such an improvement is of high priority to our military and commercial constituencies. During the year, NIST staff (Hardis, Houston, Cromer) paid two extended visits to NPL to finish construction and to commission the radiometer. After the comparison is finished between the NPL and NIST instruments, the radiometer is slated to be shipped back to the U.S. in early FY90.

Photodetector Detector Metrology (Cromer, Thomas, Zalewski, Houston)

Spectral Comparator Facility

The Visible/Near IR Spectral Detector Comparator Facility is now fully automated under computer control. This facility provides detector calibration services for the Nation, and these improvements will provide faster and more accurate calibrations. An new Ultraviolet Spectral Detector Comparator Facility is under construction, and will improve and extend detector calibrations in the UV to 200 nm. Research is continuing toward improving the accuracy of primary and secondary detector standards, and extending the detector calibrations in the infra-red to 2.5 micrometers.

An intercomparison of techniques with an absolute cryogenic radiometer at Cambridge Research and Instruments was carried out. The results indicated that self calibration of silicon diodes could be carried out at a level of perhaps better than .1% accuracy and agree to the estimated accuracy with the absolute cryogenic radiometer. Efforts are underway to improve the capability of the light trapping diode configuration by the use of modern photodiodes with improved spectral response and which are more ammenable for amplifer design.

Advanced Radiometry (Migdall, Parr, Hardis, Cromer)

Heterodyne Optical Density Measurements

Studies of the uncertainties in the heterodyne optical density measurements have been made in the visible region of the spectrum. The origin of what is believed to be the largest systematic effect has been discovered. This effect results from the acousto-optic frequency shifter producing a unwanted second frequency shifted beam superimposed on the primary frequency shifted beam. Work is currently underway to rebuild the apparatus using two frequency shifters operated at different frequencies. This arrangement has been shown to reduce the undesired effect and thus should reduce the ultimate system uncertainties. An infrared heterodyne experiment has been setup to allow optical density measurements using heterodyne detection to be extended to the 10.6 micron wavelength region. Heterodyne signals have been observed with the system and first measurements are under way.

In conjunction with the heterodyne work, a system has been setup to determine the effect of light power density on detector linearity. A variety of detectors are being tested to determine where nonlinearity becomes important as the power density increases. These tests are important as measurements of light levels using lasers as sources frequently have moderate total power but high power density.

ARPES

The Angularly Resolved Photoelectron Spectroscopy (ARPES) experiment has been stationed at the Daresbury (UK) Synchrotron Light Source. This collaboration combines the high resolution ultraviolet beamline available at Daresbury with the NIST high resolution, position sensitive electron spectrometers. During the year, experiments were conducted on the photoionization of N_2. This study was undertaken to assist in the identification of series of autoionizing states and to encourage further theoretical work on the interaction between electronic and vibrational motion in the region of autoionizing resonances.

Advanced Light Source Development

A new type of light source is being developed utilizing laser induced fluorescence in a metastable atomic beam. The metastable atomic beam is produced by charge exchange of Kr ions with Rb atoms. This source could serve as a transfer standard between the UV and Visible/Near IR spectral regions. We are also investigating the possibility of using laser excited Rydberg atoms in high-sensitivity, Infra-Red radiometry.

Spectrophotometry (J. J. Hsia, Group Leader)

The Spectrophotometry Group is responsible for the establishment and dissemination of primary measurement scales for transmission and reflection spectrophotometry, densitometry, and spectrofluorimetry, and for the development of methods for the radiometric characterization of optical components and materials. For these purposes, the Group:

- develops and maintains reference instrumentation for performing spectrophotometric measurements of the highest accuracy;
- develops methodologies for highly accurate spectrophotometric measurements;
- publishes critically evaluated reference data on intrinsic standards for spectrophotometry;
- provides transfer standards, measurement quality assurance programs, and special calibrations as needed to support the national measurement system for spectrophotometry;
- provides spectrophotometric measurements to support other research being conducted by the Radiometric Physics Division.

The FY89 accomplishments of the Group in three key areas are presented below.

UV-VIS-NIR-IR Spectrometry (Eckerle, Barnes, Fink, T.M. Wang, Hsia)

Measurement Services and Standard Reference Materials

In FY89 calibration services for industrial laboratories totaling $37K were performed. Barnes provided special calibration services for spectral transmittance, specular reflectance, diffuse reflectance and 45°/0° reflectance factor. Eckerle performed three major high accuracy calibrations for other NIST staff. One calibration was the measurement of four filters over the visible spectrum which are to be used in red-blue photometry. Another measurement was the calibration of three $V(\lambda)$ filters to be used in detector based photometry. Visible transmittance measurement and relative infrared specular reflectance measurements for other NIST staff were also performed by Eckerle. Barnes provided 26 support measurements for NIST staff. Barnes provided NASA with calibrations of 6°/hemispherical reflectance measurements and BRDF measurements totaling $30K. Barnes and Fink screened a number of potential standard reference materials. Screening consisted of checking for defects, flatness, and performing reflectance measurements at one wavelength. The following materials have been screened: fifty gold mirrors (SRM 2011), ninety-four second surface aluminum mirrors(SRM 2023a), fifty-eight black glasses (SRM 2026), twenty-five white diffusers (SRM 2044), and twenty-five black diffusers (SRM 2041). Barnes has upgraded the control and data acquisition system of the commercial spectrophotometer used for transfer measurements. The hardware and software have been installed and are operational. Some user software remains to be written for data analysis.

Transmittance International Intercomparison

A manuscript has been submitted to Metrologia by Eckerle (USA), Sutter (FRG), Freeman (UK), Andor (H), and Fillinger (H).

Secondary Standardization Laboratory

Establishment of RIT Munsell Color Lab as a secondary lab providing 45/0 reflectance calibrations was reported in the Project: "Materials for Instrument Calibration" report which is contained in the Inter-Society Color Council (ISCC) July/August 1989 News. NIST continues to provide RIT with Measurement Assurance Program (MAP) measurements as well as methodologies on how to prepare pressed PTFE samples.

Transmission Densitometry

Fink has calibrated 150 x-ray step tablets (SRM 1001) and 150 photographic step tablets (SRM 1008) for use in the calibration of transmission densitometers in the transmission density range 0 to 4. Fink did several special tests to calibrate/re-calibrate step tablets, film, and filters for transmission density or absolute visual reflection density for industrial laboratories. Fink intercompared with Eastman Kodak Company transmission densities for photographic step tablets and X-ray step tablets according to the new ISO method using an opal glass diffuser.

Infrared Spectrometry

T.M. Wang, Eckerle, and Hsia have developed a novel method of measuring absolute specular (regular) reflectance using a special reflectance attachment in a grating spectrophotometer. Accurate alignment of this attachment is achieved using an autocollimator telescope and two auxiliary mirrors. This technique reduces one of the largest systematic errors in this type of absolute measurement. This instrument operates over the wavelength range of 2 to 22 μm, and has an average angle of incidence of 12.8 degrees. Measurements on an electroplated gold mirror were made with a total uncertainty less than 0.0025 reflectance units. A manuscript covering this activity has been prepared. L. Wang and Eckerle have demonstrated the feasibility of making relative diffuse reflectance and regular transmittance measurements using a Fourier transform spectrometer. High resolution (0.03 cm^{-1}) wavelength calibration of this same instrument has been achieved. Liu, T.M. Wang, L. Wang, Ge, and Eckerle have compared the transmittance of a germanium filter at 10.6 μm using a grating spectrophotometer, two Fourier transform spectrometers, and a laser based instrument. The agreement was within 0.003 transmittance units.

Hsia and Eckerle attended the CCG meeting in Boulder, Colorado to discuss the needs of military standardization laboratories. Hsia and Eckerle also visited NRL to discuss collaboration and standardization needs of the Navy for diffuse reflectance in the 2-20 μm region.

Bioradiometry (Thompson, Liu, Eckerle, Branch)

Thompson and Eckerle completed the measurements and the uncertainty analysis for four fluorescent standards (SRM 1931). The certificate for SRM 1931 was written and is currently being reviewed. A NIST Special Publication describing the preparation and calibration of SRM 1931 is in preparation.

Thompson and Liu in collaboration with Blackburn and Kaufman of Division 420 have made lead-doped glass samples (approximately 70) and designed a sample holder for the measurement of the UV fluorescence of these materials. These samples are currently being measured and the suitability of these samples is being assessed for their eventual use as ultraviolet emission spectra SRMs. The reference spectrofluorimeter is currently being modified and recalibrated for the certification of these materials over the wavelength range from 285-500 nm.

Thompson and Branch, a summer student, are undertaking the reautomation of the reference spectrofluorimeter from the Cromemco based control to a PC-Family stand alone data acquisition system. In addition, a high throughput monochromator system is being assembled for the measurement and calibration of low-level emission sources and measurement of luminescence quantum yields.

Thompson has consulted with USDA and EPA on measurement needs for their research programs to monitor and assess the effects of enhanced solar UV which could result from the destruction of the atmospheric ozone layer. Currently Saunders, Thompson and Chen are working with the EPA on the acquisition and radiometric characterization of two high-accuracy solar UV spectroradiometers which will be the measurement basis for this program.

Bidirectional Scattering Distribution Function (BSDF) (Hsia, Asmail, Roop, L. Wang)

Final designs for the BSDF instrument have been completed by Asmail. Bids for the mechanical bi-goniometric subsystem are currently being solicited for contractual procurement with an expected delivery date of March 1990. Fink designed, fabricated, and refined sample holders and press assemblies for PTFE reflectance measurements. These holders have two, five, and fourteen inch diameters and will be used by NIST, NASA, and the Air Force. Asmail visited Optics MODIL at Oak Ridge National Laboratory, NRL, and NASA Goddard Space Flight Center to explore the possibility of collaboration. Further assessments of the current needs in the BRDF scatter community were made by Hsia and Mielenz in their visit to Wright Paterson Air Force Base and additionally by Asmail and Barnes at the annual SPIE conference. Three papers were presented at the SPIE conference on Scatter from Optical Surfaces. Barnes presented a talk on pulverizing and pressing PTFE powders into an intrinsic diffuse reflectance standard. Asmail presented two papers. These were on the reconciliation of surface scatter data and the cleanliness requirements for air in a BRDF facility.

A first draft of a tutorial on the measurement process for BRDF has been completed by Asmail. In this tutorial all critical parameters which are pertinent for the accurate measurement and interpretation of BRDF data are discussed in detail. A bibliography of related papers is included.

Roop completed a preliminary research report reviewing possible techniques which may be pursued in order to arrive at a reliable infrared diffuse standard. In this report, she indicated those which seem to have the potential for success such as surface acoustic waves or uniform deposition of silicon carbide spheres. A phosphor-coated glass hemisphere is being developed as a qualitative diagnostic detector to evaluate the various techniques that will be examined for producing diffuse scattering surfaces. Roop has also completed the interferometer of the 10.6 μm heterodyne transmittance instrument. The detector and noise properties of the system are being characterized. Also, to help characterize the system, heterodyne filter transmittance measurements are being compared to traditional measurements.

Eckerle has prepared and calibrated twenty-five optical quality neutral density filters. These filter glasses range in transmittance (optical) density from 2 to 5. These filters are to be used in low BRDF measurements. The measurements were performed at 441.6, 488, 532, and 632.8 nm using the high accuracy reference spectrophotometer.

Asmail and Hsia are members of the ASTM subcommittee E12.09 on scattering and they have provided extensive consultation in regard to the technical content of the standard for angle-resolved surface scatter measurements. A draft of a standard test method for BRDF scattering measurements is in the process of subcommittee balloting.

Thermal Radiometry Group (R.D. Saunders, Group Leader)

The group is responsible for the Radiation Temperature Scale, Thermal Imaging Research, and the Facility for Automatic Spectroradiometric Calibrations (FASCAL). This is a new group that combines the old Radiometric Measurement Services Group (except for Photometry) and the old Thermal Radiometry Project. This reorganization brings together the basic research, applied research, and dissemination activities associated with the National Scales of Radiation Temperature, Spectral Radiance, and Spectral Irradiance. Group activities cover a broad range and include experiments to increase the use of absolute detectors to improve radiometric scales, intercomparisons (domestic and international), consultation, internal support programs, measurement assurance programs, measurement support for new technologies, and research into new radiometric areas (ir pyrometry, imaging, low level radiometry ...)

Radiation Temperature (Walker, Zhu, Saunders)

The International Temperature Scale will be redefined in 1990. One of the anticipated changes involves lowering the upper end of the resistance temperature scale to the silver freezing point from the previously defined gold freezing point. This change will give radiation thermometry the responsibility for the temperature range above the silver point. To prepare for these changes, the group is conducting three experiments: 1. a redetermination of the thermodynamic temperature of freezing gold based on absolute detectors, 2. a comparison of gold and silver point blackbodies to determine the temperature interval between these two fixed points, and 3. a comparison of the NIST resistance temperature scale with the optical radiation temperature scale maintained by this group.

The experiment to determine the temperature of freezing gold based on absolute detectors has been described in previous reports. During the past year a number of refinements were introduced. The new high sensitivity detector amplifier package was tested and proved to be stable. This detector will allow the use of smaller lasers and allows new approaches to solving the non-uniformity problems of the present quartz-windowed detectors. As a first attempt to solve this non-uniformity problem, an integrating sphere detector package was built and tested. This experiment showed that the silicon detector-sphere' uniformity was worse than the silicon detector alone. As a alternative, we are now investigating the use of trapped silicon detectors, built by the photodetector project, as possible detectors. QED 200 detectors were used to calibrate the measuring detector. A study of integrating sphere-sources was undertaken because it was found that construction of the spheres influenced the radiance uniformity at the exit port more than originally expected. Alignment and distance measuring techniques were investigated which led to new procedures to perform these functions. We expect to use the ideas developed this year to extend these methods to other temperatures in the future.

The experiment to intercompare the NIST resistance temperature scale with the optical radiation temperature scale has been designed and preliminary results obtained. The work will be concluded in FY90.

The experiment to directly compare the freezing points of gold and silver is underway. Although this experiment will not affect our radiation temperature scale, it is of interest to validate our procedures for determining radiation temperatures. Preliminary measurements are in process and final measurements are expected early in FY90.

Intercomparisons (Walker, Jackson, Gibson)

The Consultative Committee on Photometry and Radiometry (CCPR) spectral irradiance intercomparison involving 13 national laboratories is now underway. NIST is serving as the central laboratory. The National Physical Laboratory (England) shipped three lamps to each participating laboratory in the spring of 1989. The lamps are being measured and are due to be shipped to NIST in August 1989. NIST will realize its spectral irradiance scale, measure all of the test lamps, and then reconfirm its scale again. This work is scheduled for September 1989 through January 1990. The participating laboratories will then remeasure their lamps and NIST will collect and analyze the data. A report on the results will be issued for consideration at the next CCPR meeting in September 1990.

An international intercomparison of space borne UV measuring spectroradiometers in the spectral region 200-400nm was organized among members of the uv solar monitoring community. Although this is independent intercomparison, it is being coordinated with the CCPR spectral intercomparison described above. The goal of this intercomparison is to put the space uv monitoring community on a common base so that results obtained can be directly compared. A complete workstation containing NIST calibrated uv light sources (4 FELs and 4 D_2

standards) was shipped to the laboratories. Each laboratory will have the workstation twice and will use it to calibrate their instruments. The Radiometric Physics Division designed and constructed the workstation and calibrated it in the fall of 1988. It was then shipped to several labs, who made measurements, and then returned it for recalibration in June 1989. The second round of measurements is now being made by the participating labs. The participants in the intercomparison include the University of Colorado (SOLSTICE--Solar Stellar Irradiance Comparison Experiment), the Naval Research Laboratory (SUSIM--Solar UV Spectral Irradiance Monitor), NASA (SSBUV--Shuttle Solar Backscatter UV Radiometer), a joint Belgian-French group (SOLSPEC--Solar Spectrometer), and the Technische Studien Gmbh of West Germany (ASSI--Airglow Solar Spectrometer Instrument). These experiments are of immediate, critical importance to both the scientific community (atmospheric physics and weather prediction models) and the general public (ozone monitoring and greenhouse effects).

Thermal imaging project (Bruening, Oroshnik, Saunders)

The thermal imaging facility was upgraded with the installation of better environmental control hardware for both sources and radiometers. The facility is now fully operational for basic calibrations and as a first effort, a blackbody simulator has been calibrated. The project staff is working on the development of a new radiometer to replace the aging (>20 years) Barnes Radiometer. This work will continue in FY90 and is important to replace the borrowed Barnes Radiometer. A Pt-Si camera was delivered in September 1989, and is being setup. Staff visits were made to RCA where the camera was developed to gain familiarity with its operation.

Characterization of the NIST designed water-bath blackbody sources showed that major changes were required to meet the original design goals. The modifications included the replacing of the aluminum cavities with gold coated, oxygen-free copper cavities and the redesign of the nozzle jet to achieve better water flow.

A second optical bench with associated experimental control and data analysis equipment has beendesigned and built. It is being used for the characterization of commercial ir radiometers. The information developed in this work will help in the design of the ir radiometer described above. A variable temperature, gas controlled heat-pipe blackbody was purchases this year. This will allow measurements in the temperature range 350 °C-1100 °C. Future plans call for the addition of spectral capability to the facility so that the emmissivity of low-temperature blackbodies can be studied.

Ultraviolet Spectroradiometry (Bruening, Thompson, Chen, guest worker)

Performance requirements were developed for a state-of-the-art spectroradiometer to cover the spectral region (250-400 nm) of atmospheric ozone absorption. Specifications were developed with the assistance of experts from the various fields needing these strict requirements. Bids from commercial vendors are being solicited. The instrument will be used by the Environmental Protection Agency to assess the performance of field instruments monitoring ground level ultraviolet radiation. Out of necessity the calibration instrument must perform reliably in various outdoor climatic conditions. Accurate measurements made with this instrument, when compared with simultaneous measurements with a field instrument, will allow the quality of the field instrument to be determined. The results of a series of such measurements with different field instruments will establish a consistent base line for ozone monitoring experiments.

The construction of a facility to characterize the uv spectroradiometer is underway. The NIST uv monochromator used in 1980 for ozone measurements is being retrofitted with new electronics and detectors. The 1980 spectroradiometer is being upgraded with an IBM compatible computer which will enhance instrument control and allow for faster data reduction.

Aviator Night Vision Imaging System (ANVIS) (Gibson, Saunders)

This project has as its principal activity the development of a low light level radiance facility in which to measure night vision calibration sources. Stable, highly uniform large area low light level radiance sources are being developed in collaboration with scientists in industry. These sources will perform at the 10^{-5} femtolumens (fL) to 2 fL luminance levels. When operational this new measurement service and facility will meet the existing need for calibrations of low light level radiance sources.

FASCAL Absolute Detector (FAD) (Gibson)

Goals of this project are to shorten the spectral irradiance scale realization chain and to intercompare the blackbody-based and detector-based phtotmetric scales. Presently the NIST photometric scale is derived from the NIST scale of spectral irradiance. An effort is underway to shift the NIST photometric scale to a detector base. A photopically corrected detector designed by Eppeldauer (guest scientist) has been setup in FASCAL and preliminary measurements have been taken. This photometer will routinely monitor the NIST, spectral irradiance primary working standards (PWS) to determine their stability and need for re-calibration. During the spectral irradiance scale realization.

the photometer will monitor the stability of the integrating sphere source (ISS) which is used to transfer the scale to the PWS. The FAD will also be used for intercomparisons between FASCAL and the photometric facilities and for independent checks on the blackbody-base spectral irradiance scale.

FASCAL (Gibson, Jackson)

FASCAL staff performed about 60 radiometric calibrations and special tests this year. FASCAL had been slated for the CCPR spectral irradiance intercomparison this year but due to the unavailability of lamps from GEC, the intercomparison was delayed until FY90. Special calibration work performed on FASCAL included a luminous intensity scale realization, measurements of the spectral irradiance of high pressure sodium lamps, and the solar monitoring intercomparison.

A spectral radiance intercomparison was initiated with the USSR late in this year. The work will include the exchange of scientific staff and the comparison of radiance sources in the 200-2500 nm spectral region. The work will be completed in FY90.

Steps were taken to upgrade the FASCAL system such as replacing the old MIDAS components (analog scanners, stepping motor controllers, etc.) with GPIB controlled devices. It is hoped that FASCAL will be completely updated in FY90. In the past, upgrades have been difficult to schedule because of the work load.

Pyrometry (Waters, Hunter)

The pyrometry facility has been completely renovated this year to provide an enhanced capability for the future. As a result, the time needed to perform a calibration has been significantly shortened and hence more calibration can be perfromed on the facility. System upgrades included the installation of programmable power supplies for operrating the lamps and computer control for all of the measurements. Silicon cell detectors were investigated to determine their suitability as pyrometric detectors. Promising initial results were obtained. In FY90 the facility will be expanded to meet the increasing technology demands for higher accuracy and to calibrate new pyrometers based on silicon and other near ir detectors.

In FY89, the FAA-sponsored, joint effort with the Center for Fire Research to develop standards for flammability testing was completed.

In FY90 this work will be incorporated in a routine calibration service.

Future Directions

During Fiscal Year 1989, the Council for Optical Radiation Measurements (CORM) finalized its Fifth Report on "Pressing Problems and Projected National Needs in Optical Radiation Measurements." CORM has over 350 members representing the principal U.S. industrial, academic, and government institutions involved in radiometry. The Fifth CORM Report was established by soliciting information from these members regarding their measurement problems and needs, followed by an evaluation and prioritization the responses by the CORM Board of Directors. The following needs are among the highest priorities listed in the Report:

- Lower measurement uncertainties of NIST calibrations of spectral radiance, spectral irradiance, luminous intensity and color temperature;
- More stable standard sources for spectral radiance and irradiance;
- Extended wavelength range for spectral reflectance measurements and extended dynamic range of regular transmittance measurements.

It is anticipated that the fulfilment of these needs will be a major program goal for the Division in the next several years.

LBIR FACILITY

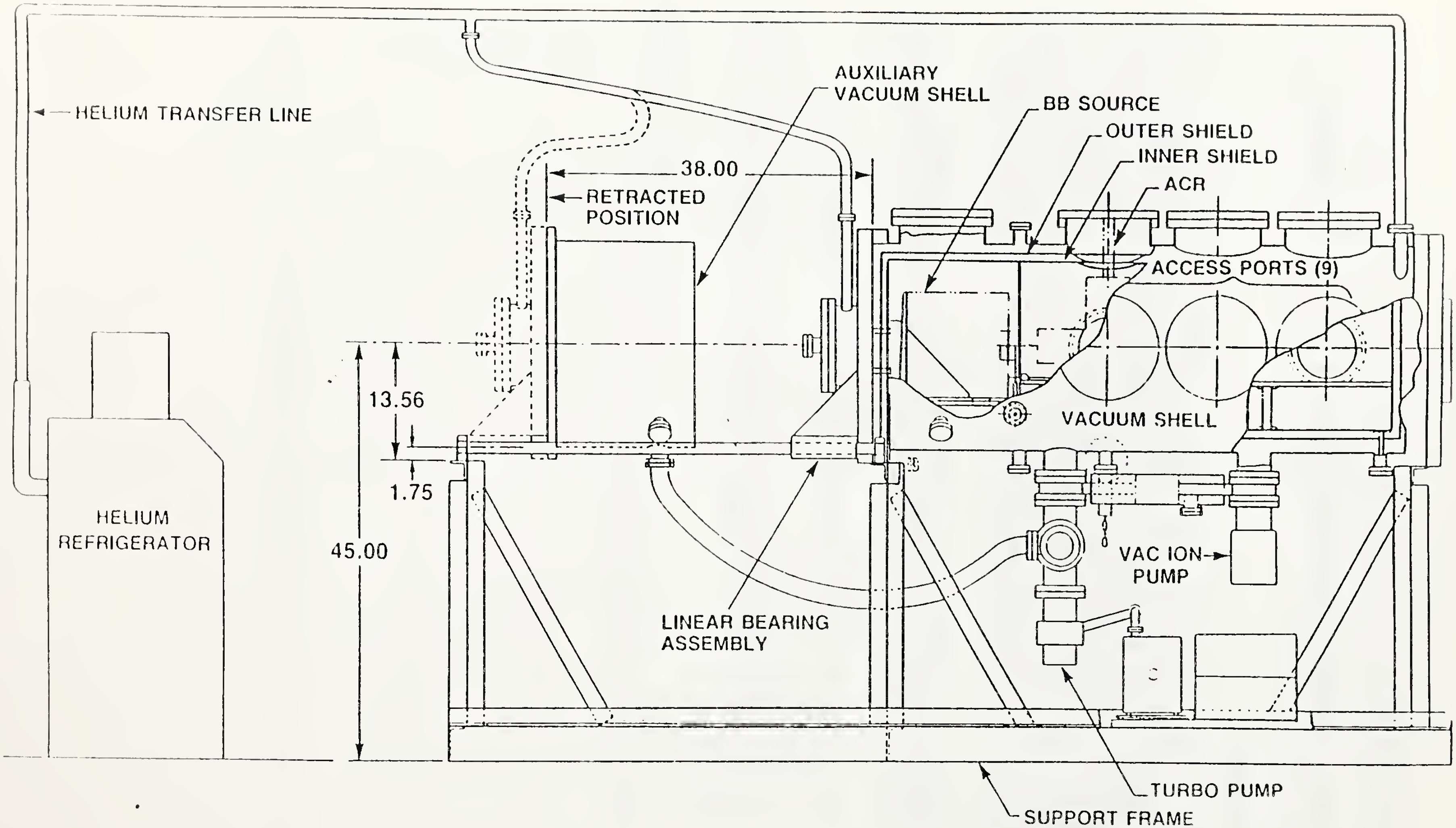

Fig. 1

SPONSORED WORKSHOPS, CONFERENCES, AND SYMPOSIA

Division 534, Radiometric Physics

S.C. Ebner organized the Workshop on Low Background Infrared Calibrations, NIST, Gaithersburg, MD, November 15, 1988.

J.E. Hardis attended the Workshop on New Directions in Environmental Tritium Analysis, NIST, Gaithersburg, MD, November 8-9, 1988.

J.E. Hardis attended the Gordon Conference on Atomic Physics, Wolfeboro, N.H., July 3-7, 1989.

A.L. Migdall orgainized the Workshop on New Directions in Environmental Tritium Analysis, NIST, Gaithersburg, MD, November 8-9, 1988.

A.L. Migdall attended the Gordon Conference on Atomic Physics, Wolfeboro, N.H., July 3-7, 1989.

A.L. Migdall attended the Workshop on Low Background Infrared Calibrations, NIST, Gaithersburg, MD, November 15, 1988.

A.C. Parr organized the Workshop on Low Background Infrared Calibrations, NIST, Gaithersburg, MD, November 15, 1988.

A.C. Parr attended the LBIR users advisory Board, Logan, UT, June 1989.

A.C. Parr attended the SDIO Project 5 review, San Diego, CA, February, 1989.

INVITED TALKS

Division 534, Radiometric Physics

Eckerle, K. L., "Uncertainties for Some NIST Spectrophotometric Standard Reference Materials," ISCC Annual Meeting, Chicago, IL, 1989.

Datla, R.U., "Neon-like 3s-3p X-ray laser transitions studied in a theta-pinch plasma," Atomic and Plasma Radiation Division Seminar, NIST, Gaithersburg, MD, June 1989.

Datla, R.U., "Update on the LBIR Calibration Facility at NIST," Arnold Air Force Station, TN, June 1989.

Houston, J.M., "Photodetector Spectral Response Based on 100% Quantum Efficient Detector," Proceedings of the SPIE Technical Symposium on Aerospace Sensing, Orlando, FL, March 27-31, 1989.

Migdall, A. L., "Using Heterodyne Detection for Optical Radiometry," National Capitol Section of American Optical Society, NIST, Gaithersburg, MD, March 21, 1989.

Migdall, A. L., "Optical Radiometry Using Heterodyne Detection," Precision Measurements Association, San Diego, CA, March 22, 1989.

Migdall, A. L., "Optical Radiometry Using Heterodyne Detection," Navy Aviation Depot Operation Center, San Diego, CA, March 23, 1989.

Migdall, A. L., "Optical Heterodyne Densitometry," Workshop on Low Background Infrared Calibrations, NIST, Gaithersburg, MD, November 15, 1988.

Roop, B., "Photochemistry of Small Molecules on Metal Surfaces," American Vacuum Society Meeting, 1989.

Saunders, R.D., "The Impact of Radiometric Physics Division on the Navy Future Needs," Navy CCG Meeting at Corona, CA, April 1989.

Saunders, R.D., "Determination of the Freezing Point of Gold Using Absolute Detectors," CORM Meeting at NIST, May 1989.

Thompson, A., Eckerle, K. L., "Standard Reference Materials for fluorescence," 19th International Congress on Photobiology, Jerusalem, Isreal, 1988.

Thompson, A., "Bioradiometry," Instituto de Otica, Florence, Italy 1988.

Thompson, A., "NIST Irradiance Standards and Solar UV-B Terrestial Measurement Accuracy," Dept. of Agriculture Workshop on "Effect of Ozone Depletion on Crop Yield," Florida, 1989.

Thompson, A., "Accuracy Assessment of Terrestial Solar Spectral Irradiance measurements in the Ozone Cut-off Region," Symposium on Stratospheric Ozone Depletion and its Biological Consequences - American Society for Photobiology Annual Meeting, Boston, MA, July 4, 1989.

Thompson, A., Eckerle, K. L., "Standards for Corrected Fluorescense Spectra" SPIE Symposium on Lasers and Optics Conference 1054, Los Angeles, CA, January 16, 1989.

PUBLICATIONS

Division 534, Radiometric Physics

Cooper, J.W., Clark, C.W., Cromer, C.L., Lucatorto, T.B., "Marked differences in the 3p-photoabsorption between the Cr and Mn+ isoelectronic pair: reasons for the unique structue observed in Cr," Phys. Rev. A, 39, 6074 (1989).

Datla, R.U., Roberts, J.R., Woodward, N., Lippman, S., and Rowan, W.L., "Line identifications and radiative branching ratios of magnetic dipole lines in the Si-like Ni, Cu, Zn, Ge, and Se," Phys. Rev. A. (accepted for publication).

Ebner, S.C., Parr, A.C., Hoyt, C.C., "Update on the Low Background IR Calibration Facility at NIST," Proceedings of SPIE Conference, Orlando, FL, March 30-31, 1989.

Elton, R.C., Datla, R.U., Roberts, J.R., and Bhatia, A., "Neonlike Ar and Cl 3p-3s emission from a O-pinch plasma," Phys. Rev. Rapid Communications (accepted for publication).

Elton, R.C., Datla, R.U., Roberts, J.R., and Bhatia, A., "The Measurement of Vacuum-uv Line Intensities for Neon-Like Ions Generate in a O-pinch Device," Phys. Csr. Proceedings of VUV-9 Conference (1989).

Ferrett, T. A., Parr, A. C., Southworth, S. H., Hardis, J. E., and Dehmer, J. L., "Vibrationally-Resolved Photoionization Studies of the 7s Level in N_2O", Chem Phys. 90(3), 1551 (1989).

Hardis, J.E., Peifer, W.R., Cromer, C.L., Migdall A.L., Parr, A.C., Using "Resonant" Charge Exchange to Detect Traces of Noble Gas, Proceedings of the Fourth International Symposium on Resonance Ionization Spectroscopy and its Applications (RIS 88), Inst. Phys. Conf. ser. No. 94; Section 5, 237 (1989).

He, M., Bruening, R.J., "High Pressure Sodium discharge Lamp Characterization For Use As Standards of Geometrically Total Luminous Flux," NBS Technical Note 594-14, August, 1988.

Hunter, E.P.L., Desrosiers, M.F., Simic, M.G., "The effect of oxygen, antioxidants and superoxide on formation of tyrosine dimers," Free Radicals in Biology and Medicine. 6(6), 501, 1989.

Houston, J.M., and Zalewski, E.F., "Photodetector Spectral Response Based on 100% Quantum Efficient Detectors," Proceedings of SPIE Technical Symposium on Aerospace Sensing, Orlando, March 1989.

Lean, J.L., Kostkowski, H.J., Saunders, R.D., Hughey, L.M., "Comparision of the NBS Surf and Argon Mini-Arc Irradiance Standards at Ultraviolet Wavelengths," Applied Optics vol. 28, no. 15, August 1, 1989.

Lloyd, K.G., Roop, B., Campion, A., and White, J.M., "Surface Photochemistry: Preparation of Ethyl Fragments on Pt(111)," Surface Sci., 214, 227 (1989)

Migdall, A.L., "A Search for Optical Molasses in a Vapor Cell: General Analysis and Experimental Attempt," (accepted by Journal of Research of NIST).

Roop, B., Blass, P.M., Liu, Z.M., and White, J.M., "Interactions of CO and K: Negligible CO adsorption of K/Ag(111)," J. Chem. Phys., 90, 608 (1989).

Roop, B., Zhou, Y., Liu, Z.M., Henderson, M.A., Lloyd, K.G., Campion, A., and White, J.M., "Photochemistry of Small Molecules on Metal Surfaces," J. Vac. Sci. Tech., A7, 2121 (1989).

Saunders, R.D., Kostkowski, H.J., Roughened Quartz Surfaces and Teflon as Small-Angle Diffusers and Depolarizers Between 300 and 400 nm," Applied Optics vol. 28, no. 15, August 1, 1989.

Thomas, D.B., Zalewski, E.F., "A Radiometer for Precision Coherent Radiation Measurements," SPIE Tech. Sym. on Aerospace Sensing, Orlando, FL, March 1989.

Thompson, A., Biggley, W.H., Seliger, H.H., "Luciferase Reverse Micellar Bioluminescence: Kinetics and Emission Spectra" in Oxygen Radicals in Biology and Medicine, Ed. by Simic, M.G., Taylor K.A., Ward, J.E., vonSonntag, C., Plenum Publishing Corp., New York (1989).

PUBLICATIONS IN PREPARATION

Division 534, Radiometric Physics

Andor, G. "Temperature Dependence of High Accuracy-Photometer Heads," (to be published in Applied Optics Letters).

Asmail, C., "The Measurement of the Bidirectional Reflectance Distribution Function (BRDF) of Optical Surfaces: A Tutorial," (in preparation)

Asmail, C., "Cleanliness Requirements for the Air in a BRDF Facility" (to be published in the Proceedings of the SPIE, Vol., 1165, August 1989).

Asmail, C., and Hsia, J.J., "Reconciliation of Surface Scatter Data Obtained with Solar Simulaotrs and Lasers," (To be published in the Proceedings of SPIE, Vol. 1165, August 1989).

Barnes, P.Y., Hsia, J.J., "45°/0° Bidirectional Reflectance Distrubution Function Standard Development" (to be published in the Proceedings of SPIE, Vol., 1165, August 1989).

Cooper, J.W., Clark, C.W., Cromer, C.L., Lucatorto, T.B., Sonntag, B.F., Kennedy, E.T., Costello, J.T., Junwen, C., and Tomkins, F.S., "Autoionizing resonances in Mn, Mn+, and Cr 3p subshell absorption," (to be submitted to Phys. Rev. Lett.)

Cromer, C.L., "Double-resonance optogalvanic spectroscopy in a low pressure discharge of neon," (to be submitted to Appl. Opt.)

Cromer, C.L., "Isolated core excitation and the Fano q," (to be submitted to Phys. Rev. A.).
Eckerle, K.L., Sutter, E., Freeman, G.H.C., Andor, G., Fillinger, L., "International Intercomparison of Regular Transmittance Scales" (to be published in Metrologia).

Datla, R.U., Roberts, J.R., Bhatia, A.K., "Magnetic dipole line intensity measurements for Si-like ions in the TEXT tokamak and comparison to theoretical predictions," (in preparation).

Datla, R.U., Eshhar, S., Roberts, J.R., "Excited Level Populations in CIV in a recombining O-pinch plasma," (in preparation).

Eppeldauer, G., Novak, L. "Linear HgCdTe Radiometer," (to be published in SPIE Procedings, Conference 1110, March 27-31, 1989)

Gibson, C.E., Walker, J.H., "The Faint Object Spectrograph Calibration." (in preparation).

Eppeldauer, G., "13 Decade Photocurrent Measurement of Large Surface Silicon Photodiodes at Room Temperature," (in preparation).

Hillard, B.G., "Radiation Thermometry at NIST: An Update of Services and Research Activities" (to be published Proceedings of NASA Workshop on Noncontact Temperature Measurement; Pasadena, CA; January 17-19, 1989)

Houston, J.M., Zalewski, E.F., "Photodetector Spectral Response Based on 100% Quantum Efficient Detectors" (to be published SPIE Conference Proceedings 1109, Orlando, FL, March 26-31, 1989).

Hu, R., "The Importance of Alignment in Goniophotometry," (to be published as a NIST Technical Note).

Liu, Z.M., Costello, S.A., Roop, B., Ahkter, S., and White, J.M., "Surface Photochemistry: Methyl Bromide on Pt(111)," (to be published in J. Phys. Chem.)

Mielenz, K.D., Saunders, R.D., Shumaker, J.B., "Spectroradiometric Determination of the Freezing Temperature of Gold" (to be published in Metrologia)

Migdall, A.L., Roop, B., Zheng, Y.C., Hardis, J.E.,"A Study of the Use of Heterodyne Detection to Measure Optical Transmission over a Wide Range," (in preparation).

Migdall, A.L., Giest, J., Baltes, H., "Failure to Detect the Second Indirect Gap in Silicon Absorption Coefficient Data," (in WERB).

Parr, A.C., "Update on the Low Background IR Calibration Facility at the National Institute of Standards and Technology," (to be published in the SPIE Conference, Orlando, FL.)

Parr, A.C., Hardis, J.E., Dehmer, J.L., "Automation and Calibration of Instrumentation for Gas phase Angle Resolved Photoelectron Spectrmetry" (to be published ...)

Roop, B., Lloyd, K.L., Campion, A., White, J.M., "Surface Photochemistry of Coadsorbed Methyl Halides," (to be published in J. Chem. Phys.)

Southworth, S.H., Ferrett, T.A., Hardis, J.E., Parr, A.C., Dehmer, J.L., "ARPES Study of Resonant Photoionization of the $2\pi^{-1}$ Channel of NO," presented at the Ninth International Conf. on Vacuum Ultraviolet Radiation Physics, Univ. of Hawaii, July 19, 1989.

Thomas, D.B., Zalewski, E.F., "Preliminary Report on the CIE detector Response Intercomparison," (in preparation).

Thompson, A., Eckerle, K.L., Standards for Corrected Fluorescence Spectra (to be published in SPIE Proceedings).

Thompson, A., and Eckerle, K.L., "Fluorescent Emission Standards for the Calibration of the Relative Response of Spectrofluorimeters in the Visible Region," NIST Certificate Standard Reference Material 1931. (in preparation).

Walker, J.H., "Intercomparing the Optical and Resistive Temperature Scales," (in preparation).

Walker, J.H., "Direct Comparison of the Freezing Temperatures of Gold and Silver," (in preparation).

Wang, T.M., Eckerle, K.L., Hsia, J.J. "Absolute Specular Reflectometer with an Autocollinator Telescope and Auxilliary Mirrors," (in preparation).

West, J.B., Hayes, M.A., Parr, A.C., Hardis, J.E., Southworth S.H., Ferret, T.A., Dehmer, J.L., "A High Resolution Angle Resolved Photoelectron Spectroscopy Study of N_2," (under review)

Zalewski, E.F., Hoyt, C.C., Miller, P.J., Foukal, P.V., Comparison "Between a Side-Viewing Cryogenic Radiometer and Self-Calibrated Silicon Photodiodes" (to be published SPIE 1989 Technical Symposia on Aerospace Sensing, March 27-31, 1989, Orlando FL).

TECHNICAL AND PROFESSIONAL COMMITTEE PARTICIPATION AND LEADERSHIP

Division 534, Radiometric Physics

Clara Asmail

Member, ATSM E-12.09, Scattering

Yvonne Barnes

Member, ASTM E-12 Committee, Appearance of Materials

Robert J. Bruening

Member, Lamp Testing Engineers Conference

Kenneth L. Eckerle

Member, ASTM E-13 Committee on Molecular Spectroscopy, Subcommittee E-13.01 on Ultraviolet and Visible Spectroscopy, Subcommittee E-13.03 on Infrared Spectroscopy, Subcommittee E-13.06 on Luminescence.

Member, CIE TC2-28 on Methods of Characterizing Spectrophotometers.

Laurence E. Fink

NBS Representative, ANSI IT2 on Photographic Sensitometry and IT2.28 on Densitometry

G. Barry Hillard

Member, ASTM E-20 Committee, Temperature Measurement, Subcommittee E-20-2, Radiation Thermometry

Jack J. Hsia

Secretary, CIE Division 2, Physical Measurement of Light and Radiation.

Chairman, CIE TC 2-11 Technical Committee on Goniophotometry.

Secretary, U.S. National Committee of the CIE.

Division 534, Technical and Professional Committee Participation and Leadership (cont'd)

Jack Hsia (cont'd)

Member, ASTM E-12 Committee, Appearance of Materials (Spectrophotometry, Colorimetry, Geometric Properties, and Scattering).

Member, ASTM E-13 Committee, Molecular Spectroscopy; Subcommittee E-13.01, Ultraviolet and Visible Spectroscopy; E-13.03, Infrared Spectroscopy, and E-13.06, Molecular Luminescence.

Secretary, CORM/NBS Task Force on Spectrophotometry.

Donald A. McSparron

Member, ANSI Z311, Photobiological Safety of Lamps and Lighting Systems.

Member, Illuminating Engineering society (IES), Testing Procedures Committee.

Member, Lamp Testing Engineers' Conference.

Member, Tellers Committee, Optical Society of America.

Klaus D. Mielenz

Vice President, U.S. National Committee of the CIE.

Director, CIE Division 2, Physical Measurement of Light and Radiation.

Member, ASTM E-13 Committee, Molecular Spectroscopy; Subcommittee E-13.06, Molecular Luminescence.

Member, IES Subcommittee C012, Nomenclature.

Exofficio member, CORM Board of Directors

Vice Chairman, CORM Task Force on Spectrophotometry.

Member, OSA International Affairs Committee.

Member, Advisory Board, Munsell Color Science Laboratory, Rochester Institute of Technology.

Division 534, Technical and Professional Committee Participation and Leadership (cont'd)

Albert Parr

Visiting Senior Fellowship, Aberdeen University, Scotland.

Member, Queen Match Calibration Review for SDC.

Robert D. Saunders, Jr.

Member, ANSI Z311, Photobiological Safety of Lamps and Lighting Systems.

Member, IES Photobiology Committee.

Member, CIE TC2-05, Distribution Temperature.

Douglas B. Thomas

Member, U.S. National Committee of the CIE

Alternate, ASTM E-20 Temperature Measurements

Member, ASTM E44, Solar Energy Conversion.

Ambler Thompson

Member, Division 6 on Photobiology and Photochemistry, U.S. National Committee of the CIE.

William R. Waters

Member, ASTM Subcommittee E20.20 Radiation Thermometry.

Edward F. Zalewski

Chairman, CIE TC2-06, Absolute Spectral Responsivity.

Member, U.S. National Committee of the CIE.

MAJOR CONSULTING AND ADVISORY SERVICES

Division 534, Radiometric Physics

C.C. Asmail, provided consultation to ASTM Committee E-12.09 (scattering) on bidirectional scattering distribution function measurements.

P.Y. Barnes provided conslutation to NASA on pulverizing and preparing PTFE powders.

J.J. Hisa provided consultation to Peter Silverglate and Norman H. Macoy of Perkin Elmer Corporation on PTFE applications.

J.J. Hsia provided consultation to J. Misano of AT&T Co. on specular reflectance measurements.

J.J. Hsia provided consultation to Lou Ellen of IR Laser labs., AF, Ohio on Spectrophotometric calibration.

D.A. McSparron and T. Lusk,provided consultation and special measurements to Carl Siesbentritt of the Federal Emergency Management Administration (FEMA) on the specification and measurement of instrument readout brightness for radiation dosimeters.

D.A. McSparron provided consultation to M. Fecteau of the Army on appropriate standards and measurement techniques for the calibration of a UV actinic meter.

D.A. McSparron provided consultation to F. Eichmiller of the Dental Research program on measuring and specifying illuminance levels for dental work.

D.A. McSparron provided advice to G. Lieberman of the Law Enforcement Standards Laboratory (LESL) on measuring luminance contrast ratios on the instrument panels of law enforcement equipment.

A.E. Thompson provided Consultation to USDA and EPA on calibration of instruments to measure the solar UVB region.

STANDARD REFERENCE MATERIALS

Division 534, Radiometric Physics

1. SRM 1001, X-Ray Film Step Tablet

   For calibration of optical densitometers and similar equipment used in the photographic, graphic arts, and x-ray fields. Certified for transmission densities from 0 to 4.

2. SRM 1008, Photographic Step Tablets

   For calibration of optical densitometers and similar equipment used in the photographic, graphic arts, and x-ray fields. Certified for transmission densities from 0 to 4.

3. SRM 1010a, Microscopy Resolution Tests Charts

   For determining the resolving power of microscopy systems.

4. SRM 2061, Reflection Step Tablets

   For calibration of optical densitometers and similar equipment used in the photographic, graphic arts, and x-ray fields. Certified for reflection densities from 0 to 2.

5. SRM 2019 and 2020, White Ceramic Tile for directional-Hemispherical Reflectance from 350 to 2500 nm. SRM 2021 and 2022, Black Porcelain Enamel for directional-Hemispherical Reflectance from 280 to 2500 nm. SRM 2015 and 2016, White Opal Glass for directional-Hemispherical Reflectance form 400 to 750 nm.

   For use in calibrating the reflectance scale of an integrating sphere reflectometers.

6. SRM 2003b, First Surface Aluminum Mirror for Specular Reflectance form 250 to 2500nm. SRM 2011, First Surface Gold Mirror for Specular Reflectance form 600 to 2500 nm. SRM 2023, 2024, and 2025 Second Surface Aluminum Mirror for Specular Reflectance form 250 to 2500 nm.

   For use in calibrating the photometric scale of specular reflectometers.

7. SRM 2009, 2010, 2013, 2014 Didymium-Oxide Glass, Wavelength Standards between 400 and 760 nm.

Division 534, Standards Reference Materials (con't)

8. SRM 2034 Holmium oxide in Perchloric Acid Solution as Wavelength Standards between 241 and 640 nm.

9. SRM 1920 Near Infrared Reflectance Wavelength Standards from 740-2000 nm.

CALIBRATION SERVICES PERFORMED

Division 534, Radiometric Physics

Type of Service	Customer	SP250	Number of tests	
Pyrometry		35010C thru 35070S		29
	Defense & Aerospace		16	
	Instrument & Cal labs		7	
	Foreign		1	
	Electrical & Materials		5	
Spectroradiometry -	Sources	39010C thru 39060S		19
	Defense & Aerospace		5	
	Instrument & Cal labs		5	
	Lighting & Photography		8	
	Electrical & Materials		1	
Spectroradiometry -	Detectors	39070C thru 39080S		11
	Defense & Aerospace		5	
	Instrument & Cal labs		6	
Photometry		37010C thru 37180S		16
	Defense & Aerospace		4	
	Instrument & Cal labs		2	
	Lighting & Photography		6	
	Foreign		2	
	Electrical & Materials		2	
Spectrophotometry		38010C thru 38100S		24
	Defense & Aerospace		4	
	Instrument & Cal labs		10	
	Lighting & Photography		3	
	Foreign		1	
	Electrical & Materials		6	
				99

TRIPS SPONSORED BY OTHERS

Division 534, Radiometric Physics

A. Thompson to give an invited talk by USDA in Florida 1989.

A. Thompson to give an invited talk by SPIE in Los Angeles, 1989.

R. Bruening visted Navy Primary Standards Laboratory, sponsors of NIST program, June 1989.

SPONSORED SEMINARS AND COLLOQUIA

Division 534, Radiometric Physics

Lean, J., Naval Research Center, "Solar Emission Variation: Measurements and Interpretation," Radiometric Physics Division Seminar, July 11, 1989.

Huttemann, Dr. Thomas J., "Metrology at Kodak," Radiometric Physics Division Seminar, December 13, 1988.

Reisfeld, Prof. R., Department of Inorganic and Analytical Chemistry, "Optical Properties and Applications of Dyes in Glass Matrices," Joint Radiometric Physics and Gas and Particulate Science Divisions. May 11, 1989.

TECHNICAL ACTIVITIES

Division 535, Radiation Source and Instrumentation

The division's main activity this year was the development of two major radiation sources, the 185-MeV racetrack microtron (RTM) electron accelerator and the NIST Free-Electron Laser (FEL). When commissioned in 1990, the RTM beam will comprise a continuous pulse train with a combination of high beam quality and high average power (up to 100 kW) unequalled anywhere. The RTM electron beam will serve as the gain medium for the FEL and will also be available for other applications that exploit its unique properties. Scheduled to begin operation in 1991, the FEL will provide a unique photon beam for research in a broad range of fields. Figure 1 shows the RTM, the FEL, and the planned FEL user facility.

In December, 1988 the 150-MeV NIST Electron Linac was decommissioned after 23 years of operation. Approximately 2000 ft^2 of space that had been occupied by Linac beam lines and shielding has been cleared and made available for the FEL and other applications of the RTM beam. Aside from the RTM-FEL project, the division continued to provide national leadership in standards for nuclear instrumentation in 1989. The division's role in providing mechanical and electronics instrumentation services to the other divisions of CRR was decreased this year to expedite development of the RTM-FEL.

Racetrack Microtron   M. Wilson

This 185-MeV, 500-μA electron accelerator, shown in Figure 2, consists of a 5 MeV injector feeding a racetrack microtron. In the microtron, a pair of 180° end magnets will recirculate the electron beam through an 8-m, 12-MeV rf linac up to 15 times for an energy gain of up to 180 MeV. Up to 450 kW of microwave power from a single, continuous-wave (cw) klystron operating at 2380 MHz establishes standing-wave accelerating fields in both the injector (5-MeV) linac and the RTM (12-MeV) linac. The beam can be extracted from any of 14 separate return lines in 12-MeV steps.

This year the accelerator was commissioned at 17 MeV with a single pass through the linac. The 17-MeV beam met or surpassed all design specifications. In 1990 the beam-return lines will be installed to permit recirculation, and the RTM will be commissioned at full energy. This will be done without the FEL mirrors or the mirror chicane in place. The existing injector produces pulses of 5-MeV electrons with peak currents of up to approximately 70 mA. We are developing a new injector with the additional capability of up to 4-A peak current for driving the FEL. In 1991 we will change injectors and commission the RTM as an FEL driver.

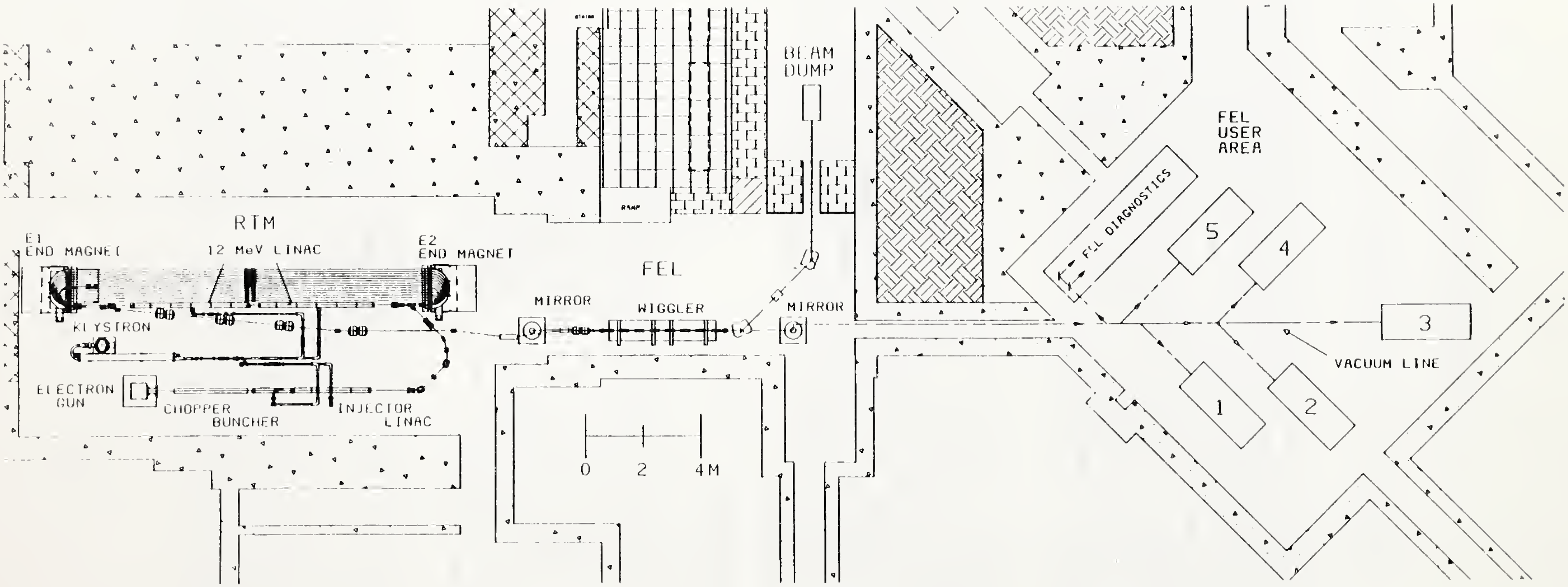

Figure 1. The planned NIST RTM-FEL Facility. The electron beam from the RTM will be transported through the FEL and into a beam dump. A large area (not shown) beyond the beam dump is available for electron beam applications. Photons from the FEL will be transported to the user area, shown on the right.

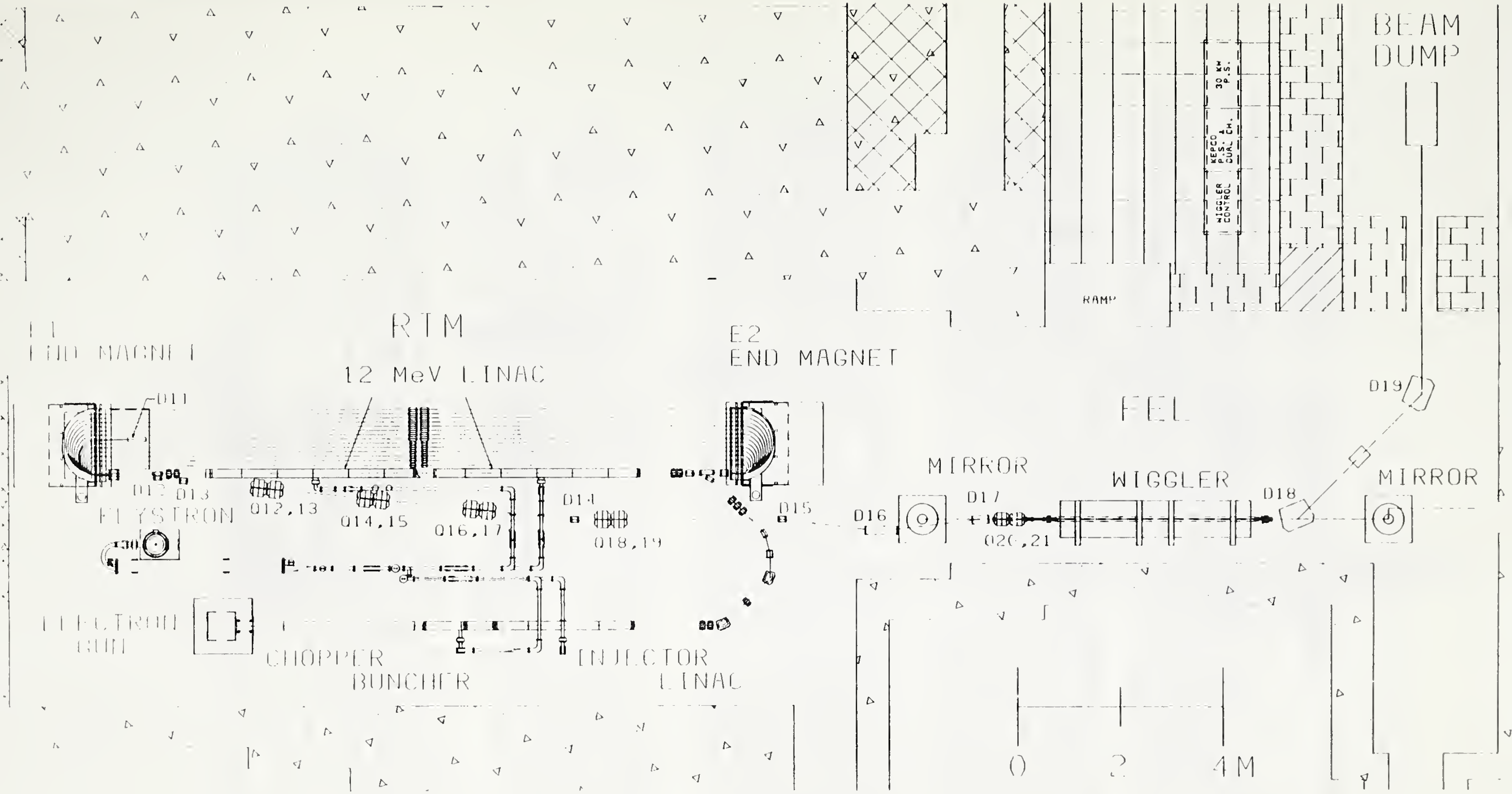

Figure 2. Plan view of the NIST RTM, electron beam transport, and FEL. A 5 MeV injector, at the bottom of the diagram, feeds the racetrack microtron. In the microtron, a pair of 180° end magnets recirculates the beam through a 12 MeV linear accelerator up to 15 times for an energy gain of up to 180 MeV. The beam may be extracted after any number of recirculations by moving magnet D11 to the desired return line. Microwave power from a single klystron is distributed to the injector linac and the RTM linac through a waveguide distribution system.

a. RTM Construction M. Wilson (project leader), R. Ayres, S. Bruce, R. Cutler, E. Lindstrom, and A. Raptakes

In the past year, the RTM has been operated at 17 MeV (one pass through the linac). Most components of the return lines required for the completion of the RTM are on hand, and the remaining devices are scheduled for delivery by the end of 1989. Several of the magnets for the transport line between the RTM and the Free Electron Laser are in procurement, and designs of the remainder are nearing completion.

Starting in late September, 1988, the 5-MeV electron beam was injected onto the linac axis and accelerated. To determine the energy gain and emittance, the accelerated beam was deflected by end magnet E1 into a temporary beam line containing beam profile and position diagnostics and a high-power beam stop (Figure 3). Measurements of the beam momentum and emittance demonstrated that the one-pass design energy, 17 MeV, was achieved and that the beam quality exceeds the design requirements by about a factor of 2.

These pulsed beam measurements were interrupted by three breakdowns of the klystron high voltage power supply. (These problems are discussed in the Accelerator Operations section of this report.) After the third breakdown, which occurred during preparation for high-average-power cw beam tests, it was concluded that further attempts to conduct beam tests with this supply would lead to serious project delays. A new power supply is being procured. In the meantime, the one-pass beam line has been removed, and preparations are underway to install the return beam lines.

Shown in Figure 2, the return lines consist of 14 parallel beam transport systems containing independent focusing elements (quadrupoles Q10 and Q11) and steering elements, that prepare the beam for successive passes through the RTM linac. Each return line also contains a viewscreen and wirescanner for beam position and profile measurements. A movable magnet, D11, can be positioned over any return line to deflect the beam into the extraction beam line, which begins at dipole magnet D12.

At present, the steerer yokes have been machined from a special nickel-iron alloy and are being annealed for good magnetic properties. All coils and approximately 25% of the yokes for the return-line quadrupole magnets have been delivered and tested. The remaining yokes are due to be finished in the NIST shop by the end of September. All components for the viewscreens and wirescanners are on hand or on order. Components for the return-line support structure are either in the final design stage or on order. The vacuum envelope is fully designed, and all components are either on hand or will be ordered this year. All power

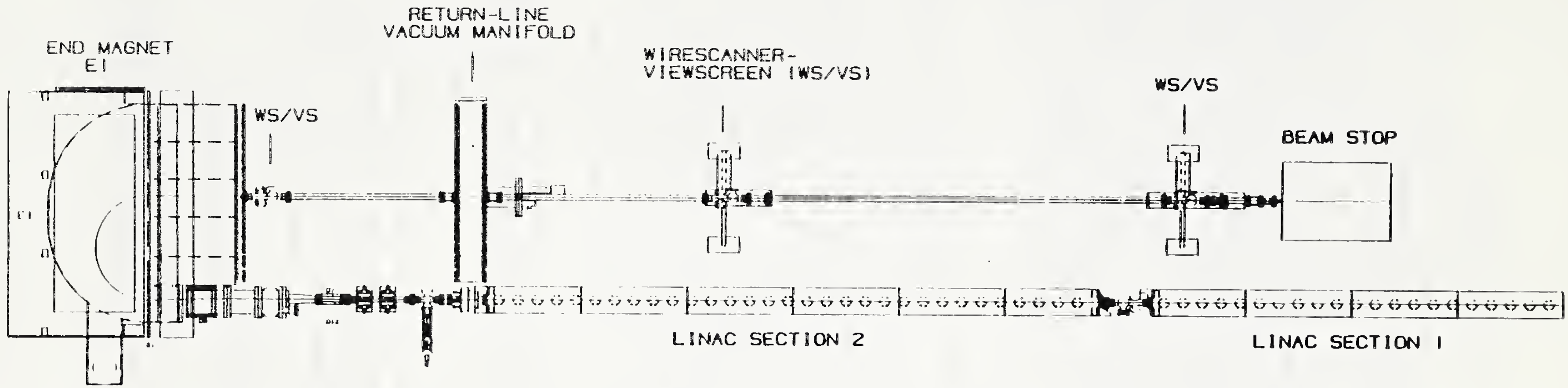

Figure 3. E1 end of the RTM with the temporary, diagnostic beam line for one-pass beam tests.

supplies for the return-line magnets are on hand, and plans for the control and power wiring layout are complete.

The transport system from the RTM to the FEL (Figure 2) consists of dipole magnets D12 and D13 followed by the quadrupole doublets, Q_{12}-Q_{17}, positioned for achromatic beam transport. Dipole magnet D14 aligns the electron beam to the FEL axis, and quadrupoles Q18-21 focus the electron beam for the optimum match to the optical radiation in the FEL cavity. Dipole magnets D15-D17 direct the electron beam around the upstream cavity mirror. At the exit of the FEL, the 45°-deflecting magnets D18 and D19 serve as the dipoles of an achromatic bending system to direct the electron beam into a high power, shielded beam dump/current monitor. Dipole magnets D11-D13 are in procurement, and quadrupole magnets, Q12-Q21, will be in procurement by the end of September. Theoretical designs of all other dipole magnets are complete and construction drawings have begun.

b. <u>High-Current RTM Injector</u> Roy Cutler (project leader), E. Lindstrom, and S. Penner (contractor)

A new, high-current injector for the RTM will provide the 2-4-A, 3.5-ps electron beam pulses required by the FEL for lasing. This is 40 times the maximum current capabilities of the present injector. The electron beam pulses will have repetition rates of 66.111 MHz and 16.528 MHz, which are subharmonics of the RTM accelerating frequency of 2380 MHz and harmonics of the FEL cavity frequency of 16.528 MHz. During 1989, a choice of technologies was made for the injector, and a high-current injector was designed to meet or exceed all of our design requirements. After extensive computer modeling a design report was produced which specified all components for the new injector. Procurement of major items of the new injector has commenced.

Originally, two different technologies were considered for the injector. In the first, a mode-locked, cw laser is focused on a suitable photo-electron-emitting cathode material, and the resulting electrons are then accelerated. The electron pulses produced by such a method are quite short, ≈30-100 ps, and photocathode materials are capable of emitting as much as 100 A/cm^2. Two types of photocathode materials have been investigated by accelerator research scientists. The first are high quantum-efficiency (≈1%) materials such as CsSb. These materials require extremely high vacuum conditions (10^{-10} Torr or better) and only have a few hour lifetimes at our required average current. The second class of photo-emitters are either pure metals or low-work function compounds such as LaB_6, with quantum efficiencies of 0.01-0.0001%. The use of these materials would require 50-1000 Watt cw lasers in the visible or UV to illuminate the cathode, which are extremely expensive and not practical. While further research may uncover better photocathode materials, at present a cw photo-injector for our usage is unobtainable. Photo-injectors also present significant design problems involving pulse-to-pulse current variation produced by the drive laser, and lifetime problems of the laser itself.

The other technology studied, and the one adopted for the new injector, involves the use of a conventional, pulsed, thermionic electron gun and subharmonic rf chopping and bunching. The design produced is similar to the existing RTM injector and satisfies all of our design goals. The new injector will also be able to produce electron beams identical to the ones produced by the existing injector for accelerator research and other uses. A schematic drawing of the injector is shown in Figure 4. A continuous train of 2-ns long, 300-mA pulses are emitted from a grid-controlled thermionic cathode at the desired repetition rate and accelerated to 120 kV in a dc-biased electron gun. This beam is deflected by a subharmonic rf cavity driven at 1190 MHz horizontally and 793.3 MHz vertically to form the Lissajous figure shown in Figure 4 at the chopper aperture. The chopper aperture reduces the beam pulse length from 2 ns to 70 ps by only passing the peak of the original beam pulse. The beam pulse then has its rf-driven deflections canceled by a properly phased and powered second rf cavity, identical to the first. The beam is then bunched by a subharmonic rf buncher at 1190 MHz to 15 ps and injected into the existing injection linac. For operation at 2380 MHz, as in the existing RTM injector, the electron gun produces 1-10 mA dc electron beams which are chopped to 2380 MHz by using only the 1190 MHz deflection, which causes the beam to oscillate horizontally over the chopper aperture, crossing twice per deflection period. The beam then has its deflection cancelled by the second deflection cavity and is bunched by the buncher cavity, which is driven at 2380 MHz.

The computer program PARMELA has been used to model the transport of the electron beam from the gun to the exit of the 5 MeV injector linac. The predicted emittance values are given in Table 1. These values are based on a gun emittance of 2 mm-mr (for 95% of the beam) for the high current beams for FEL usage, and the use of the existing electron gun (or cathode) for the low current beams.

Contracts for the new electron gun and for the deflection cavities are being prepared, and specifications for the other components are being written. Plans call for the acquisition of all components during 1990 for installation in early 1991, after the completion and acceptance tests of the RTM with the existing injector.

c. <u>Beam Dynamics</u> M. Wilson (project leader), E. Lindstrom and S. Penner (contractor)

Several calculations have been performed to optimize the parameters of the beam transport system and to establish the conditions for the corrected operational tune of the RTM. These calculations include tuning

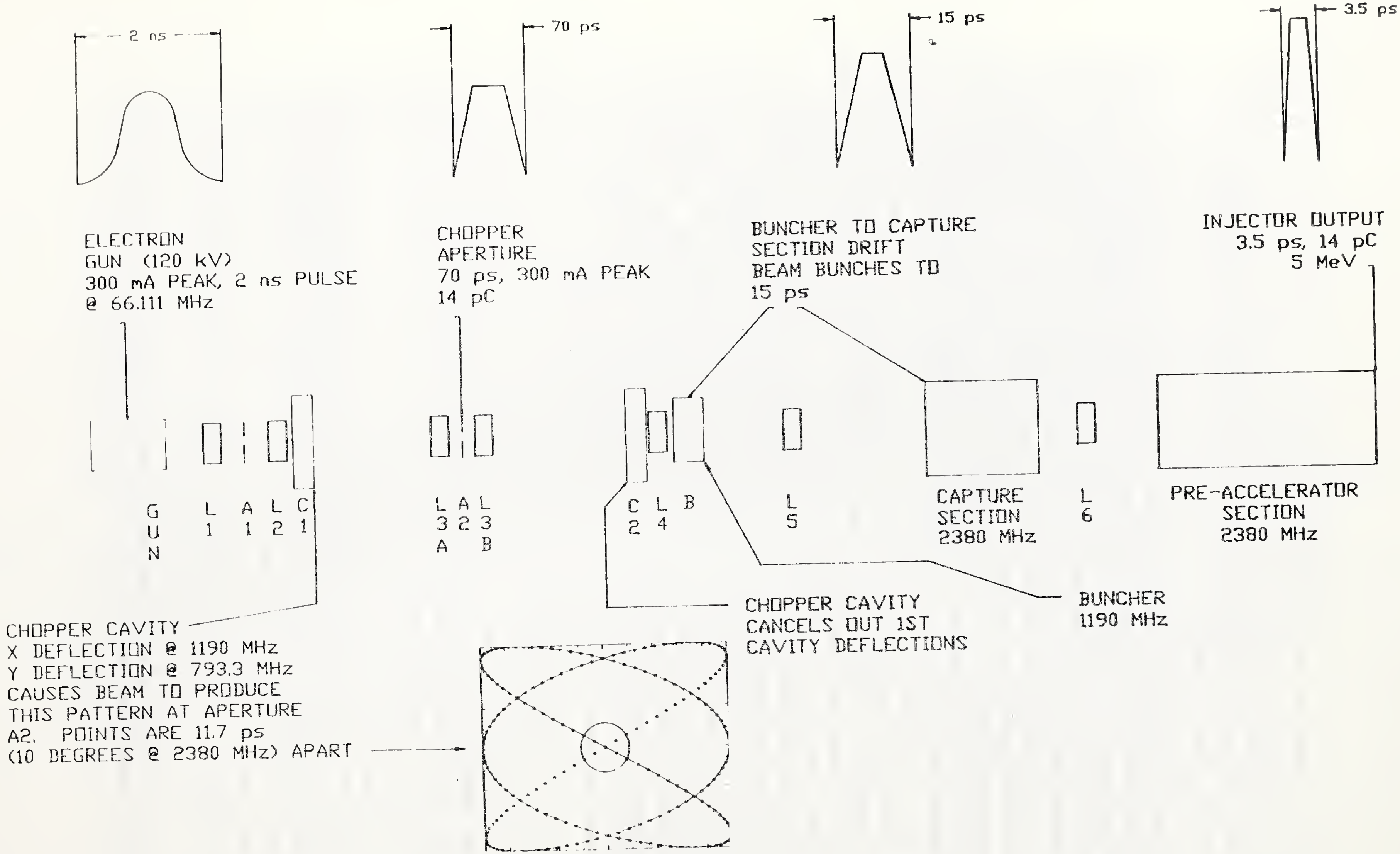

Figure 4. Schematic representation of the high-current injector. Not to scale.

Table 1. Calculated values of longitudinal and transverse emittances for 95% of beam particles from the high-current injector.

Charge per Pulse, pC	Transverse Emittance, (Normalized) μm	Longitudinal Emittance, keV-degrees
0.25	0.7*	5*
7	4.3	17
14	6.1	34

*Actual values measured at 5 MeV with present injector.

the 5-MeV transport system for a 6-dimensional phase space match into the RTM and the development of an operational description of the beam behavior in the RTM so that transverse and longitudinal beam oscillations can be diagnosed and minimized, to reduce beam loss and optimize beam quality.

In order to establish sufficient clearance to vacuum structures, accurate location of the beam return orbits has been calculated using the measured fringe fields of the end magnets. These calculations also provide information necessary for ongoing efforts to model the 6-dimensional phase space of the beam in the RTM in order to determine the beam emittance growth during acceleration.

In addition, the final design of the beam transport system between the RTM and FEL has been established, including calculations of the transverse emittance growth due to magnetic field aberrations. This has provided the information required to complete the design of the beam transport elements.

Calculations were performed to determine the current threshold for subharmonic beam break-up (BBU) in the high current mode of operation of the RTM. As reported by S. Penner at the 1989 Particle Accelerator Conference, March 20-23, Chicago, IL, the approximate threshold for subharmonic BBU for 15 passes through the RTM is between 400 μA and 600 μA average beam current, depending on the strength of the focus system. This range is near the upper limit of beam current defined by rf power limits.

For corroboration of the beam behavior near this important limit, we are currently working with members of the beam dynamics group at the Continuous Electron Beam Accelerator Facility (CEBAF) who are using their computational facilities to independently determine the subharmonic beam break-up effects in the NIST RTM.

We are also currently investigating the effects on beam phase of beam loading fluctuations in the RTM due to subharmonic injection. Beam phase stability affects the performance of the FEL.

<u>Free-Electron Laser</u> R. Johnson (project leader), C. Johnson, S. Penner (contractor), M. Price, and J. Rose

A free-electron laser (FEL) is being constructed by NIST in collaboration with the Naval Research Laboratory (NRL). The FEL, which will be driven by the RTM, will form the basis of a national user facility for fundamental and applied research with an intense, tunable photon beam. The radiation will consist of a continuous train of 3-ps pulses, tunable from 200 nm to 10 μm with transform-limited line width and average power of 10 to 200 W. During this year excellent progress has been made on this project.

The contractor for the undulator (wiggler) has for the most part remained on or ahead of schedule. They have completed the mechanical structure, vacuum chambers, control system, and magnetic field measurement system. The magnetic structure for the first half of the undulator has been installed and measurements of the magnetic field have begun. The contractor anticipates a delay in completing the magnetic structure for the second half of the undulator due to the late delivery of permanent magnets. Installation of the undulator is still expected to be in early 1990. The anticipated delay will not affect the overall project.

Our colleagues at NRL have continued to supply valuable detailed calculations on several factors which can affect FEL performance including short electron and optical pulse effects, undulator magnetic field errors, diffraction losses, and coherent harmonic generation. There are two possible effects on FEL operation associated with the short duration (3 ps) of the electron-beam pulse from the NIST microtron. Since the electrons travel at a velocity slightly less than c, they will fall behind the laser pulse. When the pulse slippage becomes comparable to the length of the electron pulse, the gain is reduced. In our case, the slippage is smaller than the electron pulse length, and consequently the peak gain is not substantially altered from the long pulse limit. The second effect is known as "laser lethargy." In the build-up of the radiation pulse, the growth tends to be on the trailing edge. The result is that the group velocity of the laser pulse is less than c. To maintain synchronism with the electrons the cavity length has to be shortened slightly. This change in length is known as the "detuning length." To calculate the consequences of short-pulse effects a semi-analytical formulation of the one-dimensional FEL oscillator in the linearized, small-signal, low-gain limit has been developed. The model includes the effects of arbitrary pulse shape, length detuning, and mirror reflectivity. This model has been used to simulate the performance of the NIST-NRL FEL. Two conclusions can be drawn from the results. First, the gain calculated for gaussian and square electron pulses is essentially the same. Second, the mirror detuning length for the expected electron-pulse length of 3 ps becomes critical at short wavelengths, where a cavity length stability of about 1 μm is required.

Errors in the magnetic field of an undulator can walk the electron beam off the undulator axis and out of the optical mode and can alter the phase between the electrons and the radiation. Both effects lead to a loss in gain. The rms field error of the NIST undulator is specified to be no more than 0.5% of the maximum field. In addition the undulator will have steering at each quarter which can bring the beam back on axis. We have performed calculations which indicate that these specifications will ensure an acceptably small reduction in gain. The computer code developed at NRL for final calculations includes the effects of multiple steering and correlated errors and predicts electron beam trajectories, phase errors, and loss in gain. This code will also allow us to predict the performance of our undulator when the magnetic field is measured.

Recent calculations of diffraction losses have confirmed earlier estimates that they are negligible for the UV and visible wavelengths. In the IR the diffraction losses at the aperture of the undulator vacuum chamber were conservatively estimated to be 0.6% per pass at 10 μm. Both the estimate and the calculations used cylindrical symmetry; however, the vacuum aperture is oval, 8.6 mm (vertical) by 16 mm horizontal. It will be necessary to modify the calculations for the non-symmetry in order to determine if the estimates are too conservative. Since the losses increase with wavelength, an accurate estimate is required to determine the upper limit for lasing.

Mirror damage is an important issue for the NIST-NRL FEL. We have completed a study in which the problems of thermal distortion and harmonic radiation damage were investigated. Suppliers of mirrors with sufficiently low absorption to avoid thermal distortion were identified. In addition estimates of mirror lifetime when subjected to harmonic radiation were made and found to be acceptable.

Estimates were made of the intracavity optical power at the fundamental wavelength for a saturated FEL with the NIST operating parameters. If mirror absorption is high, thermally-induced distortion of the cavity end mirrors can destroy the well-defined spatial modes of the resonator, so that lasing in the fundamental TEM_{00} mode is not possible. The critical parameters are the average intracavity power and the amount of absorption in the cavity end mirrors. The NIST-NRL FEL will have the highest average power of any FEL in the world. We have identified suppliers for cavity mirrors that have 10-20 ppm absorption in the visible spectral region. These mirrors will perform well in the NIST-NRL FEL. In addition, we began a study to predict thermally induced distortion using a finite-element analysis code.

FELs also generate substantial amounts of harmonic radiation. Therefore, we also calculated the intensity of the spontaneous emission from the undulator at the various harmonics and estimated the intensity of the coherent-harmonic emission, based on other FEL and transverse optical klystron devices. When lasing in the visible, the mirror lifetime due to harmonic radiation damage is expected to be about one week. We are also coordinating efforts to solve this problem through resources available at the Department of Commerce; a Small Business Innovative Research grant (Phase I) has been awarded for an experimental study of mirror damage from UV radiation. Finally, our colleagues at NRL have calculated the coherent harmonic emission for several cases. These calculations will be used for more accurate estimates of mirror lifetimes.

Since the NIST Linac has been shut down the shielding between the FEL room and the RTM room is no longer needed. Removal of this shielding allowed us to increase the length of the optical cavity from 8.062 m to 9.069 m. The new design eliminates clearance problems between the electron-beam transport system and the cavity end mirrors, reducing the cost of several transport magnets. The extra meter of length in the cavity increases the flexibility of intracavity alignment and diagnostic devices. The length increase reduces the maximum frequency in the FEL from 74.375 to 66.111 MHz.

The design of the FEL alignment system is in progress. The magnetic axis of the undulator and the optical axis of the cavity must be parallel to and superimposed on the electron-beam trajectory over the entire length of the undulator. The optical axis of the cavity will be aligned with the magnetic axis of the undulator using mechanical and optical techniques, in the absence of the electron beam. Electron-beam position monitors will be aligned to this axis as well. The goal is to align the three axes well enough so that lasing can begin after a low-power, pulsed electron beam is aligned to the beam-position monitors. Fine tuning of the electron-beam position and the optical-cavity axis can then be done remotely, using the full power electron beam and the FEL diagnostics (including spontaneous emission from the undulator). We are assembling a folded, full-scale model of the FEL optical cavity on an optical table in order to evaluate alignment techniques, mirror positioning and cavity stability before proceeding to the engineering design of the FEL cavity.

Preparation of the FEL area is well along. The FEL room has been cleared of beam lines from the NIST Electron Linac, and the 12-ft-thick shielding wall between the FEL room and the RTM has been removed. A shielded equipment room was also cleared for electronic equipment that must be shielded from the electron beam line. Electrical service is being installed in the FEL room and the shielded equipment room, and modification of the air conditioning system is planned to reduce noise and dust. In order to reduce vibrations in the optical cavity, concrete bases for the cavity mirrors were designed to be supported by the 4-ft-thick concrete subfloor of the FEL room. These were poured directly on the subfloor after cutting through the 6-in-thick floor, which is separated from the subfloor by 14 inches of gravel. Vibration measured on the mirror bases is a factor of 100 below that on the floor.

The conceptual design of the optical-beam transport from the FEL to the user area (MR2) is well underway. Transport will be in vacuum for high transmission and for laser safety. The transport line will include a horizontal translation in the FEL area that, combined with shielding against x rays and neutrons, will ensure safe radiation levels in the FEL user area in the event of an electron-beam spill in the RTM or FEL room. This section of the transport line will have nearly 100% throughput over the FEL wavelength range and, using grazing-incidence mirrors, about 80% throughput in the extreme ultraviolet (≈300 Å to 1000 Å).

The location of the FEL diagnostic table and possible locations of several user experiments in MR2 are shown in Figure 1. The optical-beam transport in this area will consist of several "beam-extraction points", located along a straight line that is parallel to the axis of the undulator, and mounted on a single concrete pier. The users' experimental stations will be located on each side of the transport line. The user area is mostly cleared of old equipment, and material for a raised floor is on hand.

Micropole Undulator Experiment — C. Johnson (project leader), R. Johnson, D. Mohr, M. Wilson, R. Cutler, and R. Madden

Micropole undulators, i.e., undulators with submillimeter periods, offer the possibility of generating highly coherent x rays with relatively low-energy (hence economical) electron accelerators. Among the leaders in developing these devices are Dr. R. Tatchyn of the Stanford Synchrotron Radiation Laboratory (SSRL) and Dr. A. Toor of Lawrence Livermore National Laboratory (LLNL). The small apertures of micropole undulators (MPU's) require electron beams with very low emittance and disqualify these devices from insertion into storage rings. Because the NIST RTM beam is nearly ideal for this application, a collaboration of NIST, SSRL, and LLNL was formed to test MPU's here. The initial experiment was to be a test of a 1-mm-period MPU at 17 MeV, where the peak of the spontaneous emission spectrum is blue light.

The experiment was scheduled to follow completion the one-pass RTM beam tests. The experimental apparatus was designed and constructed, including a bending magnet to separate electrons from photons, provision for optical beam transport and spontaneous emission diagnostics. The failure of the klystron power supply has postponed the experiment until late 1990 or early 1991.

Accelerator Operations — J. Broberg (project leader), T. Hotchkiss, and J. Pitt

Activity this year included decommissioning the Electron Linac and construction, operation and maintenance of the RTM. The Linac was shut down in December, 1988, and we are preparing it for surplus property status. George Mason University has borrowed the klystron modulator and rf drive circuit of Linac section 9 for an experiment in microwave generation. We also assisted in rf-testing the 8-m RTM linac, operated the RTM for one-pass beam tests, and installed a system that shuts off the cooling water if water is detected on the floor.

Mechanical Instrumentation D. Mohr (project leader), R. Baker, J. Billos, C. Bostian, J. Bradley, D. Fox, H. Lantz, and P. Liposky

Mechanical instrumentation services were provided for the Center in connection with its particle accelerators and experimental programs. The services consisted of design, construction, and installation of new equipment and facilities as well as maintenance and modification of existing equipment to improve performance and reliability.

Devices that were designed and constructed this year include: the RTM extraction magnet (D11) and a precise, movable support structure which will allow D11 to be positioned on any return line for extraction of the electron beam at energies between 29 and 185 MeV; extraction-beamline dipole magnets D12 and D13; and an electron beam transport line for the micropole undulator experiment, including support structures, vacuum envelope and a magnet to separate electrons from photons. We also prepared drawings and specifications for the quadrupole magnets on the extraction beam line.

A requirement for the FEL mirror mounts to be free of vibration was investigated. The floor in the FEL room was measured with accelerometers and found to be unacceptably noisy. We then designed a mirror mount that was poured on the subfloor, which sits on bedrock and is isolated from the main floor. These mounts reduce vibration by two orders of magnitude and should solve this problem.

Some examples of major construction and maintenance tasks for this year are: clearing the magnet room, the vertical shaft to the neutron time-of-flight facility, and MR2 of all the magnets and beam transport system associated with the Linac; repair of the RTM high voltage power supply; and rebuilding of vac-ion pumps for SURF and other divisions in CRR.

We have three operational CAD/CAM work stations and plan to purchase another for an engineer (P. Liposky) who was added to our permanent staff this year. These are essential for designing RTM and FEL components in a timely manner. The Mechanical Group has been heavily involved in the planning of the FEL program, and the group leader serves as the alternate technical representative to the contracting officer for the undulator.

Electronic Instrumentation J. Whittaker (project leader), A. Marella, J. Owen, L. Shuman and N. Wilkin

The effort of the Electronics Group has been redirected to concentrate on the RTM/FEL construction project. Assistance was provided to other divisions of CRR in the time available outside this effort. We also continued to assist Harry Diamond Laboratories (HDL) on their important fuze development project.

Instrumentation constructed this year for the RTM includes: 25 wirescanner amplifiers; two systems to scan the electron beam across vacuum-to-water interfaces on beam stops to prevent thermal failure; and vacuum controls and interlocks for the extraction beam line. We are now engaged in a large project to plan the replacement of the present RTM control system with one utilizing multiple workstations which will run control software developed by CEBAF. The CEBAF software, with its great versatility and proven effectiveness, will enable us to meet very tight deadlines for installing and commissioning the new system. This installation will entail extensive rewiring. Preparations for rewiring have reached an advanced stage, including hardware installation. Programming to control the NMR gaussmeter for the RTM end magnets is complete and ready for installation in the present control system.

We upgraded our CAD computer from an HP350 to an HP370, and the CAD system that we maintain for others was used extensively to design a large detector-telescope array. In the time available, we provided instrumentation support for x-ray standards and the States Regional Calibration services, as well as consultation to other CRR divisions, NIST, DoC, DoE and HDL.

Our participation in the HDL program to automate fuze testing has continued. Ten 386-based computers and two Macintosh computers have been configured and delivered to HDL. A system has been provided that will allow "PostScript" printing capabilities for the fuze tester reports. Optical scanner equipment has been configured and delivered which permits inclusion of various documents in the fuze reports. We also have provided five different printed circuit boards to HDL, which permitted HDL to meet necessary deadlines.

Radiation Instrumentation Standards L. Costrell

The division provides national leadership in standardization concerned with nuclear instrumentation. The standards fall into three categories: National Voluntary Standards, Nuclear Instrumentation Module (NIM) Standards, and International Electrotechnical Commission (IEC) Standards.

The division plays a leadership role in the development and processing of National Voluntary Standards of the American National Standards Institute (ANSI) and of the Institute of Electrical and Electronics Engineers (IEEE), and participates in the associated policy boards. L. Costrell serves as Chairman of ANSI Committee N42 on Radiation Instruments and as Secretary of the IEEE Nuclear Instruments and Detectors Committee. In these capacities he has processed a considerable number of ANSI and IEEE standards, serves on the ANSI Nuclear Standards Board and is a member of its Planning Committee.

The NIM Committee, of which L. Costrell is Chairman, oversees development and maintenance of instrument standards in cooperation with the National Laboratories and other major laboratories, primarily for nuclear applications. NIST has management responsibility for this work, with L. Costrell serving as Project Manager.

The NIM system[1,2], initiated by NBS[3], has been adopted nearly universally in the U.S. and all other industrialized nations. A continuous coordination effort is required and is provided, involving contact with numerous laboratories and manufacturers. Similar management, direction and maintenance services are provided in the U.S. for the international CAMAC (Computer Automated Measurement and Control) system[4]. CAMAC is utilized in the National Laboratories and in a large number of other laboratories and installations throughout the world. A third system for which the division has management responsibility is the FASTBUS high speed modular data acquisition and control system for high

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[1] "Standard Nuclear Instrument Modules." AEC (now DOE) Report TID-20893 (Rev 4), July 1974 (currently under revision).

[2] Standard NIM Digital Bus (NIM/GPIB), "Department of Energy Report DOE/ER-0173, August 1983 (currently under revision).

[3] "S^{t}andard Modules for Nuclear Instrumentation," NBS Report 8137, December 5, 1963, L. Costrell.

[4] "CAMAC Instrumentation and Interface Standards," IEEE Publication SH08482, Library of Congress Catalog No. 8185060 (ANSI/IEEE Stds 583, 595, 596, 675, 683, 726, 758).

energy physics and other applications[5,6,7]. The FASTBUS development has been a major effort, with commercial equipment now available and systems in operation or in preparation in numerous laboratories in the U.S., Europe and Japan. Coordination and processing of the specifications is handled by the division. The standards are initially issued as reports of the U.S. Department of Energy and are later processed as standards of ANSI, the IEEE and the IEC.

The NIM and CAMAC standard instrumentation projects have resulted in a savings in excess of 3 billion dollars. This estimate is based on extrapolation of the 1.9 billion dollar minimum savings calculated in 1982 in a study conducted for the Department of Energy[8]. Since the NIM and CAMAC systems are in worldwide use, the total worldwide savings resulting from these two systems can be reasonably projected to be double the U.S. savings, or in excess of 6 billion dollars. Figures are not yet available on the savings resulting from the newer FASTBUS system.

L. Costrell serves as Technical Advisor to the U. S. National Committee of the IEC for IEC Committee TC45 on Nuclear Instruments. He serves as Chief U.S. Delegate to TC45, as Chairman of the Working Group on Detectors and as a member of other working groups. Numerous draft documents were prepared and reviewed, resulting in a number of approved international standards. These include documents that are identical to the NIM, CAMAC and FASTBUS standards. Similarly, the international standards for numerous radiation detectors, radiation measurement instrumentation, test procedures, radiation protection instrumentation, and several other standards are technically identical to ANSI/IEEE standards developed by the committees referred to above.

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[5] "FASTBUS Modular High Speed Data Acquisition and Control System," ANSI/IEEE Std 960-1986 (currently under revision).

[6] "FASTBUS Standard Routines," Department of Energy Report DOE/ER-0323, March 1987 (currently being processed as an ANSI/IEEE Standard).

[7] "FASTBUS Modular High Speed Data Acquisition System," International Electrotechnical Commission (IEC) Publication 935 (to be published).

[8] "Benefit Analysis of Selected Accomplishments of DOE's Office of Health and Environmental Research, Final Report ER-166, Nov. 29, 1982, Ecosometrics, Inc., Bethesda, MD (M. Lago, M. J. Ramsdell, S. F. Knapp, S. I. Siddique).

INVITED TALKS

Division 535, Radiation Source and Instrumentation

Debenham, P.H., "The NIST-NRL Free-Electron Laser," 1989 Particle Accelerator Conference, Chicago, IL, March 21, 1989.

Debenham, P.H., "The NIST-NRL Free Electron Laser Facility," International Congress of Optical Science and Engineering, Paris, France, April 25, 1989.

Johnson, B.C., "The NIST Free-Electron Laser Facility," NIST Inorganic Analytical Research Division Weekly Seminar, NIST, Gaithersburg, MD, November 29, 1988.

Johnson, R.G., "The NIST-NRL Free-Electron Laser," 11th International Conference on Free Electron Lasers, Naples, FL, August 30, 1989.

Wilson, Mark A.D., "NIST-Los Alamos Racetrack Microtron Status," 1988 Linear Accelerator Conference, Williamsburg, VA, October 4, 1988.

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Wilson, M.A., Debenham, P.H., Penner, S., and Bruce, S.S., "Orbit Reversing Magnets for the National Bureau of Standards-Los Alamos Racetrack Microtron," IEEE Transactions on Nuclear Science, Vol. 36, No. 1, 1306, February 1989.

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Division 535, Radiation Source and Instrumentation

Cutler, R.I. and Young, L.M., "Performance of the High Power RF System for the NIST-Los Alamos Racetrack Microtron," to be published in the Proceedings of the 1988 Linear Accelerator Conference, October 2-7, 1988, Williamsburg, VA.

Cutler, R.I., Lindstrom, E.R., and Penner, S., "Conceptual Design of a High Current Injector for the NIST-NRL Free Electron Laser," to be published in the Proceedings of the 1989 Particle Accelerator Conference, March 20-23, 1989, Chicago, IL.

Cutler, R.I., Lindstrom, E.R., and Penner, S., "Design of a High Current Injector for the NIST-NRL Free Electron Laser," to be published in the Proceedings of the 11th International Conference on Free Electron Lasers, August 28 - September 1, 1989, Naples, FL.

Debenham, P.H., Ayres, R.L., Broberg, J.B., Cutler, R.I., Johnson, B.C., Johnson, R.G., Lindstrom, E.R., Mohr, D.L., Rose, J.E., Whittaker, J.K., Wilkin, N.D., Wilson, M.A., Tang, C-M., Sprangle, P., and Penner, S., "The NIST/NRL Free-Electron Laser Facility," to be published in the Proceedings of the 1989 Particle Accelerator Conference, March 20-23, 1989, Chicago, IL.

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Johnson, B.C., Johnson, R.G., Mohr, D.L., and Price, M.S., "Optical Resonator for the NIST-NRL Free Electron Laser," to be published in the Proceedings of the 11th International Conference on Free Electron Lasers, August 28 - September 1, 1989, Naples, FL.

Johnson, R.G., Mohr, D.L., Wilson, M.A., Penner, S., Younger, F.C., Ng, B., and Thomas, K.M., "The Hybrid Undulator for the NIST-NRL Free-Electron Laser," to be published in the Proceedings of the 11th International Conference on Free Electron Lasers, August 28 - September 1, 1989, Naples, FL.

Johnson, R.G., Ayres, R.L., Broberg, J.B., Cutler, R.I., Debenham, P.H., Johnson, B.C., Lindstrom, E.R., Mohr, D.L., Rose, J.E., Whittaker, J.K., Wilkin, N.D., Wilson, M.A., Penner, S., Tang, C-M., and Sprangle, P., "The NIST-NRL Free-Electron Laser Facility," to be published in the Proceedings of the 11th International Conference on Free Electron Lasers, August 28 - September 1, 1989, Naples, FL.

Johnson, R.G., Ayres, R.L., Broberg, J.B., Cutler, R.I., Debenham, P.H., Johnson, B.C., Lindstrom, E.R., Mohr, D.L., Rose, J.E., Whittaker, J.K., Wilkin, N.D., Wilson, M.A., Penner, S., Tang, C-M., and Sprangle, P., "The NIST-NRL Free-Electron Laser Facility," to be published in the Proceedings of the Symposium on Lasers and Optics at OE/LASE '90, January 14-19, 1990, Los Angeles, CA.

Wilson, M.A., Ayres, R.L., Cutler, R.I., Debenham, P.H., Lindstrom, E.R., Mohr, D.L., Penner, S., Rose, J.E., and Young, L.M., "NIST-Los Alamos Racetrack Microtron Status," to be published in the Proceedings of the 1988 Linear Accelerator Conference, October 2-7, 1988, Williamsburg, VA.

TECHNICAL AND PROFESSIONAL COMMITTEE PARTICIPATION AND LEADERSHIP

Division 535, Radiation Source and Instrumentation

John B. Broberg

Member, Organizing Committee of the 1990 Linear Accelerator Conference

Louis Costrell

Chairman, NIM (National Instrumentation Methods) Committee

Chairman, American National Standards Institute Committee N42, Radiation Instrumentation

Member, American National Standards Institute Nuclear Standards Board

Member, American National Standards Institute Nuclear Standards Board Planning Committee

Secretary, IEEE Nuclear Instrumentation and Detectors Committee

Ex-Officio Member, IEEE Nuclear and Plasma Sciences Society Administrative Committee

Chairman, IEEE Nuclear and Plasma Sciences Nominating Committee

Chairman, IEEE Nuclear and Plasma Sciences Annual Meetings Committee

Member, Organizing Committee, 1989 IEEE Particle Accelerator Conference

Member, IEEE Nuclear Science Symposium Program Committee

Member, U.S. National Committee of the International Electrotechnical Commission (IEC)

Technical Advisor, U.S. National Committee of the International Electrotechnical Commission (IEC)

Chief U.S. Delegate, International Electrotechnical Commission Committee TC45, Nuclear Instrumentation

Chairman, International Electrotechnical Commission Committee TC45 Working Group 9, Detectors

Division 535, Technical and Professional Committee Participation and Leadership (cont'd.)

Philip Debenham

Member, DOE Technical Advisory Panel on CEBAF High Resolution Spectrometers

Member, Program Committee, 1989 IEEE Particle Accelerator Conference

Julian Whittaker

Member, ASTM Committee D22 on Sampling and Analysis of Atmospheres

Secretary, Department of Commerce, Bureau of Export Administration, Electronic Instrumentation Technical Advisory Committee

Mark Wilson

Member, Program Committee, 1989 IEEE Particle Accelerator Conference

Member, Review Committee, Advanced Test Accelerator, Lawrence Livermore National Laboratory, Livermore, CA

MAJOR CONSULTING AND ADVISORY SERVICES

Division 535, Radiation Source and Instrumentation

M. Wilson continues to provide Accelerator Technology and Assessment and Oversight for DARPA.

J. Whittaker serves as consultant to the Department of Commerce TWG-6 and the State Department TTG-G relating to export licensing and control.

J. Whittaker served as part of the Department of Commerce delegation to the COCOM International Export Control Committee.

N. Wilkin serves as consultant on microcomputers and semiconductor radiation hardness testing to Harry Diamond Laboratories.

N. Wilkin serves as consultant on microcomputer control of fuze instrumentation for Harry Diamond Laboratories.

SPONSORED SEMINARS AND COLLOQUIA

Division 535, Radiation Source and Instrumentation

James W. Dodd, Columbia University, New York, NY, "Sideband and Short Pulse Generation in a Free-Electron Laser," August 4, 1989.

Hans Weise, Institut für Kernphysik, Technishe Hochshule Darmstadt, Darmstadt, West Germany, "The Darmstadt Superconducting Electron Accelerator and Free Electron Laser Program," September 28, 1989.

TECHNICAL ACTIVITIES

Division 536, Ionizing Radiation

The functions of the Ionizing Radiation Division may be summarized as follows:

- Provides primary national standards, dosimetry methods, measurement services, and basic data for applications of ionizing radiation (x rays, gamma rays, electrons, neutrons, and radioactivity, etc.) in such areas as:

    - Radiation protection of workers and the general public
    - Radiation therapy and diagnosis
    - Nuclear medicine
    - Radiography
    - Industrial radiation processing
    - Nuclear energy
    - National defense
    - Environmental protection

- Conducts theoretical and experimental research on the fundamental physical and chemical interactions of ionizing radiation with matter to provide the competence for:

    - Developing improved understanding of the physical stage of the interaction of ionizing radiation with matter
    - Developing an understanding of basic mechanisms involved in radiation-induced chemical transformations and the parameters that influence the yields of short-lived intermediates, final chemical products, and biological effects
    - Developing improved methods for radiation measurement, dosimetry, and radiography
    - Developing improved primary ionizing radiation standards
    - Producing highly accurate standard reference data for ionizing radiation and radioactive materials

- Provides essential standards and measurement support services to the National Measurement Support System for Ionizing Radiation that provides calibrations and measurement quality assurance services to:

    - Medicine
    - Industry
    - States
    - Other Federal Agencies

- Develops and operates well-characterized sources of electrons, photons, and neutrons to provide:
  - Primary radiation standards and fields
  - Well-characterized beams of radiation for research on radiation interactions and for measurement methods development.

The current organizational structure of the division consists of four groups:

Ionizing Radiation Division (R. S. Caswell, F. J. Schima)

Office of Radiation Measurement (B. M. Coursey, acting)

Radiation Interactions and Dosimetry (B. M. Coursey)

Neutron Interactions and Dosimetry (J. A. Grundl)

Radioactivity (D. D. Hoppes)

Some of the key future programs of the Ionizing Radiation Division are:

Radiation Interactions Research

Chemical mechanisms of biological effects and applications to radiation dosimetry

Physics of radiation interactions with condensed matter (at the microscopic level, especially)

Neutron and high-LET radiation interactions (includes radon)

Dissemination of Measurement Services

Develop national measurement support system for ionizing radiation

Radiation Measurement Science

High-energy electron & photon dosimetry standards (5-35 MeV)

Chemical dosimetry/industrial radiation processing

Dosimetry for personnel radiation protection

Radon measurement standards

Radionuclide atom counting

Radiology imaging research

I. Office of Radiation Measurement

The function of the Office of Radiation Measurement (ORM) is to promote the dissemination to federal, state, and local radiation control programs, and to the medical, industrial, and defense communities, of the measurement standards and technology required for reliable measurement of ionizing radiation. The Office assists the technical organizational components of the Ionizing Radiation Division in monitoring and evaluating the radiation measurement needs of these national user groups, and in research, metrology development and quality control activities undertaken to meet national needs. The latter include methods for improving the consistency of field measurements with the national physical measurement standards through a national system of secondary standards laboratories. The Office maintains liaison and participates in collaborative measurement quality assurance programs with organizations that conduct measurement-intensive programs in the areas of radiation safety, energy, health, and contamination of the environment. Examples are the Nuclear Regulatory Commission, Department of Energy, Food and Drug Administration, Environmental Protection Agency, Health Physics Society, and the Conference of Radiation Control Program Directors.

Radiobioassay and Environmental Radioactivity (K.G.W. Inn)

The American National Standards Institute Committees N13 and N42, with significant input from the Office, have been active in developing consensus performance criteria for radiobioassay and environmental radioassay laboratories. These criteria include guidance on measurement accuracy and precision, proficiency testing for traceability, in-house quality assurance, and quality assurance for customer related services. The draft radiobioassay laboratory performance standard is poised for trial testing, and the Office has begun discussions to address the Department of Energy's needs for a proficiency testing program. The draft of the environmental radioassay laboratory performance standard will soon be ready for comment and trial use.

State-Operated Calibration Laboratories (H. T. Heaton & E. H. Eisenhower)

The secondary laboratory in Illinois has moved to a new facility. The lab is now in the process of characterizing the new ^{137}Cs sources (50 Ci and 130 mCi) and x-ray unit. With these major changes, the laboratory will have to reapply for Conference of Radiation Control Program Directors (CRCPD) accreditation. The laboratory in South Carolina is also building a new laboratory site which will allow them to install a gamma-ray source in addition to the x-ray unit. A visit was made to the California laboratory to discuss revisions to their protocol as well as to review the laboratory against the CRCPD accreditation criteria. These three laboratories are using the calibration computer code developed by the Office. This necessitated a complete rewrite of the Illinois and South Carolina protocols. There have been no major changes in the laboratories in Washington or Arkansas.

Private-Sector Calibration Laboratories (E. H. Eisenhower & H. T. Heaton)

The operational protocol for a new secondary calibration laboratory was reviewed. Additional revisions are necessary before requesting proficiency testing by NIST. The relationship between this program and the Federally-owned Laboratories Program was discussed at the Health Physics Society's Laboratory Accreditation Standing Committee (LASC) mid-year meeting.

Federally-Owned Calibration Laboratories (E. H. Eisenhower, K.G.W. Inn & H. T. Heaton)

The accreditation for these laboratories is being set up under the National Voluntary Laboratory Accreditation Program (NVLAP) as the Secondary Calibration Laboratories for Ionizing Radiation program. The criteria developed by 26 representatives from DoC, DoD, DoE, FDA, and FEMA have been completed. A checklist for use by the Technical Experts for NVLAP has also been developed. Personnel from the Office actively participated in the development of these documents, will serve on the on-site assessment team, and will conduct the proficiency tests.

Personnel Dosimetry (H. T. Heaton & E. H. Eisenhower)

A site visit was made to the testing laboratory for the NVLAP program on Personnel Radiation Dosimetry. Intercomparsions of exposure and exposure rate measurements, as well as half-value layer and homogeneity coefficient determinations, were made for selected x-ray beams. The results of all the intercomparsions were within acceptable limits (±4%). At the same visit, the checklist developed for the NVLAP Secondary Calibration Laboratories for Ionizing Radiation program was tested.

Transfer Standard QC Test Facilities (H. T. Heaton)

The facilities for monitoring the consistency of the transfer standards for proficiency testing have been completed. There are separate facilities for x-rays (150 kV range) and gamma rays (^{137}Cs horizontal source range). These facilities were designed to verify the response of the transfer standard before and after the proficiency test. Methods are being developed to extend the capabilities of these facilities by rigorous intercomparisons with the standard photon sources in the Radiation Interactions and Dosimetry Group.

Accredited Dosimetry Calibration Laboratories (P. J. Lamperti & H. T. Heaton)

There are presently five accredited dosimetry calibration laboratories (ADCLs) in the American Association of Physicists in Medicine (AAPM) program. The steering committee for the program is Task Group 3 of the AAPM. In the past year a NIST representative attended two meeting of the steering committee and made a site visit to the K & S Associates laboratory in Nashville, TN. In Nashville, their instrument calibration and brachytherapy source calibration procedures were discussed. The laboratory director from the University of Wisconsin ADCL visited NIST on two occasions to discuss ophthalmic applicator calibrations and iridium-192 brachytherapy calibrations, respectively.

Radon (R. Collé)

The Office continued to provide a leadership role in planning activities for developing new radon measurement transfer standards, and upgrading "in-house" radon measurement capability. New and ongoing technical studies, performed in collaboration with members of the Radioactivity group, include work on: the primary radon measurement system; the prototype transfer standard for flux density measurements; measurement intercomparisons with other national and international laboratories; the radon-in-water standard generator; and radon calibrations by liquid-scintillation counting. Technical aspects of these projects are described under the Radioactivity Group (536.04) section of this report.

Measurement Uncertainties (R. Collé)

For the past two years, a member of the Office served as chairman and NIST representative to the ISO international working group on measurement uncertainties. These duties and responsibilities were transferred in the beginning of the year to a new chairman following the Office member's resignation from these positions. The second draft of the guidance document, initiated and partially completed under the direction of the Office, has since been completed and distributed for comment.

ASTM Standard on Dosimetry Calibration Laboratory (J. C. Humphreys & E. H. Eisenhower)

A standard is being developed in ASTM Subcommittee E 10.01 (Dosimetry for Radiation Processing) entitled "Practice for the Characterization and Performance of a High-Dose Gamma Radiation Dosimetry Calibration Laboratory". This practice contains performance criteria for laboratories that provide dosimetry calibration services for the measurement of absorbed dose in materials undergoing industrial radiation processing and testing. Organizations that might provide such calibration services and thereby serve as a link to national standards include private companies, universities, or other government-owned laboratories (state or federal). To ensure the provision of adequate services by such a calibration laboratory, appropriate criteria need to be satisfied. This ASTM standard has been balloted and revised and is expected to be approved and published within a year. It will form the basis for the accreditation of these calibration laboratories. The accrediting organization and procedures have not been formalized yet, but it will possibly be done through the NVLAP program at NIST.

II. Radiation Interactions & Dosimetry Group

In the March 1988 reorganization of programs in the Ionizing Radiation Division, the Radiation Interactions and Dosimetry Group was created to consolidate programs in radiation sciences and dosimetry of x-rays, gamma-rays and electrons. The mission for the Group is to develop, maintain and disseminate the national standards for these radiations, and to engage in research on radiation interactions and effects to meet requirements for new standards. The new group is presently divided into four Projects:

- Radiation Sources
- Physical Interactions and Dosimetry
- Chemical Interactions and Dosimetry
- Radiation Measurement Services

The Radiation Sources Project consolidates the operation, maintenance, and updating of the electron, x-ray, and neutron producing sources of the division. These sources when combined with the high precision x-ray generators used for dosimetry and calibrations and a large number of radioactive sources are the backbone of the experimental programs of the division.

The Physical Interactions and Dosimetry Project combines the experimental, theoretical and computational research and metrology which was formerly carried out in three separate Groups. The four programs in this project are: theoretical dosimetry, medical dosimetry, radiation protection dosimetry and x-ray imaging. The Chemical Interactions and Dosimetry Project has two programs: radiation and oxidative biochemistry, and chemical dosimetry. All of these programs are interdisciplinary and a high degree of cross-talk between physicists and chemists is encouraged.

The Radiation Measurement Services Project combines the calibration services and measurement assurance programs for industrial, medical, military and personnel protection applications. The project also includes technical support for the accredited dosimetry calibration laboratories (ADCLs) as well as measurement assurance programs in dosimetry and radiographic imaging for other agencies.

The technical activities of these four projects during the past year are given on the following pages.

A. Radiation Sources Project (C.E. Dick, R. J. Biss & M. R. McClelland)

This project encompasses the 300-kV industrial x-ray source, the 500-, 1500-, and 4000-keV electron accelerators and the 3000-keV positive ion accelerator. In addition, consulting is provided for the 600- and 2000-keV flash electron generators. Operationally, the flexibility of consolidating radiation source management and operations is providing a more efficient vehicle for the servicing and improvement of these sources, since more personnel are available for any particular situations that arise. In the past year, an additional x-ray source has been obtained and significant improvements have been made to several sources as outlined below.

The experimental room associated with the 300-kV x-ray machine has been improved with the addition of optical benches and a mount for the tube head on these benches. This system permits accurate repositioning of the source to object and source to detector distances in those measurements where reproducibility of these distances is essential. This machine has been utilized for a number of measurements including the study of PIN diode x-ray detectors and the radiographic examination of a sealed time capsule for the National Geographic Society.

Work has continued to upgrade the performance of the 3-MeV positive ion accelerator which is used to produce neutrons via nuclear interactions. Modifications to the electronics have been completed and the accelerator is now capable of stable operation at voltages up to 3 million volts. Additional pumping has been added to improve the vacuum in the accelerator tube structure to increase the available beam current. The entire vertical beam handling system has been realigned and deuteron currents of up to 100 μamp are now attainable.

A new x-ray source with maximum voltage of up to 420 keV has been obtained from the U. S. Navy. This source which was used in the missile inspection program has been refurbished and is presently being installed. This source will provide high-energy x-ray beams with a maximum beam power of 4 kW.

B. Physical Interactions and Dosimetry Project

1. Theoretical Dosimetry

The general objective is to carry out studies of radiation interactions with matter, and of radiation transport in bulk media, in order to generate basic radiological physics information in areas including biomedical radiation dosimetry, assessment of radiation hazards in nuclear technology, modeling of biological radiation action, radiation metrology and source characterization, space shielding, auroral physics and space science, and industrial and military technology. This work includes the development of transport-theoretic methods, the compilation and critical evaluation of the underlying single-scattering cross sections, and the application of the transport methods to radiological physics problems.

Computational ^{60}Co Dosimetry (S. M. Seltzer)

For purposes of assessing energy response of detectors used to monitor the dose in radiation processing, a series of Monte Carlo calculations has been completed of the photon fluence (unscattered and scattered) at various depths in a unit-density water product irradiated by a large ^{60}Co plaque source assumed comprised of AECL Type C-188 source pencils. The fluence spectra were used to calculate the ratio of the absorbed dose in various thick dosimeters to that in the water product; dosimeter materials of C, LiF, $Li_2B_4O_7$, SiO_2, PMMA, nylon, and alanine, and of ferrous sulfate, ceric sulfate, K-Ag dichromate, and ethanol-chlorobenzene solutions were considered. A paper describing this work was given at the 7th International Meeting on Radiation Processing, Noordwijkerhout, The Netherlands, April 23-28, 1989, and will be published in the Journal of Radiation Physics and Chemistry.

Auroral Bremsstrahlung Calculations (S.M. Seltzer)

Extensive Monte Carlo calculations of the bremsstrahlung flux produced by electrons slowing down in air have been done for a NASA project to characterize auroral bremsstrahlung phenomena. The generated information includes the electron and photon fluence distributions (differential in energy and angle) and the energy deposition as functions of altitude in the Earth's atmosphere, from auroral electrons with initial energies from 1 keV to 20 MeV.

Accelerator Shielding Studies (S.M. Seltzer & G. Barnea)

Calculations of thick-target bremsstrahlung production and transport were done to provide input for shielding studies for the NIST free-electron laser project.

Transport Theory (S. M. Seltzer & M. J. Berger)

The book Monte Carlo Transport of Electrons and Photons (Eds. T. M. Jenkins, W. R. Nelson, and A. Rindi), Plenum, NY, has been published. This work is based on lectures given at the 8th International School of Radiation Damage and Protection (Ettore Majorana Center, Erice, Italy), and contains six chapters focussing on the NIST general-purpose electron-photon transport code ETRAN, including the cross-section input, the underlying Monte Carlo model, computational aspects, and a review of the extensive results obtained with the code.

Monte Carlo Code Development (S.M. Seltzer)

A number of improvements to the ETRAN code have been made this year, including: the treatment of binding effects on the incoherent scattering of photons from atomic electrons, and of coherent photon scattering from the screened nuclei of the atomic constituents; an improved treatment of multiple and plural elastic scattering of electrons over short path segments; corrections to the sampling of electron energy-loss fluctuations; and the treatment of fluctuations in the transverse and longitudinal displacements in the multiple-scattering electron random walk.

Bremsstrahlung Cross Sections (S. M. Seltzer)

A PC database and code has been developed for the calculation of bremsstrahlung production cross sections, differential in emitted photon energy, for electrons with kinetic energies from 1 keV to 10 GeV for any material specified by the user. The code handles a variety of input for the composition of the material, including chemical formulas, and includes graphics output to screen and printer. The code has been given to the NIST Office of Standard Reference Data for public distribution.

Photon Cross Sections (J. H. Hubbell)

In preparation for a new compilation of photon energy-absorption coefficients, a critical review and evaluation of the x-ray fluorescence yield has been completed. This work is detailed in a report NIST IR 89-4144 (1989), which includes tables of recommended, state-of-the-art values of the fluorescence yields for the K, L, and M shells of all elements Z=1 to 100; parameters for standard-form empirical fits of the yields; and a review and bibliography of measurements covering the period 1978-1988 since the last major review of such data.

Proton and Alpha Particle Stopping Powers (M. J. Berger)

Two stopping-power and range tabulations have been completed, one for protons with energies from 1 keV to 10000 MeV, and the other for alpha particles with energies from 1 keV to 1000 MeV. The printed tables include data for 25 elements and 48 compounds and mixtures. Above a cut-off energy of 0.5 MeV for protons and 2.0 MeV for alpha particles, electronic stopping powers were calculated using Bethe's theory, with empirically-determined mean excitation energies, shell corrections, Bloch and Barkas corrections, and density-effect corrections. Below the cut-off energy, the evaluation of electronic stopping powers was done on a strictly empirical basis, relying on critical reviews of experimental stopping powers. Nuclear stopping powers and detour factors were obtained as part of a calculation of elastic-scattering cross sections. In addition to the csda range (mean pathlength), the tables also include the detour factors which represent the ratio of the mean penetration depth to the tabulated csda range. A universal computer program has been developed which can be used on a personal computer to obtain electronic stopping powers in the Bethe energy region (above 0.5 MeV/amu) for any charged particle (electron, meson, proton, or heavy ion) in any element, compound or mixture.

Electron Elastic Scattering Cross Sections (S. M. Seltzer, M. J. Berger & A. Schechter)

The database of electron elastic-scattering cross sections was expanded at low energies (below 8 keV). The angular distributions from the previous calculations (based on a relativistic partial-wave expansion, using Hartree-Fock potentials) show a complicated structure due to virtual bound states, particularly for high-Z atoms. Interpolation using the previous database was found to be inaccurate at the low energies. New, systematic phase-shift calculations were done to provide finer coverage in energy and angle in this region. The "exact" phase-shift calculations done to develop the original electron elastic-scattering cross-section database have been repeated for positrons. The results, which cover energies from 1 keV to 1 MeV (above which simpler methods can be used) and all elements with atomic numbers from 1 to 100, are being organized into a computer-readable database for later incorporation into our transport codes.

Electron Stopping Powers (S. M. Seltzer)

A PC program EPSTAR has been developed, and given to the NIST Office of Standard Reference Data for dissemination, to calculate the stopping powers (collision and radiative), csda ranges and radiation yields of electrons and positrons in the energy region from 1 keV to 10 GeV. The code incorporates the basic cross-section data (with minor improvements) and algorithms used in preparing the tables for ICRU Report 37 "Stopping Powers for Electrons and Positrons", so will allow the user to reproduce those results and to extend the calculations to any material and energy-list of choice.

2. Medical Dosimetry

National standards for therapeutic uses of ionizing radiation are based on instruments and radiation beam facilities maintained at NIST. The major radiation therapy modalities are 1) radiation beams (both ^{60}Co and megavoltage photons and electrons from accelerators), 2) radiation sources (photon sources such as ^{125}I and ^{192}Ir for brachytherapy, ^{90}Sr beta-particle sources for surface tumors), 3) radiolabelled therapeutic drugs (^{90}Y labelled monoclonal antibodies), and 4) neutron therapy. Radiation beams account for greater than 90% of patient treatments, and NIST has had a program for over 40 years to provide exposure (Roentgen) and now air kerma and absorbed dose (Gray) standards. Development of national standards for brachytherapy and dosimetry for radiolabelled drugs depends strongly on the radiations of the radionuclides employed. NIST priorities in developing national dosimetric standards are set in consultations with outside groups, such as the Radiation Therapy Committee of the American Association of Physicists in Medicine (AAPM).

Dosimetry of High-Energy Photon and Electron Beams (L. J. Goodman, C. G. Soares & R. Loevinger)

The electron beam of the NIST racetrack microtron will be used to produce collimated beams of high-energy photons and electrons, which will simulate those applied clinically to treat cancer. A beam line will be used to transport the electron beam to a transmission window from which it will enter a target, filter, and collimator assembly. The electron beam current and energy required will range from about 180 μA at 5 MeV to about 1 μA at 35 MeV. The apparatus which has thus far been designed and constructed includes a target, filter, and collimator assembly, a special alignment and support table for this assembly, and a rolling table with a remote-controlled translation platform for positioning the phantoms and dosimeters. Updated information on water-phantom systems has been obtained from vendors and evaluated relative to the needs of this project. Using these data, detailed specifications for the water-phantoms system have been written to expedite ordering this apparatus as soon as funds become available.

Absorbed Dose Calorimetry (S. R. Domen)

NIST has developed a series of calorimeters as part of a program to develop reliable national measurement standards for absorbed dose. The NIST water calorimeter has aroused much interest and has been studied in a number of standards laboratories and universities. One of the persistent problems, which has not received adequate attention, is the effect of convection on the accuracy of temperature readings by the tiny thermistors. An experiment was devised to study this phenomenon using controlled flow past thermistors operated at various power levels. The results of this experiment will allow water calorimeters to be operated at room temperature without loss of accuracy because of concerns about convection. A new model of a high-purity water calorimeter has been designed, which is also based on calculations of the effects of materials other than the high-purity water. Preliminary work has been successfully completed on the fabrication and assembly of micro-bead thermistors within thin glass capillaries, which are to be the temperature sensors, located in two opposite arms of a Wheatstone bridge circuit. They are enclosed in a thin-walled glass container filled with high purity water. Three such complete assemblies have been constructed and the thermistors were calibrated to permit measurements of temperature rises. Some preliminary measurements are in progress by using the present ^{60}Co source. Higher precision measurements will begin after the installation of a more active ^{60}Co source. Extensive measurements are planned to resolve the heat-defect problem.

Examination of the internal structure of the A-150 plastic calorimeter built for NIST revealed some undesirable features. A new calorimeter must be designed and constructed. Preliminary work in progress are calculations and measurements of heat flow studies, which will aid in the proper design of the calorimeter. The completed calorimeter will be tested in the NIST ^{60}Co beam for comparison of calorimeter and ionization-chamber measurements. A similar comparison will be made at another institution using a beam of 15-MeV neutrons.

Ophthalmic Applicator Calibrations (C. G. Soares)

NIST has offered a calibration service for strontium-90/yttrium-90 ophthalmic applicators since 1976. This service provides the customer with source area and surface absorbed-dose rate averaged across the source. In FY89, 11 sources were calibrated, the largest number of any year to date. Recently a large discrepancy in calibrations of the same source between NIST and the only remaining ophthalmic applicator source manufacturer (Amersham International) was brought to light. This has stimulated renewed research into the proper ways to calibrate such sources. In March 1989, NIST hosted a Workshop bringing together representatives from medicine, calibration laboratories, source manufacturers and regulators to discuss the problems. One of the outcomes of this workshop was a planned calibration intercomparison between NIST, Amersham International and other laboratories. At NIST, research was begun on the possibility of replacing the current extrapolation ionization chamber-based calibration with one based on the use of radiochromic dye films. This has been made practical with the acquisition by NIST of a scanning laser micro-densitometer. Such a calibration has the advantage of providing the user with much more information about how the activity is distributed across the surface of his source, which is especially important to know when the source is used with defining apertures.

Wide-Angle Free-Air Chamber for Low-Energy Photons (R. Loevinger)

Several authors have noted that the NIST standard for ^{125}I brachytherapy sources is probably in error by 5% to 10%. This problem is due to the presence of characteristic x rays from the titanium cladding of the sources, which was not taken into account when the NIST standard was established (T.P.Loftus, J. Res. Nat. Bur. Stand, 89, 295-303, 1984). It has been found impossible to correct this error by reexamination of the existing data. Instead of repeating the difficult free-air-chamber measurements used in establishing the standard, a new wide-angle free-air chamber (WAFAC) has been designed that accepts a solid angle about 65 times larger than the conventional free-air chamber used by Loftus. Because of the short range of low-energy electrons in air, it has been found possible to design a large-volume chamber in which electrons from the side walls cannot reach the measurement volume. Electrons from the thin entrance and exit windows are accounted for by a compensation method that subtracts measurements made with a suitably shortened chamber. The WAFAC has been designed for measurement of photon beams with energy up to about 35 keV. Initial measurements will consist of comparison with an existing NIST standard free-air chamber, using 10-keV to 30-keV x-ray beams. If these tests are satisfactory, the WAFAC will become the NIST standard for ^{125}I (photons up to 35 keV) and ^{103}Pd (photons up to 23 keV) brachytherapy sources. Mechanical design of the WAFAC has been completed. It is expected that construction will be completed early in FY90, and tests started immediately thereafter.

Development of Dosimetry Standards for Neutron Therapy (L. J. Goodman, D. M. Gilliam, S. R. Domen, J. J. Coyne & R. S. Caswell)

Neutron radiation therapy is being clinically tested at several cancer treatment centers in the United States and at other centers worldwide. To facilitate the exchange of clinical information between treatment centers, it is essential that the U.S. neutron dosimetry standards be accurate and consistent with the international standards system. The National Cancer Institute (NCI) has sponsored a dosimetry program aimed at improving the accuracy, developing national dosimetry standards, and providing improved data on neutron interactions in tissue an tissue-like materials. Although this NCI contract was terminated, two tasks require further work. First, we will compare the ionization-chamber-dosimetry method of measuring neutron kerma to the determination of this quantity from measurements of neutron fluence using mono-energetic 15-MeV neutrons, an energy more appropriate for developing a neutron standard then that used previously. Second, a comparison between the ionization-chamber method and a tissue-equivalent calorimeter is planned, using a new calorimeter to be designed and constructed at NIST. Completion of these comparisons will help NIST provide the required standards.

Reactor Dosimetry and Consultation at AFRRI (L. J. Goodman, R. B. Schwartz, E. D. McGarry, D. M. Gilliam & C. M. Eisenhauer)

Work performed under this contract with the Armed Forces Radiobiology Research Institute (AFRRI) aims to improve the accuracy and long-term consistency of neutron and gamma-ray dosimetry at the AFRRI research reactor by consultations with a group of NIST scientists and by providing specific dosimetry services. This effort is needed to support the radiobiological studies at AFRRI because of the relatively frequent (approximately 2-year) turnover of scientific military personnel at AFRRI. It is essential that accurate dosimetry methods support the radiobiological experiments in order to relate this research to similar work at other laboratories.

During the past year, we have performed dosimetry inter-comparisons in the mixed neutron and gamma-ray fields of the AFRRI reactor, we have tested and calibrated the fission-chamber monitoring system we designed and installed, and we have made spectra measurements and calculations for the reactor radiation fields.

3. Radiation Protection Dosimetry

Currently, a significant effort of the Radiation Interactions and Dosimetry group in the radiation protection area is in the area of standards writing. We are attempting to spearhead the introduction and use of the SI system of units and particularly the new series of radiation protection quantities introduced in ICRU Publication 39, "Determination of Dose Equivalents Resulting from External Radiation Sources". Experimental work is carried out on the NIST x- and gamma-ray ranges, and with monoenergetic electron beams to test the efficacy of some of the written protocols.

Personnel Dosimetry (C. G. Soares & M. Ehrlich)

Work on revision of ANSI Standard N13.11, "Personnel Dosimetry Performance - Criteria for Testing" continued, with C. Soares attending three meetings of the working group. In support of this work a collaboration with AFRRI personnel was begun for generating new spectrum-averaged conversion factors using the new ICRU 39 measurement quantities, which involves measuring photon backscatter as function of phantom geometry, energy and angle. Geometries investigated so far include the conventional Lucite (polymethylmethacrylate) slab phantom, and a 30-cm diameter Lucite sphere. Acquisition of a nearly tissue equivalent 30-cm sphere from Germany is under way.

Activities of M. Ehrlich in radiation-protection dosimetry relate to work on two committees of the International Standards Organization. One deals with radiation fields for the calibration of radiation-protection instruments and the other with performance characteristics of photographic personnel dosimeters. She was present at meetings of both in Bologna, Italy in June. She also works on a committee of the American National Standards Institute, dealing with dosimetry quantities for use in radiation shielding.

Hot-Particle Characterization Studies (C. G. Soares & B. M. Coursey)

An emerging problem in the nuclear power industry concerns the correct assessment of skin dose from contact exposure to highly radioactive microscopic particles. In collaboration with the University of Lowell, preliminary measurements on some test hot particles were made at NIST, including diameter, activity and exposure rate. A technique is being developed for measuring 1-cm^2 averaged dose rate from hot particles using multiple exposures of radiochromic dye films read with a scanning laser micro-densitometer.

Standard Monoenergetic Electron Beams (C. G. Soares)

NIST has been requested by the radiation protection community to establish standards for and assist in the development of methods of measuring the beta-particle radiation fields that are found in nuclear power installations. Beta-particle detection instrumentation is currently being calibrated using only broad-spectrum radionuclide sources at only a few fixed dose rates. In order to determine instrument response as a function of energy and rate in detail, NIST has developed a set of accelerator-produced nearly monoenergetic electron beams. A paper describing the current status of the facility was presented at the Second Conference on Radiation Protection and Dosimetry in Orlando in November 1988. The flexibility of the beam monitoring system also allows radiation processing level exposures to be made. In this mode, a cooperative effort was initiated with COMSAT Inc. for testing a GaAs displacement-damage dosimeter.

Development of High-Dose and Emergency Neutron Dosimeters
(W. L. McLaughlin, D. Gilliam, V. Spiegel, S. Kronenberg, J. Grundl & M. F. Desrosiers)

There is a need for improved measurements of absorbed dose in mammalian tissues due to irradiation of mixed fields of neutrons, photons, and electrons. Several successful experiments have been performed during the past year on optical waveguide dosimeters designed to operate in the albedo mode, to measure the dose components in pairs, with one dosimeter more sensitive to neutrons and the other less sensitive to neutrons. The measurable dose range in question is 0.2 to 10 Gy (gray), which will be useful for post-accident evaluation and epidemiology. The system is more accurate than thermoluminescence albedo dosimeters in this dose range, mainly because of the good linearity and tissue equivalence.

4. X-Ray Imaging Sciences

The NIST program in radiation imaging is mainly in the area of x-ray sensor development for dental, medical and industrial applications. Real-time digital radiography is the primary goal in all these applications and the US is in a highly competitive race with other industrial nations to develop these imaging systems. The Group's program takes full advantage of the wide range of x-ray sources available in-house, theoretical support from the theoretical dosimetry program, and strong collaborations with university and industry investigators to test and evaluate new classes of sensors.

Photostimulable Storage Phosphors (C. E. Dick, G. Barnea, E. Navon, H. Roehrig & R. C. Placious)

For diagnostic radiology, a new type of imaging system based on the properties of photostimulable phosphors is becoming available. These materials record the incident x-ray exposure in deep traps in the material which have long lifetimes but can be destructively read out upon interrogation by an infrared laser. The resulting output is detected by a photomultiplier system and digitized by an online computer. The chief advantage of this system is that it has wide dynamic range and a nearly linear response. In addition, since the data is stored in a digital format, image processing can be applied to enhance the image. Experiments have been completed to investigate the storage efficiency and sensitivity of this imaging medium. Preliminary results indicate that the process can be successfully modeled by a Monte Carlo calculation of the charge storage and retrieval process. Presently, the calculated and experimentally measured data agree to within 10% for an x-ray excitation energy of 662-keV. Data are also being gathered on the fading of the storage screen and the lifetime of the stored image information.

Characterization of Metallic Intensifying Screens (C. E. Dick, E. Navon & G. Barnea)

In industrial radiography, metallic screens are frequently used between the x-ray source and the photographic film recording media. The purpose of these screens is two-fold: a) to reduce the amount of scattered radiation reaching the image plane; and b) to increase the sensitivity of the imaging system. The reduction of scattered radiation helps remove the background fog from the radiographic image since scattered radiation impinges on the imaging system at non-normal incidence. The second effect is produced by the generation of secondary electrons in the metal screens upon the absorption of the primary x-ray beam. The photographic film is far more sensitive to electrons than to the primary x-ray beam. Previous experiments carried on at NIST have measured this photographic effect for aluminum, copper, and lead screens for 662-keV incident photons. These measurements have been extended to

250-keV. The relative photographic effect (RPE) has been measured as a function of the screen thickness and screen location (front or back) for both the front and back emulsion of a typical x-ray double emulsion film. The process has been modeled by a Monte Carlo calculation based on the ETRAN model which includes geometrical factors. The experimental and calculated data agree to within 5% and indicate the relative energy deposition in the film emulsion by electrons generated by photon interactions in the metallic foils.

Solid-State X-Ray Imagers and Detectors

a) PIN Diodes (C. E. Dick, D. Salerno & G. Barnea)

Recent experiments in the imaging properties of solid state devices have indicated that even very thin silicon devices are capable of detecting x-ray photons with energies in the diagnostic imaging range (20-70 keV). A series of experiments has been initiated to study the response of PIN (positive-intrinsic-negative) diode structures with thicknesses of less than 100 μm to x-rays in this energy range. The data indicate that even these thin devices are not only capable of detecting the x rays but provide some degree of energy discrimination. The x-ray detection efficiency is quite small (10^{-5} - 10^{-6}) so that these devices may be useful in measurements of the outputs of diagnostic x-ray machines where conventional x-ray spectrometers cannot be used. Monte Carlo calculations to correct for the diode energy response have been initiated. Studies are also underway to investigate the radiation resistance of these devices.

b) Phosphor/CCD Imagers (C. E. Dick, B. M. Coursey, J. H. Sparrow & J. W. Motz)

For the dental x-ray system developed for the U. S. Army, a new type of x-ray imager is being developed by an outside contractor. This imager consists of an x-ray sensitive phosphor directly coupled to a large format charge coupled device (CCD). This hybrid imager will produce a video compatible signal with a spatial resolution of 5 line pairs per mm over an area of two by three cm. In addition, the whole package will be capable of cold sterilization and be small enough to be used intraorally in dental applications. Experiments have been carried out to determine the radiation hardness of commercial CCD chips and these data were used to design a radiation hardened chip for these devices. Concurrent with this development, a miniature frame store/computer acquisition unit is being developed under separate contract. This unit will provide the necessary logic and interface signals to enable complete image and archival storage of the images produced. Initial tests of the properties of the system, x-ray sensitivity, resolution, contrast, etc. are scheduled to begin in the first quarter of FY90.

Portable 70 kV Dental X-Ray Source (J. H. Sparrow, C. E. Dick & M. R. McClelland)

A portable, battery powered, hand-held, dental x-ray unit has been developed at NIST for the Army Institute of Dental Research. To date, 14 of 18 units have been delivered. These prototype units are presently being tested by various Army groups. USAIDR personnel have reported that these units have been demonstrated at Army facilities in Europe and the US and have been used for personnel identification at several international air crash sites. It was also demonstrated at the International Dental Society meeting held in South America. During this year, other US Government agencies have become aware of the development and two units has been delivered to one of these agencies.

X-Ray Imaging Applications (C. E. Dick, J. H. Sparrow, M. R. McClelland, D. Polanski & R. C. Placious)

This group supports the NIST staff's needs for radiographic nondestructive testing (NDT) by maintaining several x-ray units with energy ranges of from 20 keV to 300 keV. During this year we increased this capability by acquiring, on permanent loan from the Navy, an industrial x-ray unit capable of 420 keV operation. This will significantly increase our capability to inspect thicker materials. During the year we radiographed construction bricks for the Institute of Materials Science and Engineering, protective vests and hand cuffs for the Federal Law Enforcement Standards Laboratory, and a time capsule for the National Geographic Society. The reported 200-year old time capsule with memorabilia from the first inauguration was inspected by computed tomography (CT) at the Washington Hospital Center and at the NASA, Huntsville, AL, CT facility. Only the NIST radiography showed a readable dated medallion, which allowed personnel from the Smithsonian Institution to identify it as a medallion cast for the centennial celebration of the Constitution. (National Geographic magazine, May and September 1989.)

C. Chemical Interactions and Dosimetry Project

1. Radiation and Oxidative Biochemistry

The goal of the program is to understand the kinetics and mechanisms of the interactions of diverse radiations and oxidative processes (single and multiple) with model and complex biosystems at the molecular level, in order to develop measurement approaches and standards for dosimetry of damage (integral and local) and repair. This fundamental understanding of molecular effects leads to diverse applications in radiation processing, radiation protection, radiation biology, radiation therapy, preventive medicine, post exposure dosimetry, and physiology.

Crosslinking Mechanisms (L. R. Karam, D. S. Bergtold & M. G. Simic)

Mechanisms of radiation-induced crosslinking between DNA and protein components have been investigated as part of an ongoing project. It has been demonstrated that crosslinking between DNA bases and amino acids in nucleohistones may occur *via* two distinct mechanisms: (1) aliphatic C-centered radicals and base radicals, and (2) aliphatic C-centered radicals and DNA bases. Crosslinks of oligonucleotides and amino acids have been investigated by a number of techniques, including light-scattering methods.

Antioxidants and Radioprotectors (S. Jovanovic, E.P.L. Hunter & M. G. Simic)

Antioxidants and sulfhydryls act as radioprotectors and anti-carcinogens and in both cases the mechanism of action is being studied. Mechanisms of heterocyclic thiols have been investigated. The impact of this work is also of significance in food preservation and human physiology. NIST is the only institution in the U.S. dealing with kinetic aspects of antioxidants. The redox potentials of radioprotectors and physiological antioxidants are being investigated at NIST and in collaboration with the Max Planck Institute (S. Steenken) of West Germany.

Oligonucleotide Directed Site Specific Mutagenesis (L. R. Karam, P. Brooks & M. Radman)

Oligonucleotide directed site specific mutagenesis, a technique used to induce specifically defined base alterations (modification, deletion, addition, etc.) at predetermined sites in DNA, can be utilized as a precise model system for radiation-induced DNA alteration. Toward this end we have developed, in collaboration with l'Institut Jacques Monod (Paris), a mutated SK bacteriophage (from M13) derivative with a new restriction endonuclease recognition site. Quantities of the new DNA and host organisms (in inert form) in which to amplify production of the DNA now are available to continue this project at NIST.

Detection of Hydroxy Radical Generation in Biological Systems (L. R. Karam, D. S. Bergtold & M. G. Simic)

Since radiation and other mechanisms of hydroxy radical generation all contribute to modifications and oxidative damage in living systems, the detection of these alterations *in vivo* may be important to both the study of biological systems and the development of post irradiation dosimetry (PID) techniques for use in the event of accidental exposure of personnel to radiation or exposure of radiation therapy subjects.

Gas chromatography-mass spectrometry (GC-MS) has been used to measure quantities of o-tyrosine in hydroxy radical generating systems both in vitro (Fenton-Haber-Weiss reaction) and in vivo (E. coli grown in the cell biology/biochemistry laboratory). By this approach the mechanisms of free radical reactions have been examined in parallel systems so the results obtained in vitro are more directly applicable to the situation in vivo.

By similar methods, analytical PID techniques of potential use in radiation therapy and in measurements of the dose received by NASA personnel exposed to cosmic showers and solar flares in space are under investigation. One approach receiving particular attention is the measurement of urinary excretion of unique radiolytic products (URP's), or specific markers, in individuals exposed to ionizing radiations.

Enzyme Deficiencies (L. R. Karam, D. S. Bergtold, M. G. Simic, T. Lindahl & M. Radman)

Several strains of E. coli from l'Institut Jacques Monod are currently under study at NIST in the newly operational cell biology/biochemistry laboratory. These strains have various enzyme deficiencies inhibiting their ability to modify DNA or repair radiation damaged DNA. Along with cells from Ataxia telangiectasia (a human disease characterized by an accelerated build-up of radical-induced damage and extreme sensitivity to ionizing radiation) patients, these differently deficient cells serve as biological models for the study of biomarkers and radiation-induced DNA damage.

Damage to Mitochondrial DNA (D. S. Bergtold & A. M. Hruszkewycz)

Damage to the DNA of the mitochondrion, a primary site of energy metabolism and presumably of oxy radical production, has been detected in the absence of any perturbation, and enhancement of that damage has been linked to the induction of peroxidation in the mitochondrial membrane lipids. Comparison of the relative levels of alteration of the DNA in the nucleus versus the mitochondrion suggests that the level of DNA damage is intimately related to the level of free radical activity at a given location in the cell.

2. Chemical Dosimetry

Radiation applications in clinical and diagnostic medicine, biology, agriculture, radiation protection, power production, pollution control, and a variety of materials effects and industrial processes cover a very broad range of doses (10^{-6} to 10^{6} Gy) and dose rates (up to 10^{14} Gy s^{-1}.) Chemical dosimetry offers useful means of measuring such quantities, and is well suited to solving particular problems in each of these fields. This program encompasses both fundamental chemical mechanistic studies and experimental aqueous, and organic, liquid and solid-state R & D afforded by chemical radiation sensors. At the forefront is the development of new and practical dosimetry systems, as well as state-of-the-art analytical methods, for addressing key measurement needs and achieving standardization and measurement quality assurance.

Reference Chemical Dosimeters (W. L. McLaughlin, B. M. Coursey, M. Desrosiers, J. C. Humphreys, M. Farahani, M. Al Sheikhly, Chen Yundong & L. Sheahen)

Development of several chemical dosimeters suitable as reference standard systems has been started during the past year. Now that the new ESR spectrometer is installed and operating, the development of amino acids, saccharides, glasses, polymers, and solid state systems is proceeding with promise for SRM and reference standards within another year. These would serve as solid radiation measurement systems for wide dose ranges ($1-10^5$ Gy) and broad applications. Other reference chemical dosimeters were developed during the year and include both organic (radiochromic dye) and aqueous (dichromate) liquid solutions, analyzed by spectrophotometry. ASTM standards, now in the final draft stage, cover some of these newly developed dosimeters, and those on alanine and dichromate are in the preliminary draft stage. One of the leuco dye solutions has just been initiated as NIST SRM 4500.

Dosimeter Film Developments and Applications (W. L. McLaughlin, C. G. Soares, M. L. Walker, J. C. Humphreys, M. Al Sheikhly, M. Farahani & Chen Yundong)

Far-reaching advances occurred in 1988-1989 in the development of radiochromic systems. In particular, the two existing collaborations between NIST-CRR and commercial suppliers (Far West Technology, Inc. and GAF Chemical Corporation) have lead not only to highly promising thin film sensors, but also to revolutionary advances for applications in clinical medicine and dentistry, brachytherapy, maxillo-facial and ophthalmic tumor treatment planning, dosimetry mapping in food and industrial processing, radiation sterilization, environmental and emergency dosimetry, and beta-ray and photon calibrations. The new dosimeters have very high spatial resolving power and the two most promising ones in use are FWT-63-20 (thick PVB films) and GafChromic™ Dosimetry Medium (thin coated films). The dose range for both film types is $10 - 3x10^4$ Gy. A new scanning densitometer has been programmed especially to analyze the second of these film types for two- and three-dimensional dose mapping. Another collaboration is just underway with 3M Co. to develop and test still another promising film system useful at higher doses ($10^4 - 10^6$ Gy). This film has less sensitivity to ultra-violet light than the others. Still another dye film is being developed in NIST-CRR for remote sensing and telemetering of dosimetry data.

Chemical Dosimetry Mechanisms (W. L. McLaughlin, M. Al Sheikhly, M. F. Desrosiers, M. L. Walker & M. Farahani)

Two papers have been published and two are in preparation describing the radiation-induced mechanisms of dye formation in liquid- and solid-phase organic triphenylmethane leuco dye solutions and of reduction of the dichromate ion in acidic aqueous solutions. By unraveling the kinetics and fast intermediate stages leading to dye cations and Cr(III) valence states in these two systems, as well as the measurement of accurate radiation chemical yield and molar absorptivities, improvements and enhancements of sensitivities have now been achieved. Perhaps the most important accomplishment for practical dosimetry is the broadening of dose responses in these solutions as reference standards, thus improving the state-of-art in chemical dosimetry well beyond the rather limited range and capability of the Fricke (ferrous sulfate) aqueous system. During the next year there are plans to investigate the chemical kinetics of other novel radiation sensors having promise for dosimetry.

Laser Telemetering Dosimetry System (M. L. Walker & W. L. McLaughlin)

Work is underway on the development of a long-range laser-based system for the remote detection of radiation fields and the dose delivered by these fields. The system employs several wavelengths of laser light characteristic of Ar-ion and HeNe lasers (488 to 514 nm, and 632.8 nm, respectively) with the appropriate radiosensitive materials (radiochromic films and solutions) to assess the dose received at a given point. The system should, in principle, detect and quantitate fields from considerable distances. Several industrial and medical applications of the system are presently being investigated.

Laser Densitometry Mapping of Beam Profiles (M. L. Walker, W. L. McLaughlin, J. C. Humphreys, J. M. Puhl, C. G. Soares & H. T. Heaton)

Work is underway to determine the usefulness of laser scanning densitometry for reading radiochromic films exposed to isotopic radiation sources and beams. The films are exposed to these sources and the image produced on the film is read by the LKB Pharmacia laser densitometer. The densitometer employs a HeNe laser operating at 632.8 nm and is capable of both 1 and 2-dimensional scans with a spatial resolution of 40 micrometers in both the x and y directions. The densitometer digitizes the film image and then outputs it via the vender software package or in-house routines. Current applications include the profiling of strontium-90 ophthalmic applicators, submillimeter radioactive sources ("hot particles"), and several gamma-ray and x-ray sources. Considerable success has been achieved in these efforts with enhanced resolution over previous methods.

Alanine Dosimetry (W. L. McLaughlin, M. F. Desrosiers, J. C. Humphreys, L. Sheahen & J. M. Puhl)

A new class of radiation dosimeters is being developed using crystalline alanine as the detector. The measurement method is ESR spectrometry. The advantages of this dosimeter are numerous: stability, broad dose range (0.5-10^5 Gy), independence of dose rate, near tissue equivalence, non-destructive measurement technique, small size, good reproducibility.

The dosimeters would be in the form of a pellet for ^{60}Co dosimeters and a film for electron beam dosimetry. Optimization of the physical dimensions and chemical composition is in progress. Studies on the radiation response of numerous candidates for a polymer binder have been made. This study has led to the serendipitous discovery of a few polymer materials which may themselves be useful ESR dosimeters (i.e., no alanine needed).

Post-Irradiation Monitoring of Foods (M. F. Desrosiers & W. L. McLaughlin)

The use of ionizing radiation to extend the shelflife of foods is increasing rapidly worldwide. Currently, U.S. food regulatory agencies have no reliable methods for screening imported irradiated foods. Electron spin resonance (ESR) spectrometry is the most sensitive and unequivocal technique for monitoring irradiated foods. ESR has been most successfully applied to foods which contain hardened tissue such as the bones and shell of meats and shellfish, and perhaps seeds and skins of fruits, nuts, and vegetables. The level of precision that this method offers is unattainable through any other technique.

An important feature of this method is that dose measurements can be made with sufficient accuracy and precision using the additional dose method. Re-irradiation in the laboratory generates a well characterized dose response curve for the food examined in terms of ESR signal amplitude (ordinate) versus dose (abscissa). The original, unknown absorbed dose is calculated by careful curve fitting and back-extrapolation to a point on the abscissa. Thus, control samples are unnecessary, also any knowledge of environmental- and sample-dependent parameters such as bone origin and age is not required. Refinement of this method is in progress for several promising food types.

Radiation Accident Dosimetry (M. F. Desrosiers & W. L. McLaughlin)

In the past, there have been numerous incidents of accidental radiation exposures to personnel ranging from individual professional or patient exposures to Chernobyl. Tissue samples were obtained following a recent accidental exposure to two radiation workers. We are applying newly developed ESR methods to estimate the absorbed dose pattern and level for each victim.

The project will be extended to study the radiation-induced ESR signals produced in tooth enamel, hair, nails, articles of clothing and household items. The measurements will allow us to evaluate the feasibility and accuracy of the ESR method and compile a data base for future use.

Chemical Carcinogenesis (M. F. Desrosiers & D. A. Wink)

Nitrosamines have been shown to cause cancer in a wide variety of tissues. The major pathway for metabolism and activation of these carcinogenic agents is a dealkylation pathway via P-450 enzymes. The ultimate carcinogen then is believed to alkylate various macromolecules, damaging both DNA and the DNA repair mechanism. It is presumed that the nitrosamine is activated by abstraction of a hydrogen atom to produce an alkyl radical. In conjunction with the National Cancer Institute, ESR and pulse radiolysis measurements are in progress to identify the reactive intermediates and provide a kinetic analysis of nitrosamine metabolism.

Novel Radiation Sensor Development (W. McLaughlin, M. Farahani, M. Desrosiers, M. Simic & M. L. Walker)

A broad assortment of unusual detectors of radiation are being explored. Several systems have been tested during the past year and show considerable promise for imaging of radiographic patterns, particle track registration, radiochemical sensing, telemetering dosimetry data, and real-time *in vivo* dose-rate measurement. These include liquid crystal assemblies; mono- and polysaccharides; rare-earth and transition-metal doped glasses and inorganic and organic crystals; metallo-porphyrins; metallo-organic complexes; metal-dye complexes; optical waveguide radiophosphors and radiochromic sensors; leuco-base thermo-developing dyes; tetrazolium and phosphomolybdic- and silicotungstic salts; halo- and transition metal-substituted phenylated polystyrenes; polyolefins, polyamides, and vinyl plastics; conducting polymers; and radiochromic gels.

D. Radiation Measurement Services

Radiation measurement services provided by this project provide the physical basis for most of the Nation's quality assurance programs for ionizing radiations: medical, worker protection, industrial, and military. Combining similar services into one project provides economies of scope and scale in delivery of services to users. Innovative practices in one service are quickly adopted by others. Calibration reports, statements of uncertainties, reimbursement practices and database management are coordinated within the project, rather than evolving separately for each type of service.

Performance Evaluations of DOD Radiographic Inspection Systems (J. H. Sparrow & M. R. McClelland)

NIST provides, under contract to the Navy's Special Strategic Programs group, a radiographic/radioscopy quality assurance program in support of their large missile motor NDT program. This function was achieved through nine on-site visitations to Navy and their contractor facilities. We review manufacturer's proposed x-ray NDT procedures for motor components and report to on-site Navy personnel. We periodically perform x-ray energy flux density measurements on the x-ray sources and simultaneously train the on-site personnel to perform the measurement procedures. We also supplied a limited number of instrument calibration services in support of this program.

NIST was represented at two joint Army-Navy-NASA-Air Force, (JANNAF), committee standards meetings where NDT methods and procedures were discussed in relation to military needs.

Dosimetry of High-Energy Electron Beams (J. C. Humphreys, W. L. McLaughlin & S. R. Domen)

Development continued on calorimetry techniques to calibrate and fully characterize high-energy, high-dose-rate electron beams used in the radiation processing industry. These beams generally are in the energy range of 4 to 50 MeV. Some of the applications of such electron beams are to determine the effects of radiation on electronic devices, to sterilize disposable medical products, and to modify polymers. Initial designs of the calorimeters intended to calibrate these beams include multi-foil arrays of graphite or metal with multiple channel data acquisition to provide depth-dose and total dose information. Measurements will be made initially on the University of Maryland 10 MeV linac to provide proof-of-principle data. The design can then be scaled to suit other electron beam energies. Once a given electron beam facility has been calibrated, then it can be used to calibrate the response of passive dosimeters such as dye films and TLDs. This will show whether their response is the same for electrons as for gamma rays.

High-Dose Radiation Calibration Services (J. C. Humphreys, J. M. Puhl & W. L. McLaughlin)

During the past year about 290 calibration irradiations and measurement services were performed for industrial radiation processing facilities, national laboratories, universities, other government agencies, and other users at NIST. Quality control and data analysis for these services have been improved by the use of a new, more efficient, computer-controlled spectrophotometer for dosimeter analysis and by use of more sophisticated data processing techniques. Detailed dose mapping (i.e., the relative dose rate as a function of location within the usable irradiation volume) was performed in the two ^{60}Co sources used in these services. These mappings provide data on the best location for samples to be irradiated and the dose rate uniformity within a given volume at that location. Design work was begun on a new high-activity (approximately 25 kCi (kilocurie)) underwater ^{60}Co irradiator to supplement or replace the present source that has decayed to only 1 kCi. The new source will have automated irradiation timing and computerized data acquisition of all calibration parameters and should greatly improve the throughput of customer calibrations.

High-Energy Electron and Photon Measurement-Assurance Services (C. G. Soares)

Users of medical linear accelerators for cancer teletherapy need assurance that their machines are delivering the required radiation dosage. To meet this need, NIST offers a measurement assurance service that involves mailing to the users passive dosimeters to be irradiated in a prescribed geometry and returned to NIST for evaluation of the absorbed dose delivered. For this service, ferrous-ferric (Fricke) dosimeters are used. There were three mailings of Fricke dosimeters in FY89, involving 51 sets of participants, and a total of 169 dose interpretations. Two batches of dosimeters were prepared. In order to conserve time, and thus cost to the participants, the tests are administered simultaneously to as many participants as the batch size permits.

X-Ray and Gamma-Ray Calibration Services (J. T. Weaver, P. J. Lamperti, Zhang You-zhong & M. D. Walker)

Calibration services (x-ray and gamma-ray instruments, TLD irradiations, and electrometer tests) continue at an increased rate. A total of 107 reports were issued for these tests, and 11 reports on brachytherapy calibrations. The documentation of the NIST calibration procedures, equipment, standards and history for the brachytherapy sources has been published as NBS Special Publication 250-19. Data were evaluated from past x-ray and gamma-ray instrument calibrations to establish a database of most used selectable parameters. The data proved helpful in formulating a relationship between some of the parameters involved in instrument calibration, such as: x-ray tube current, exposure time, source-to-instrument distance, value of the capacitance used to collect charge, ionization chamber volume, useful x-ray beam size, and beam quality.

An experimental technique for measuring the air attenuation correction as a function of x-ray energy was designed and tested by a Guest Worker from the Institute of Radiation Protection, Taiyuan, Peoples' Republic of China. Data for all the x-ray beams used with the 300 kV x-ray range and most of those used with the 100 kV x-ray range have been taken. Analysis and comparison with the technique used in past years, publication of the technique and results will be done in the near future. These new data will be the basis for the corrections to be applied to the NIST free-air standards.

Department of the Navy Dosimetry Calibration Program (J. T. Weaver, P. J. Lamperti & M. D. Walker)

The Navy thermoluminescence dosimetry (TLD) measurement-assurance program, sponsored by the Naval Sea Systems Command, continues. NIST routinely receives TLDs which are then irradiated to four levels of known exposure using cesium-137 gamma-rays. The boxes are dispatched to designated Naval facilities for readout. The results are returned to NIST for analysis and comparison to NIST exposures. The analysis and comparisons results are sent to the sponsoring agency, and they schedule a retest or recalibration for any TLD-readout instruments that indicate exposures differing from the NIST exposure by more than 13 percent. Measurements on an AN/UDM1A were completed and a report issued. Three Victoreen R-meter sets and four ionization chambers were calibrated for the Naval Electronics Command in Charleston, SC (NAVELEX). This latter group was also assisted, on two separate occasions, with an energy dependence study for a first-article submission of Navy TLD cases, and with a dose-response test of glass dosimeters. NIST also conducted an exposure response test for four prototype protection-level survey meters.

III. Neutron Interactions and Dosimetry

The Neutron Interactions and Dosimetry Group develops and applies well-characterized neutron fields and related capabilities for neutron dosimetry methods evaluation and standardization, for detector development and calibration, and for reaction cross section measurements. Involvement with outside organizations, both in the federal and private sectors includes many types of research and technology assistance programs as well as leadership roles on national and international standards and radiation policy making bodies.

A selection of accomplishments for FY-89 with emphasis on NBS reactor related activities are outlined below in titled paragraphs grouped under four projects.

Dosimetry for Material Performance Assessment (E. D. McGarry, D. Gilliam, C. Eisenhauer, G. Lamaze, & J. Coyne)

Dosimetry methods for monitoring the degradation of materials in high fluence neutron exposures are diverse. This project provides some form of measurement assurance, standardization, or methods development for nearly every approach to materials dosimetry employed in the United States. Interlaboratory measurement cooperation with substantial International participation are an important feature of this project.

1. NIST/Nuclear Regulatory Commission contract. The 1977 Rancho Seco Reactor incident demonstrated that it was possible for a nuclear pressure vessel subjected to thermal shock to also experience significant pressure loading. This was of particular importance to subsequent studies that showed that relatively small flaws subject to pressurized thermal shock (PTS) could lead to failure of the pressure vessel. The possibility of small flaw development increases with hardening and loss of ductility of the pressure vessel, which takes place in carbon steels subjected to neutron irradiation. Consequently, the NRC in late 1977 identified the need for improved surveillance of reactor pressure vessels. In practice this means more and better fast neutron dosimetry and improved fluence calculational capability. The NRC carried out an eleven-year international program (1977-1988), the Light Water Reactor Pressure Vessel Surveillance Dosimetry Improvement Program (LWR-PV-SDIP), dedicated to this task. NIST participated in activities to benchmark reference dosimetry measurements and calculations, and continues as consultant to the NRC.

2. NRC regulatory guide preparation. A regulatory guide to provide guidance for improving and benchmarking neutron transport calculations is being drafted. The guide is in the form of instructions on important aspects of calculations, on dosimetry needed to validate the calculations, and on the reconciliation of differences between measurement and calculation including the assignment of uncertainties. NIST is a major participant in the formulation of this document, the preparation of which will continue into FY90.

Neutron surveillance dosimetry measurements are generally made using special capsules containing dosimeters and metallurgy test samples. They are located in the water between the reactor core and the pressure vessel. Calculations are necessary to extrapolate results from these capsules to the one quarter thickness of the pressure vessel, the established point of interest for reactor licensing. The extrapolation is carried out after the calculations have been confirmed by, or normalized to, the measurements in the surveillance capsule.

3. ASTM benchmark standard balloted. Another draft of an ASTM Standard Guide for benchmark referencing of neutron dosimetry for reactor

pressure vessel surveillance, E706IIIB (4), was prepared by NIST and was accepted for ballot after revision by the ASTM E10.05 Subcommittee meeting in Orlando, Florida, January '89. A revised draft was balloted at the June 1989 E10.05 Meeting in Scottsdale, Arizona.

4. NIST/Westinghouse cooperative agreement. Measurement assurance activities with respect to Solid State Track Recorders (SSTRs) developed by Westinghouse Science & Technology Center (formerly Westinghouse Research) continues. NIST is specifically interested in problems associated with establishing reliable masses for the SSTR fissionable deposits which are in the pico-gram to nano-gram range. NIST has taken on the task of providing a basis for establishing mass scales of ^{237}Np, ^{235}U, ^{238}U, and ^{239}Pu ultra-lightweight deposits in Westinghouse SSTR dosimeters. This involves exposing heavier lightweight deposits to known neutron fluences. These irradiations are carried out in the ^{235}U Cavity Fission Source to an accuracy of about 2.5% (1σ). Initial results for ^{238}U suggest that there is a 5% discrepancy between masses assigned on this basis and those determined at Westinghouse by spiking and alpha counting techniques.

The IAEA Advisory Group Meeting on Nuclear Data for Radiation Damage Assessment and Related Safety Aspects will meet in September 1989 in Vienna, Austria. NIST will co-author a paper with Westinghouse Research entitled, "Benchmark Referencing of Ultra Low-Mass, Solid State Track Recorder Neutron Dosimeters in NIST Standards Neutron Fields."

5. Calibration of Belgian Cavity Fission Source. NIST personnel traveled to Mol, Belgium in December 1988 to re-establish the tie between the NIST and CEN/SCK fission neutron fluences in their respective ^{235}U Cavity Fission Sources. The basic calibration measurements were made with an NIST dual fission chamber containing fissionable deposits identical to these used in the calibration accomplished at Mol by NIST in 1983. Measured fission rates agreed to about ±1 % (1σ). This is a significant result because in the interim NIST had to repair and re-calibrate the run-to-run monitor used to maintain the absolute fluence scale of the Belgian Cavity Fission Source. The calibration of the Belgian ^{235}U fission field also affects the NIST ^{235}U Cavity Fission Source calibration because of complementary features of the two sources.

6. VENUS program participation. The most active use of the Belgian Cavity Fission Source for the past several years has been to calibrate miniature fission chambers for active dosimetry in the Belgian LWR-PV Benchmark Experiment, VENUS, at their CEN/SCK Laboratory in Mol, Belgium. The VENUS series of PV benchmark experiments confirm neutron transport calculations of dosimetry measurements in the vicinity of fuel corners and out through the pressure vessel into the ex-vessel cavity. Additional checks involve ex-core calculations associated with matters of high fuel burnup. The VENUS experiments, started in 1983, were completed

this year. The primary NIST function has been to provide supplementary benchmark calibrations and "hands-on" verification of the CEN/SCK benchmark referencing.

7. VENUS absolute power calibrations. NIST became involved in the VENUS power determination when the ^{235}U mass of the deposit in a commercial miniature fission chamber was determined at the reactor thermal column (1). These small sealed fission chambers make it possible to probe down in between the fuel plates in a low-power core and, without disturbing the thermal fluence rate, make vertical and horizontal scans of the absolute fission rate over the core volume. The reported ^{235}U mass of 4.72 ± 2% micrograms was determined by comparing fission rates with a known-mass deposit from the NIST inventory.

Corrections for gradients, relative spatial locations, and thermal fluence perturbations have made this measurement the subject of extensive discussions on both sides of the Atlantic. Now, after eight years of additional work in the determination of absolute power levels in experimental reactor facilities, the "4.72 microgram ^{235}U mass" stands as the constant that links three expensive VENUS campaigns.

8. Dosimetry methods development for reactor support structures. A priority in the Heavy Section Steel Technology (HSST) Program this year was evaluation of low-temperature, low-fluence-rate embrittlement on reactor vessel support structures. This issue arose from findings of higher than expected embrittlement in the High Flux Isotope Reactor (HIFR), at Oak Ridge, and in the reactor shield tank from the recently decommissioned Shippingport Reactor. NIST is responsible for consultation and some contracting for dosimetry measurements at two plants including benchmarking against NIST standard neutron fields.

9. PUD neutron sensors for cavity reactor dosimetry. Second only to the fission of ^{237}Np for good spectrum coverage of neutrons with energies $E > 1.0$ MeV, ^{238}U is the desirable reaction for pressure vessel (PV) surveillance dosimetry. However, in such partially thermalized spectra, the fission in small concentrations of ^{235}U remaining in depleted ^{238}U requires a significant correction. Avoiding this correction by using highly depleted uranium is expensive and the material is becoming scarce. The Paired Uranium Detector (PUD) dosimetry technique was developed at NIST to circumvent the need for the highly depleted ^{238}U material and to obtain a measure of the $^{235}U/^{238}U$ fission ratio, an important neutron spectrum index.

The technique involves simultaneous irradiation of moderately depleted uranium (approximately 200 ppm ^{235}U) along with natural uranium as the ^{235}U detector. Both materials are readily available. The small concentration of ^{235}U in natural uranium (0.7%), with low self-absorption, gives the ^{235}U response correction for the depleted uranium detector and a reasonable value of the $^{235}U/^{238}U$ spectral index. The ^{238}U detector of the PUD pair can be directly calibrated in the ^{235}U fission neutron spectrum of the Cavity Fission Source at the NIST Reactor.

PUD detectors, furnished by NIST, were first employed in a Surveillance Capsule Perturbation Experiment (4). Later, they were used to back up SSTR measurements in the first leakage core measurements at the H. B. Robinson commercial power plant. Following these benchmark measurements, PUDs have become useful as ex-vessel cavity fluence dosimeters in various power reactors. All of this is carried out as part of the NIST/Westinghouse cooperative agreement.

10. Sulfur dosimeter calibrations for pulsed reactor facilities and criticality accident dosimetry. Sulfur activations pellets are regularly used for neutron dosimetry at all three fast burst reactor facilities in the U.S. These facilities test military electronics and other equipment for the ability to withstand of neutron and gamma radiation.

The sulfur activation dosimeter is a pure beta emitter for which absolute detection efficiencies are very difficult to determine. The NIST method of neutron fluence transfer circumvents this problem and provides a calibration accurate to about 2.5%. Sulfur tablets, irradiated to a known fluence with ^{252}Cf fission neutrons, are counted by the user and a calibration factor, with units of counts per unit fission neutron fluence is established for each counter geometry and size sulfur detector.

In a similar way irradiation of sulfur dosimeter was carried out for criticality accident dosimetry at the request of the Reynolds Electric and Engineering Co. laboratory at the Las Vegas weapons testing site.

11. Energy response of innovative electronic-hardware dosimeter. The Nuclear Effects Directorate (NED) at the Aberdeen Proving Ground has been evaluating a new personnel dosimetry system for battlefield use by the Army. To establish the neutron energy sensitivity of this semiconductor device, multiple irradiations were performed for NED in a thermal neutron beam, in the 2-keV scandium filtered beam, in the 24-keV iron filtered beam, and at the 144-kev silicon filtered beam, at several Van de Graaff energies, and at the NIST ^{252}Cf source.

12. Microdosimetry and radiation damage to silicon. Microdosimetric spectra of energy deposition in small sites has been correlated to the vulnerability to error and breakdown in integrated circuits. The dependency of these y-spectra on the shape and size of the silicon chip has been studied in order to give guidance on the proper choice of shape and size in integrated circuits to minimize soft radiation damage. Neutrons are a convenient example of Hi-LET radiation and

the study of the interaction of neutrons with small volumes of silicon, both experimentally and theoretically is useful to evaluate the soft damage to computer components due to Hi-LET radiation, especially in space craft. The evaluated neutron cross sections in silicon are used to determine the spectra of secondary charged particles and the standard NIST code is used to calculate y-spectra for a thin-walled silicon proportional counter. These results are then correlated to circuit damage results for different neutron spectra.

Personnel Dosimetry (R. Schwartz, C. Eisenhauer, J. Coyne, & E. Boswell)

Standard neutron fields are used to calibrate radiation protection instrumentation and to investigate and test new types of dose measuring techniques. Responsibilities in national and international dosimetry methods research focuses on tissue dose modeling, and tissue equivalent proportional counter (TEPC) measurements, and the development of written standards.

1. Calibration service. Approximately 60 neutron radiation protection instruments were calibrated this year. Although the majority of the calibrations were done for commercial nuclear power plants, our "customers" also included institutions as diverse as Redstone Arsenal and the M. D. Anderson Cancer Center. For the past year we have also been performing tests of the "electronics package," before performing the actual neutron calibration. This allows us to detect nonlinearities or instabilities which are difficult to pin down using neutron sources alone.

2. Performance tests of "Bubble Dosimeter". The new "bubble", or superheated drop, detectors represent a new and promising approach to neutron dosimetry. NIST is involved in a joint project to determine the relevant properties of these detectors. Other "players" include the Naval Surface Warfare Center, the US Naval Academy, the Naval Research Laboratory, and the National Physical Laboratory (NPL) in England.

It appears that the "bubble dosimeter" (supplied by Bubble Technology, Inc. (BTI)) has high sensitivity, a good dose equivalent response, and is quite linear up to the point where the bubbles can no longer be accurately counted. Fewer data have been analyzed for the SDD-P (a pen-sized neutron personnel dosimeter supplied by Apfel Enterprises, Inc.), but this device also seems to have a good dose equivalent response. Although intrinsically less sensitive than the "bubble dosimeter", it is much easier to read.

3. TEPC dose measurement for neutron RBE. The Armed Forces Radiobiology Research Institute (AFRRI) recently obtained surprising results in experiments which examined the relative biological efficiency (RBE) for lethality in mice exposed to reactor radiations. In brief, the

experiments indicated that a slight (5%) addition of neutron dose, into a pure gamma-ray field, decreased the lethal dose for the mice by almost 40%. The neutron and gamma-ray dose components were determined by conventional AFRRI ion chamber dosimetry. In an effort to shed some light on this unexpected result, we measured the linear energy transfer (LET) spectra in some of the AFRRI fields, using a tissue-equivalent proportional counter (TEPC). The results of this measurement disagreed with the AFRRI ion chamber dosimetry. Specifically, our results indicated that the supposed 5% neutron dose was actually approximately equal to the gamma-ray dose. If the dosimetry derived from the TEPC results is used to interpret the data from the "mouse experiments", then there are no longer any surprises. We are currently trying to understand this difference in dosimetry.

4. Catalog of neutron spectra for AFRRI. A catalog of neutron spectra requested by the Armed Forces Radiobiology Research Institute has been completed. This catalog gives tabulations and plots of calculated fluence spectra, plots of calculated and measured energy deposition spectra, reaction rates measured with neutron activation foils and neutron fission chambers, neutron kerma rates measured with ionization chambers, and comparisons of measured and calculated quantities.

A paper will be given at an International Radiation Protection Symposium in Dubrovnik, Yugoslavia. Measured and calculated microdosimetric spectra for a number of experimental arrangements of interest to AFRRI have been compared, and reasonable agreement has been found. The difference in microdosimetric spectra for various configuration indicate a possible difference in the biological effectiveness of the different radiation fields.

5. ICRU publication on practical determination of dose equivalent. In a landmark publication ("Determination of Dose Equivalents Resulting from External Radiation Sources", ICRU Report 39 (1 February, 1985)), the International Commission on Radiation Units and Measurements (ICRU) recommended a new system for determining the dose equivalents resulting from exposure to external radiation sources. The advantages of the new system included a uniform approach to dose equivalent determination and reporting for gamma-rays, electrons, and neutrons, as well as a close link with the fundamental limiting quantity, effective dose equivalent (as defined in ICRP Publication 26). ICRU 39 is, however, a very terse document, giving little more than the definitions of the new dose equivalent quantities. Accordingly, another report committee was set up by the Commission to produce a document on practical determination of dose equivalents. In the rather short time an "almost-final" draft was submitted to the Commission for its preliminary approval.

6. Catalog of y-spectra for monoenergetic neutrons. Microdosimetric spectra for monoenergetic neutrons are being calculated for

energies extending from thermal to 10 MeV. Initially catalogs will be generated for a 1 micron cavity and for energy loss in ICRU tissue and for ion yield in an inhomogeneous tissue-equivalent proportional counter. For each new set of conditions a new catalog must be generated. In order to calculate a y-spectrum for a given spectrum of neutrons the y-spectra from the catalog need only to be added with the proper weights.

7. Microdosimetry of radon and radon daughters. There is much interest at present in understanding how cancer in the lung and bronchial epithelium are produced by radon and radon daughters. We are studying the physics of this process through microdosimetry. A new computer code has been constructed from our "analytic method" code for neutrons. This code involves calculating an alpha-particle slowing-down spectrum at the basal cell location based on an assumed distribution of alpha-particle sources and anatomical geometry. From this microdosimetric spectra and parameters are calculated. Calculations have been carried out for a thin and thick plane source as a function of the depth from the source.

8. Calc. of microdosimetric spectra for low energy neutrons. In order to improve our understanding of the response of TEPC-based remmeters in the neutron energy region below 100 keV, it has been necessary to perform more precise and detailed calculations of the y spectra in this region. These improved calculations have been carried out by separating the elastic and non-elastic nuclear reaction channels. Ion yield calculations for these low energy neutrons also have been improved by using a new set of W values at low energies. A program for the Monte-Carlo calculation of the penetration of low energy neutrons has been developed and the results have been used to show the effect of the thickness of the TEPC buildup cap on the nuclear reactions which contribute to the energy deposition and ionization in the proportional counters. The results of the calculated y spectra are being compared to measurements made at the filtered beams at the NBS reactor. This study will help improve the response of newly developed TEPC-based remmeters.

9. Mammography and the penetration of low energy photons. Mammographic studies are usually done with low energy photons. Because the absorption of these photons is very strong, the effect of the ion chamber on the photon field is significant. Corrections for the effective point of measurement are of the order of 20% rather than the usual 2%, encountered in ordinary photon dosimetry. Monte Carlo calculations of the penetration of low energy photons and the effects of size and shape of the ionization chambers used in the measurements of depth dose in phantom have been carried out,and are being compared to experiment. At present, these calculations are being done in the kerma approximation, i.e., the photons lose energy at the point of interaction. Later it may be necessary to consider the transport of energy from the point of interaction by secondary photons.

10. ISO draft standard for instrument calibration. The ISO Draft Standard Proposal, "Procedures for Calibrating and Determining the Energy Response of Neutron Measuring Devices Used for Radiation Protection," has again been rather completely rewritten. Although many changes in this rewrite were suggested at the ISO Meeting in Italy in June, they were mostly in the nature of word-smithing, although with some rearrangement of the text. The basic structure of the draft was, however, approved. We will attempt to make the required changes and send the finished text to ISO by the end of October.

11. Radiation protection policy committee work. C. Eisenhauer serves as chairman of a subpanel of the Science Panel of the Committee on Interagency Radiation Research and Policy Coordination (CIRRPC). The sub-panel has produced a report on the desirability of planning for research on human health effects in the event of a nuclear accident. The Subpanel recommended a follow-up effort to recommend ways of implementing such planning.

Nuclear Interactions Measurements (O. A. Wasson, A. D. Carlson, K. C. Duvall & R. A. Schrack)

Jointly sponsored by the Department of Energy and NIST, this project pursues on a long term basis accurate measurement and evaluation of standard neutron cross sections for nuclear technology. The major experimental work including detector development is carried out at intense neutron time-of flight facilities at other laboratories, and at the 100 kV ion generator, 3 MV positive -ion accelerator, and research reactor at NIST. This project coordinates all standard cross section evaluation efforts in the U. S.

1. $^{10}B(n,\alpha\gamma)$ Cross Section Measurement from 100 keV to 3 MeV Neutron Energy. Because of the large uncertainties in the value of this standard cross section in the energy region above 500 keV a collaborative effort has been started with Oak Ridge National Laboratory to measure this important cross section. The NIST calibrated "Black Detector" neutron detector has been set up at the Oak Ridge Electron Linear Accelerator facility. This detector will provide a shape determination of the neutron-fluence energy distribution in the 0.1 to 3-MeV energy region. Several test runs indicate that the detector is operating satisfactorily in the energy range desired.

2. Fission cross section measurements. Measurements are performed at the fission flight path at the Los Alamos Meson Physics Facility and cover the neutron energy region from 1 to 400 MeV. Fission cross section measurements are now being made on three isotopes of uranium: ^{233}U, ^{234}U, and ^{236}U. A large amount of the data obtained earlier with an IBM-PC acquisition system has been analyzed for fission cross section ratios and for the ^{235}U fission cross section. The neutron fluence was measured

below 30 MeV with the NIST Annular Proton Telescope (APT). At higher energies two additional telescopes were developed which overlap in their useful neutron energy ranges.

The use of the new MICROVAX-XSYS computer-data acquisition system at LANL has significantly improved the data accumulation process. It is possible, from NIST, to inspect the experimental data being accumulated at LANL. The remote user has essentially the same options as the local user.

3. The $^{235}U(n,f)$ cross section measurement at 2.5 MeV. The measurement of the $^{235}U(n,f)$ cross section at 2.5 MeV using the D(d,n)He-3 reaction and the time-correlated associated particle (TCAP) method is underway. A fission chamber containing six uranium tetra-fluoride deposits, 5 cm in diameter, and ranging in thickness from 230-300 $\mu g/cm^2$ has been installed. Although the data collection rate is slow, the measurements are being conducted around the clock as a result of the stable, unattended operation of the accelerator. Data has been collected thus far with a statistical accuracy of 4%.

4. Conference entitled "Fifty Years with Nuclear Fission". The NIST and the American Nuclear Society sponsored a three-day meeting to celebrate this historic event at NIST on April 25-28. The honorary co-chairmen were John Wheeler and Edoardo Amaldi while the general co-chairmen were Glenn Seaborg and Emilio Segrè. The 400 attendees were saddened by the death of Professor Segrè just prior to the conference. Mr. Raymond Kammer represented NIST and Ms. Gail de Planque represented the American Nuclear Society at the opening reception on Tuesday evening, April 25 in Gaithersburg. The following day plenary sessions were held at the National Academy of Sciences. Distinguished speakers, all pioneers in the nuclear revolution, reviewed the "Prelude to the First Chain Reaction - 1932 to 1942" in the morning and "Fission Research and Development-Since 1939" in the afternoon. The meeting continued at NIST on Thursday and Friday with presentations by approximately 130 distinguished scientists on the important developments in nuclear science. A banquet honoring the pioneers in this momentous discovery and subsequent development was held on Thursday evening, during which the pioneers recalled the significant events in their careers. The proceedings are being published by the American Nuclear Society under the editorship of A. D. Carlson and J. W. Behrens.

5. NEANDC endorsed working group on the B-10(n,α) cross section standards. The $^{10}B(n,\alpha)$ cross sections are important neutron cross section standards. At the higher neutron energies these reactions have received much attention as a result of the relatively poor data base and the problems it caused in the ENDF/B-VI standards evaluation process. An NEANDC endorsed inter-laboratory working group was formed this year in order to provide a mechanism for improving these cross sections. The

objective of the present working group is to have many laboratories collaborate in programs to improve the data base. A. D. Carlson is the first chairman of this working group.

6. The evaluation of the standards for ENDF/B-VI. The evaluation of the standard neutron cross sections for ENDF/B-VI as outlined in the last Annual Report has been completed. These standards have been accepted for use in ENDF/B-VI by the Cross Section Evaluators Working Group (CSEWG). The uncertainties for these standard cross sections obtained from the combination of the simultaneous and R-matrix evaluations are still being investigated.

The documentation of the standards evaluation process is now underway. This document will serve as the basis for an invited talk on the ENDF/B-VI standards to be given at the fall 1989 American Nuclear Society meeting.

7. Search for neutron emission during electrolysis. The announcement in late March by scientists in Utah of excessive heat emission and neutron production during electrolysis using Pd electrodes and heavy water-based electrolytes provided an excellent opportunity to apply our neutron detector expertise to timely measurements of a possibly important energy source. We initiated a collaboration with the scientists in the Electro-Deposition Group at NIST and supplied neutron detectors and associated electronics. We rapidly verified that there were no neutrons produced at the high rate of approximately 10^4 s^{-1} as reported by Pons and Fleishmann. The neutron energy calibration for both the large plastic scintillator and the liquid scintillator was done with 2.5 MeV neutrons produced by our 100-kV ion generator.

8. Search for cold fusion in a gas cell. An experiment was setup to explore the possibility of producing cold fusion with deuterium ions from a gaseous discharge. This approach to cold fusion is analogous to the method that has received widespread attention using an electrochemical cell. A rather novel approach is used at NIST to measure the cold fusion yield in the gas cell by detecting charged particles from the competing D(d,p)T fusion reaction. No evidence of cold fusion occurring in the gas cell was found in these measurements for either Pd or preloaded Ti cathodes, at hot and cold cathode temperatures, with ion currents up to 150 mA. The charged particle data indicated that cold fusion was not occurring at a rate above 5 fusions per second.

9. Remote data acquisition. When operating in a user mode at remote facilities there is a need to transport the data to one's home facility for analysis. When the amount of data is relatively small it is generally feasible to transmit the data over Internet using File Transfer Protocol (FTP). One complete set of data has been transmitted from ORNL by breaking the data up into eight separate files and then recombining

them locally. While the transmission was successful, it is necessary to find more convenient techniques. Several efforts which are underway include a high-speed local area network, a data compression system, and high-density magnetic tape.

10. Explosives detection by elemental imaging. A design concept for detecting explosives in baggage and cargo was developed. The technique measures the nitrogen content of baggage and more importantly, uses elemental imaging to locate in baggage the regions of high nitrogen density. The information should permit a better recognition of explosives in the presence of clothing containing nitrogen such as nylon sweaters. The technique uses 14 MeV neutrons and measures the 2.31 MeV prompt gamma rays from neutron inelastic scattering of nitrogen. The imaging is accomplished with the use of the time-correlated associated particle (TCAP) method where the time and directional characteristics of the neutron beam are determined by charged particle detection. Baggage is moved through the neutron beam on conveyor belt and processed at a rate of 10 pieces per minute. The calculated sensitivity for this system in terms of the least detectable amount of nitrogen is 28 grams per pixel at a rate of 2.3 counts per gram per pixel. This sensitivity will allow a one pound sheet of plastic explosive of the PETN type to be detectable in baggage.

11. Multielemental assay of bulk material using 2.5 meV neutrons. A new method for obtaining information on the elemental content of bulk material has been implemented. The technique employs the time-correlated associated particle method (TCAP) to produce a neutron probe with well-defined time characteristics. Measurements on bulk samples carried out with a 2.5 MeV neutron probe do not produce high energy gamma ray lines from carbon and oxygen which often impair the assessment of other important elemental constituents. The assay of coal for sulfur content is an advantageous example. The feasibility of the technique using 2.5 MeV neutrons was tested with bulk samples of coal. The detection of the small amounts of sulfur in the coal sample was successful.

RESEARCH AND TECHNOLOGY ASSISTANCE (all group members)

Research and technology assistance are strongly coupled in neutron dosimetry. A multiplicity of institutional involvements, drawn to the group by the availability of unique irradiation facilities and measurement capabilities, encourages a variety of attractive projects and unavoidable responsibilities.

1. Neutron lifetime - absolute neutron counting. An overview of the NIST involvement in measurement of the free neutron lifetime is given in the Reactor Radiation Division annual report. The paragraphs in this section will discuss only one aspect of the experiment - the improvements in the absolute neutron counting under development for the upcoming new

phase of the project at the NIST guide hall. In the measurements made at the Institut Laue-Langevin during the past year, the neutron density determination was made by employing a B-10(n,α) detector whose mass-thickness had been determined by isotope dilution mass spectrometry.

A new alpha-gamma coincidence counter for thermal and cold neutrons has been built, based on the counting of prompt gamma rays from a boron target which totally absorbs the impinging neutrons. In the calibration of the gamma detectors, the totally-absorbing B-10 target is replaced by a thin B-10 target and the alpha-gamma coincidence method is employed to establish the efficiency of the gamma detectors. Alternatively, the gamma efficiency can be determined by calibration with a standard alpha source with reference to the well-known branching ratio for the B-10(n,$\alpha\gamma$) reaction. Both of the calibration methods are believed to have the potential for approaching the 0.1 % accuracy level.

2. <u>Benchmark measurements for criticality safety.</u> In collaboration with Los Alamos National Laboratory and Oak Ridge National Laboratory, an experimental program has been undertaken to improve the understanding of neutron leakage from aqueous systems which are representative of situations occurring in chemical processing of isotopes for nuclear weapons production. There has been a long-standing difficulty in the field of criticality safety of calculating criticality of systems composed of multiple sub-critical assemblies. One possible explanation for the difficulty is that the calculations are incorrectly predicting the neutron leakage from the individual assemblies. The present program compares calculations by two of the best Monte Carlo codes with state-of-the-art measurements for spherical aqueous systems driven by ^{252}Cf neutron sources. Fission ionization chambers with fissionable deposits from the NIST collection of Fissionable Isotope Mass Standards (FIMS) are employed to make the neutron leakage measurements.

Measurements have been completed at one of two prescribed radii outside a water-filled sphere of 4-inch (10.16 cm) diameter, including fission rates for four different nuclides: ^{235}U, ^{238}U, ^{239}Pu, and ^{237}Np. It has been possible to determine the ratios of count rates for the water-filled sphere relative to the count rates for the empty sphere to an accuracy of the order of 1%, because these ratios are independent of uncertainties in the source strength, the deposit masses, and the detector positions (so long as they remain fixed). The calculations and experiments are in good agreement for these wet/dry counting ratios for ^{238}U and ^{237}Np. However, for ^{235}U and ^{239}Pu, these wet/dry ratios are calculated to be 5% to 8% (respectively) higher than measured.

3. <u>Radiation shielding calculations for the NIST cold neutron facility</u>. Calculations have been made to determine shielding necessary for two shutters to be installed at the Cold Neutron Facility. Various combinations of iron, tungsten, borated polyethylene, and lead were

explored to determine an optimum configuration. The final configuration was designed so that the dose equivalent rate due to neutrons and photons emerging from the shield be less than 100 mrem/hour.

4. Neutron penetration in slabs of finite extent. Monte Carlo calculations of neutron transmission through slabs have been performed to help the U.S. Navy estimate shielding of personnel on submarines carrying nuclear missiles. These calculations demonstrate that neutron and gamma-ray penetration is insensitive to the position of a slab between a localized (point) source and detector. Furthermore, an angular parameter can be specified such that the relative contribution of neutrons or photons within that angle is also insensitive to the slab position. This is equivalent to quantifying the increase in scattered particles as one moves from a narrow-beam to a broad-beam configuration. A paper on this subject will be submitted for publication in Nuclear Science and Engineering.

5. Carbon cross section for kerma calculations. Recent measurements of kerma in carbon indicate that values of this quantity calculated on the basis of the cross sections taken from the ENDF/B-V file are too high, particularly in the energy range from 15 to 20 MeV. A simultaneous fit to measurements of kerma in carbon and carbon cross sections from the ENDF/B-V file proved unsatisfactory. A new evaluation of the cross section data concentrated on those aspects which would have most impact on kerma calculations. A simultaneous least squares fit to measurements of kerma and the new evaluated cross section file was performed. The cross section data from this evaluation is now available in ENDF/B format.

6. Nuclear energy exhibit at National Atomic Museum. The National Atomic Museum in Albuquerque, NM, is developing a nuclear energy exhibit around an operating replica of Lady Godiva, an early experimental nuclear reactor and nuclear historic landmark. The aim of the exhibit, summed up in its title: Lady Godiva and the Realities of Nuclear Energy, is to engage public perception of nuclear energy by means of an eminently displayable and historically important nuclear reactor. A group member with unique experience in this area of nuclear technology is a consultant for the exhibit. Efforts this year have focused on the preparation and review of texts for exhibit labeling and an introductory video.

7. Response of alanine to Hi-LET radiation. Radiation dosimetry with alanine has many advantages: linearity of response over a wide dose range, good time stability of the induced free radicals, availability of non-destructive readout techniques, accuracy and repeatability of measurements. The response of alanine to Hi-LET radiation is always less than the response to Low-LET radiation (gamma rays). Since the response of alanine to the heavy ions produced by the interaction of neutrons has been measured or calculated, it is possible to combine these responses

with the initial spectra of secondary charged particles for neutrons and obtain the response for neutrons of a given energy. The response of alanine as a function of neutron energy from 0 to 20 MeV has been calculated and compared to experiments. The use of alanine in mixed radiation fields and its usefulness in predicting the biological response of a mixed radiation field is now being investigated.

Irradiation and Calibration Facilities (E. D. McGarry, J. Grundl, C. Eisenhauer & E. Boswell)

Well-characterized neutron fields built and maintained as permanent irradiation facilities, provide certified fluences of pure fission neutrons, sub-MeV distributions, monoenergetic keV beams, and thermal neutrons. Passive and active detectors are exposed in these neutron fields for response calibrations, for cross section measurements, and for the investigation of new measurement techniques. A multi-purpose fission rate measurement capability is centered around the NBS "go anywhere" double fission chambers and the NBS set of fissionable isotope mass standards (FIMS). The Manganous Sulfate Bath is the primary neutron source strength calibration facility for the U. S. Absolute neutron fluences for all fission-neutron-driven standard neutron fields at NBS are derived from source strength calibrations at this facility.

1. Neutron source strength calibrations. Fewer neutron emission-rate calibrations were done in FY-89. Some inquiries indicate that the current cost for calibrations is too expensive, especially for universities and small businesses. More in-house repeat calibration work was carried out. The number of ^{252}Cf sources at NIST may be decreased from 14 about seven as soon as re-calibrations to complete a half-life study of ^{252}Cf is completed. Current improvements of the facility include installation an intrinsic germanium detector, which is being operated on a trial basis to insure quality control, and upgrade of the remote handling manipulator arm. Further needs for upgrade center around replacing or refurbishing the aging $MnSO_4$ tank.

2. Fission neutron irradiation operations. Spreadsheets and test reports for certified fission neutron fluence irradiations have been reworked and updated and are now on PC computers. The new general purpose shield cave for storing high and intermediate level radioactive components is moving toward completion. The shield walls and top section are finished and on the reactor floor. Hardware for the rolling door is in hand. When complete, this shield cave will greatly simplify irradiation operations at the reactor thermal column, not only for the cavity fission source but also for the Intermediate-Energy Standard Neutron Field (ISNF).

3. FIMS alpha assay facility. Both the absolute calibration and the verification of long-term integrity of the Fissionable Isotope Mass Standards collection (FIMS) depend on accurate alpha assay. These fissionable deposits and the NIST fission chambers provide the basis for neutron dose measurements over more than seven orders of magnitude in intensity, from reactor experiments levels to personnel exposure levels.

A new facility for absolute alpha counting has been set up in the laboratory B123 of the Reactor Building "Warm" Wing. The new system features several improvements in both convenience and accuracy. The accuracy of the solid angle determination has been improved, and scattering from the aperture edge has been reduced by employing new copper apertures made on the diamond turning machine at the NIST Precision Manufacturing Facility.

IV. Radioactivity Group

Introduction

The guiding principles and goals of the Group are closely related to suggestions set forth in a National Academy of Sciences panel report addressing discrepant radioactivity measurements in the U.S. about 20 years ago:

- NIST should be the primary source of radioactivity standards in the country.

- Standards of 1-3 percent accuracy are required; the research necessary to produce and utilize standards and maintain a competent staff should be performed; results should be checked internationally; and significant special needs should be addressed.

- Standard reference materials to be produced should be selected in cooperation with users; availability should be announced and use described; other agencies should encourage use.

- Intercomparisons with users should test measuring ability and commercial producers of special materials should maintain traceability to NIST.

In the subsequent two decades, the Group has conscientiously attempted to follow these guidelines, often fulfilling intent by alternate means and shifting priorities to accommodate the needs of the moment with the means available.

The following examples from the past year reflect current topics and concern.

Development of National Standards (J. M. Calhoun, D. Golas, D. Gray, D. D. Hoppes, L. L. Lucas, F. J. Schima & M. P. Unterweger)

Interactions with U.S. measurers of radioactivity have revealed over 30 pertinent radionuclides for which no satisfactory U.S. standards have been established. Although user spectrometry systems calibrated for efficiency as a function of energy can be used for quantifying samples containing these radionuclides if accurate probabilities per decay are known for selected radiations, simpler systems are best calibrated by sources quantitatively linked to a common reference -- the national standard for the radionuclide. This standard, together with well calibrated spectrometry systems, is also usually the most trustworthy basis for establishing radiation probabilities per decay.

For some radionuclides no calibration can be "retained" on a comparative instrument; here the national standard is a documented method with well considered uncertainties. The measurement of any submitted or issued source is then a direct application of the standard. Examples in the past year are ^{3}H measurements of a submitted cylinder of gas by internal gas counting; the standardization of a special form of ^{35}S by liquid-scintillation calculated efficiency tracing with tritium; the preparation of ^{125}I Standard Reference Materials (SRMs); and the preparation of special test samples of ^{243}Am by liquid-scintillation counting.

However, several measurements did address the backlog of radionuclides awaiting a basic standardization. Contractor A. T. Hirshfeld developed standardization methods using a (4π pressure-proportional counter)-(NaI(Tl)) anticoincidence system for ^{153}Gd and ^{144}Ce; these were applied and resulted in a new SRM and test samples for the nuclear-power-industry program, respectively.

In cooperation with Bert Coursey of the Radiation Interactions and Dosimetry Group, and A. Grau-Malonda, E. Garcia-Torano, J. M. Los Arcos, and M. T. Martin-Casallo of Centro De Investigationes Energeticas Medioambieutales Y Technogicas (CIEMAT), Spain, liquid-scintillation counting with the efficiency traced with ^{3}H is being used to develop standards for ^{59}Ni (nuclear waste measurements); ^{114m}In (an impurity in ^{111}In used for imaging in nuclear medicine; and ^{186}Re (for therapeutic use with monoclonal antibodies).

Another method of closing the gap between the desired and readily achievable number of radionuclides is to temporarily adopt standards developed elsewhere. This has been discussed with the Radionuclide Metrology Section of the Hungarian National Office of Measures, whose competence has been demonstrated in NIST collaborations and many international comparisons. Some 12 radionuclides seem possible candidates for "standards borrowing", and eventual NIST direct measurement will be used to confirm an acceptable correspondence.

Standard Reference Materials (J. M. Calhoun, D. Golas, D. Gray, K.G.W. Inn & L. L. Lucas)

With calibrated samples of many radionuclides routinely available at lower cost from commercial suppliers linked to national standards through continuing demonstrated traceability, the Radioactivity Group is not renewing many SRMS, but concentrating on producing only selected ones. Many longer-lived SRMs will be useful for many years. Outstanding examples are the contemporary oxalic acid ^{14}C SRM developed in collaboration with the carbon-dating community and several natural-matrix environmental SRMs also produced cooperatively. Currently the last of the planned natural matrix materials, an ocean sediment, is being measured by several U.S. and international laboratories, with certification anticipated within a year.

Some SRM catagories for which NIST responsibility is expected to continue are (1) short-lived radionuclides for nuclear medicine, with 10 selected each year by the industry, (2) long-lived multi-gamma-ray SRMs for germanium spectrometry calibrations of efficiency vs energy, (3) tracer solutions for measuring the yield of another isotope of a high-atomic-number element in radiochemical separations, (4) ^{226}Ra solutions for radon measurements, with a special encapsulated source under study, and (5) special tritium solutions. Also, very long-lived radionuclides, such as ^{99}Tc, significant in reactor waste, are anticipated to be of increasing importance.

With the intended reduction in NIST SRMs, and the possible elimination of the EPA program distributing some 2500 calibrated solutions per year without cost, the traceability testing of commercial suppliers, industrial laboratories, and regulatory agencies is of greater significance. Calibrations and special measurements are still available for critical needs not met otherwise.

The following table enumerates the above interactions in the last 12 months:

Total radioactivity SRMs distributed	660
Short-lived SRMs supplied under the USCEA program for nuclear medicine	252
Scheduled calibrations	14
Special measurements	14
Traceability tests for FDA, NRC, and commercial firms	232

Calibration of Tritiated Gaseous Sources (F.J. Schima & M.P. Unterweger)

Measurements have been made on a number of tritiated gaseous cylinders sent to NIST for calibration. The activity per unit volume of the tritium contained in a cylinder of gas (i.e., tritiated methane, tritiated hydrogen) is determined by removing a sample of the gas (150 to 200 cm^3) by expansion into a well-known volume in our gas handling system. A precise measurement of the temperature and pressure of the gas in this volume determines the quantity of gas, which is then introduced into the NIST length-compensated internal gas counters for calibration. The sample is counted and the activity per unit volume of the sample is reported.

The NIST $^{10}Be/^{9}Be$ Isotopic SRM (K.G.W. Inn, D. S. Simons, B. M. Coursey, J. D. Fassett & R. L. Watters)

The Radioactivity Group, in collaboration with the Center for Analytical Chemistry's Mass Spectrometry Group, Microanalysis Research Group, and Atomic and Molecular Spectrometry Group, has certified the isotopic and radioactivity composition of a $^{10}Be/^{9}Be$ source material. The material was the starting component for the production of the NIST $^{10}Be/^{9}Be$ (3×10^{-11}:1) Isotopic SRM for the geochronology studies being conducted by the Accelerator Mass Spectrometry community. Careful evaluation of isotopic-fractionation, isobaric, and hydride effects on mass measurements were required to obtain the certification. Confirmation measurements were done at ORNL by Secondary Ion Mass Spectrometry.

Uranium and Thorium Analysis of Powdered Milk Products (K.G.W. Inn, W. R. Kelly & J. D. Fassett)

In a collaborative study between the NIST Radioactivity and Mass Spectrometry Groups, Office of Standard Reference Materials, and the IAEA (Vienna, Austria) powdered milk and whey products were assayed for sub-parts-per-billion (ppb) quantities of uranium and thorium. The interest in the IAEA powdered milk and whey materials was that they were collected shortly after the Chernobyl incident. Although the isotopic composition was natural, the levels of thorium and uranium in the powdered whey (10, 22 ppb, respectively) were about two orders of magnitude higher than those found in the powdered milk (<500, 215 parts per trillion (ppt), respectively). The uranium and thorium levels were found to be comparable to those found for the NIST powdered milk (<500 and 170 ppt, respectively, SRM 1549). Studies on locally available fresh milk and on fresh milk collected near the DOE Fernald Plant are currently being pursued to determine the distribution of the uranium and thorium between curds and whey.

Distribution of Thorium Progeny in a Thorotrast Patient (K.G.W. Inn, F. J. Schima, J. W. Tracy, L. S. Slaback, R. R. Greenberg & G. V. Iyengar)

In a collaborative study with the National Cancer Institute, the Radioactivity, Neutron Activation, and Health Physics groups have been measuring the thorium progeny's gamma-ray emissions from a variety of organs donated by a former thorotrast patient. The objective of the study is to quantitate the distribution of the short-lived thorium decay products for further refinement of human health and safety radionuclide biokinetic models and risk coefficients. Actinium-228, ^{224}Ra, ^{212}Pb, ^{212}Bi, and ^{208}Tl were sought in eye, larynx, esophagus, breast, kidney, liver, red blood cells, and blood serum.

Development of the NIST Primary ^{222}Rn Measurement System (R. Collé, J.M.R. Hutchinson & M. P. Unterweger)

Installation of the new pulse-ionization chambers and construction of the new gas-handling and gas-purification manifold for the NIST Primary Radon Measurement System was completed. Testing of the system for leaks, adsorption loses, and gas-transfer efficiencies was initiated. The measurement efficiency for ^{222}Rn in secular equilibrium with its decay products (using ^{226}Ra standard solution sources) was measured as a function of flow rate through the standard - from 0.25 standards liters per minute (SLPM) to 1 SLPM. No significant differences were found, implying that the purification system is satisfactorily removing electro-negative vapors (e.g., O_2, H_2O, and acid fumes) which would "poison" the ionization chambers' performance.

Radon Calibration by Liquid-Scintillation Counting (R. Collé, J.M.R. Hutchinson & R. Kishore)

Considerable results have been obtained in the planned series of measurements to obtain a procedure for an alternate primary calibration method for ^{222}Rn and for an independent verification of the primary ^{226}Ra standards. Extensive liquid scintillation measurements of radon-in-water samples (obtained from the prototype radon-in-water standard generator) have been made as a function of total sample volume and cocktail/water ratio. Comparative measurements against similarly prepared tritium (^{3}H) water samples have been initiated to fix a parameter in the model used to calculate the efficiency for counting progeny decaying by beta-particle emission.

^{222}Rn Flux-Density Standard (R. Collé, J. M. R. Hutchinson & R. Kishore)

Evaluations for the constrained and unconstrained flux density from the operating 40-cm diameter prototype standard have been completed. Although the efficiency of the flow-dependent extrapolation procedures used for calibrating the source was verified, problems arising from transpiration and evaporation of water through the polyethylene surface precludes the development of the prototype in its present configuration. Alternative designs incorporating small encapsulated ^{226}Ra sources under a rigid metal screen are under consideration.

Low-level Radon Symposium at PTB, Braunschweig (J.M.R. Hutchinson & R. Collé)

A seminar and workshop on radon standards and quality control under the auspices of the International Committee for Radionuclide Metrology were held at PTB, Braunschweig in May, 1989. Eleven formal papers on the standardization of radon were contributed by international experts in the field. The workshop focussed on needs of the radon community and a number of recommendations were made, one of which was that NIST take responsibility for resolving a discrepancy between the international reference laboratories in the calibration of radon gas.

Development of the Pulse-Recording Technique (L. Lucas & J. M. Los Arcos)

The Centro de Investigationes Energeticas Medioambientales y Technogicas (CIEMAT) in Spain and NIST are engaged in a cooperative effort to develop the Pulse-Recording Technique as a generally applicable method in radionuclide metrology. The cooperative effort involves theoretical development, as well as the implementation of the technique using hardware and software. The initial implementation consists of two input channels, each with an amplitude resolution of 1/256 of full scale, a time resolution of 1×10^{-7} second, and a maximum average count rate of a few thousand counts per second. The hardware is contained on a single IBM PC/AT-compatible adapter card. The first prototype is expected to be operational by the end of calendar year 1989.

US/Spain Collaborative Program on Standardization of Radionuclides by Liquid Scintillation Counting (B. M. Coursey, D. D. Hoppes, J. M. Calhoun, L. L. Lucas, D. Grey, D. Golas, A. Grau Malonda, E. Garcia-Torano, J. M. Los Arcos & M. T. Martin-Casallo)

The Radioactivity Group at NIST and the CIEMAT in Madrid are in the fifth year of a collaborative project to extend the limits of applications of liquid scintillation counting to radionuclide metrology. The theoretical aspects and code development are under the direction of Dr. Grau Malonda. During the past year the EFFY series (beta-particle emission) and VIASKL (electron capture decay) have been extended to include multiple photon emission as well. This allows the computation of counting efficiency for complex nuclides such as indium-111 and mercury-203.

The experimental measurements at NIST are carried out during visits by the Spanish team. During the past year, sulfur-35 was standardized as methionine and it was found that efficiency tracing with tritium could be extended to highly quenched samples with accuracies of the order of 1%. LSC methods were also used to standardize rhenium-186 for the first time, which has promising applications in nuclear medicine, and nickel-59, a pure electron capture decay nuclide, which has applications as a tracer for nickel in the environment. Seven papers by the US and Spanish investigators will be presented at the International Conference on New Trends in Liquid Scintillation Counting and Organic Scintillators in Gatlinburg in October 1989.

SPONSORED WORKSHOPS, CONFERENCES AND SYMPOSIA

Division 536, Ionizing Radiation

International Conference entitled "Fifty Years with Nuclear Fission" held at NIST and the National Academy of Sciences, April 25-28, 1989.

Coursey, B. M., organized a workshop at NIST on Calibration of Strontium-90 Ophthalmic Applicators, March 6-7, 1989.

Humphreys, J. C., organized a meeting of ASTM subcommittee E 10.07 on Ionizing Radiation Dosimetry and Radiation Effects on Materials and Devices at NIST on June 12-14, 1989.

Humphreys, J. C., organized a meeting of ASTM subcommittee E 10.01 on Dosimetry for Radiation Processing at NIST on June 14-16, 1989.

Hutchinson, J.M.R., organized the Radon conference in Braunschweig, FRG at the International Committee for Radionuclide Metrology Meeting and presented a paper on the NIST program, June (1989).

McLaughlin, W. L., ASTM workshop at NIST, on Dosimetry for Radiation Processing. June 12-16, 1989.

Schima, F., hosted the Tritium Measurement Workshop sponsored by the Office of Arms Control, Department of Energy, Nov. 8-9, 1989.

INVITED TALKS

Division 536, Ionizing Radiation

Bergtold, D. S., "Measurements of Biomarkers for DNA Damage and Repair," International Symposium, Free-Radical and Radiation-Induced Damage to DNA; Max Planck Institute, Mulheim, Germany, September 1988.

Bergtold, D. S., "Oxy-radicals in the Physiology of Aging," Society for Physiology; Montreal, Canada, October 1988.

Bergtold, D. S., "New Approaches in Biological Dosimetry," REAC/TS International Conference, The Medical Basis for Radiation Accident Preparedness: II. Clinical Experience and Follow-up Since 1979, Oak Ridge, Tennesee; October 1988.

Bergtold, D. S., "High LET, DNA Damage, and Repair," Armed Forces Radiobiology Research Institute, November 1988.

Bergtold, D. S., "Markers for DNA Damage and Repair and Their Relationship to Aging," American Gerontology Society; San Francisco, California, November 1988.

Bergtold, D. S., "Urinary Biomarkers in Radiation Therapy of Cancer," Society for Free Radical Research, Paris, France, December 1988.

Bergtold, D. S., "Effects of Metabolic Rate on DNA Damage in Mammals," Fifth International Conference on Environmental Mutagens, Cleveland, Ohio, July 1989.

Bergtold, D. S., "Biomarkers of Free Radical Damage in vivo," Fifth Conference on Superoxide and Superoxide Dismutase, Jerusalem, Israel, September 1989.

Bergtold, D. S., "Urinary Biomarkers in Post-Exposure Dosimetry," Third International Conference on Anticarcinogenesis and Radiation Protection, Dubrovnic, Yugoslavia, October 1989.

Carlson, Allan D., "The ENDF/B-VI Standards," Cross Section Evaluations Working Group (CSEWG), Brookhaven National Laboratory, NY, April 4, 1989.

Caswell, Randall S., "Effects of Track Structure on Neutron Microdosimetry and Nanodosimetry," Track Physics Conference, University of Nebraska, Lincoln, October 20, 1988.

Desrosiers, M., "Analytical Approaches for the Detection of Irradiated Foods," Monash University, Melbourne, Australia, March 22, 1989.

Desrosiers, M., "Analytical Approaches for the Detection of Irradiated Foods," Australian Radiation Labs, Melbourne, Australia, March 29, 1989.

Desrosiers, M., "Analytical Approaches for the Detection of Irradiated Foods," Vassar College, Poughkeepsie, New York, NY, April 6, 1989.

Desrosiers, M., "Electron Spin Resonance Spectroscopy of Irradiated Polymers," Ethicon, Inc., Somerville, NJ, August 4, 1989.

Desrosiers, M., "Analytical Approaches for the Detection of Irradiated Foods," University of Maryland, Catonsville, MD, September 19, 1989.

Gilliam, D., "Measurement of the Lifetime of the Free Neutron," Nuclear Engineering Dept. Colloqium, University of Michigan, Ann Arbor, MI, September 29, 1989.

Humphreys, J. C., "NIST High-Dose Calibration Services," Conference on the application of Accelerators in Research and Industry, Denton, Texas, November 7-9, 1988.

Humphreys, J. C. and McLaughlin, W. L., "Calorimetry of Electron Beams and Calibration of Dosimeters at High Doses," 7th International Meeting on Radiation Procesing, Noordwijkerhout, The Netherlands, April 25-29, 1989.

Hutchinson, J.M.R., Fairbank, M. T. Jr., Parks, J. E., and Spaar, M. T., "Investigation of Anomalous Odd/Even Isotopes Ratios in Resonance Ionization Spectroscopy", Workshop on Adanced Laser Tecnhology for Chemical Measurements, Argone National Laboratory, May 9-11, 1989.

Inn, Kenneth G. W., "National Institute of Standards and Technology Environmental Radioactivity Natural Matrix Standard Reference Material Program", National Physical Laboratory,UK, March 14, 1989.

Inn, Kenneth G. W., "National Institute of Standards and Technology Environmental Radioactivity Natural Matrix Standard Reference Material - Getting to the Right Value", National Radiological Protection Board, UK, March 15, 1989.

McLaughlin, W. L., "Radiation Dosimetry," Department of Energy Meeting on Food Irradiation Technology, Department of Energy, Washington, D.C., September 1988.

McLaughlin, W. L., "Reference Dosimetry and Measurement Quality Assurance," 2nd International Symposium on Electron Spin Resonance (ESR) Dosimetry and Application, Münich, Federal Republic of Germany, October 11, 1988.

McLaughlin, W. L., "Thin-Film Applications for Industrial Electron and X-Ray Beams," GAF Chemical Corporation Seminar, Wayne, NJ. November 10, 1988.

McLaughlin, W. L., "New Dosimetry Systems," 7th International Meeting on Radiation Processing," Amsterdam, Netherlands, April 27, 1989.

McLaughlin, W. L., "Radiation Measurements for Quality Control in the Processing of Polymers," Training Course, Polymers Products Department, E. I DuPont de Nemours & Company, Clinton, IO., May 25, 1989.

McLaughlin, W. L., "High-Dose Calorimetry Reference Standards," Chemistry Department Seminar, Risø National Laboratory, Roshilde, Denmark, September 14, 1989.

McLaughlin, W. L., "Calorimetric Dosimetry as High Dose," International Atomic Energy Agency (IAEA) (Vienna) Advisory Group Meeting on High-Dose Dosimetry for Industrial Radiation Processing, IAEA, Vienna, September 21, 1989.

McLaughlin, W. L., "New Radiochromic Dosimetry," Risø National Laboratory Colloquia, Roskilde, Denmark, September 27, 1989.

Schrack, R. A., "Measurement of $^{10}B(n,\alpha\gamma)$ Cross Section from 100 keV to 3 MeV" at Working Group Meeting of the $^{10}B(n,\alpha)$ Cross Section Standard of CSEWG, held at NIST, April 25, 1989.

Schrack, R. A., "Proposed Collaboration with NIST on Measurement of ^{10}B Cross Section," Oak Ridge National Laboratory, Nov. 15, 1988.

Simic, Michael G., "Resonance DNA Base Radicals," Free Radical and Radiation Induced Damage to DNA, Max Planck Institute, Mulheim, Germany, September 26-30, 1988.

Simic, Michael G., "Mechanisms of Inhibition of Free Radical Processes in Mutagenesis and Carcinogenesis," Symposium on Modulation of Mutagenesis and Carcinogenesis, XVIII European Environmental Mutagen. Soc., Varna, Bulgaria, October 3-8, 1988.

Simic, Michael G., "Oxy Radicals in Biology and Medicine," Symposium on Oxygen Stress and Aging, American Physiological Society, Montreal, Canada, October 9-14, 1988.

Simic, Michael G., "New Approaches in Biological Dosimetry Intern," Conference on The Medical Basis for Radiation Accident Preparedness Oak Ridge, TN, October 20-22, 1988.

Simic, Michael G., "Free Radical Processes in Carcinogenesis," SFRR Japan Tokyo, November 27-30, 1988.

Simic, Michael G., "Mechanisms of Inactivation of Oxy Radicals," Second International Conference on Mechanisms of Antimutagenesis and Anticarcinogenesis, Mishima, Japan, December 4-9, 1988.

Simic, Michael G., "Urinary Biomarkers in Radiation Therapy of Cancer," Free Radicals in Medicine. Current Status of Antioxidant Therapy, SFRR Europe Paris, December 9-11, 1988.

Simic, Michael G., "Effects of Metabolic Rate on DNA Damage in Mammals," Fifth International Conference on Environmental Mutagens, Cleveland, OH, July 10-15, 1989.

Simic, Michael G., "Generation of Oxy Radicals in Biological Systems," Session Chairman Fifth Conference on Superoxide and Superoxide Dismutase Jerusalem, Israel, September 17-22, 1989.

Simic, Michael G., "Biomarkers of Free Radical Damage In Vivo," Fifth Conference on Superoxide and Superoxide Dismutase," Jerusalem, Israel, September 17-22, 1989.

Simic, Michael G., "Free Radical Chemistry of Antioxidants and Thiols," Third International Conference on Anticarcinogenesis, Dubrovnik, Yugoslavia, October 15-20, 1989.

Simic, Michael G., "Urinary Biomarkers in Post-Exposure Dosimetry," Third International Conference on Anticarcinogenesis, Dubrovnik, Yugoslavia, October 15-20, 1989.

Sparrow, J., "Hand Held Dental X-Ray Inspection System," ASNT Chapter Meeting.

Walker, M. L., "Some Recent Developments in Ionizing Radiation Chemical Dosimetry," the National Organization for the Professional Advancement of Black Chemists and Chemical Engineers, Chicago, IL., March 20-25, 1989

Wasson, Oren A., "Neutron Standard Cross Section Measurement Program at NIST," Oak Ridge National Laboratory, Oak Ridge, Tennessee, Nov. 15, 1988.

Wasson, Oren A., "Experimental Aspects of Cold Fusion," Luncheon Seminar for Surface Science Division and Electron Physics Group, NIST, April 10, 1989.

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Al-Sheikhly, M. and Simic, M.G., "Oxygen Uptake in Characterization of Autoxidation and Antioxidation Processes, in Free Radicals, Methodology and Concepts, Eds. C. Rice-Evans, B. Halliwell, Richelieu Press, pp. 481-497 (1988).

Al-Sheikhly, M. and Simic, M.G., "Chain-Propagation Length of Linoleic Acid Peroxidation in Aqueous Monomeric and Micellar Systems," J. Phys. Chem., 93, 3103-3106 (1988).

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Bergtold D.S. and Simic, M.G., "Background Levels of DNA Damage," Free Radical Res. Comm., 6, 195-198 (1989).

Burger, G. and Schwartz, R.B., "Guidelines on Calibration of Neutron Measuring Devices." Technical Reports Series No. 285, International Atomic Energy Agency, Vienna, 1988.

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Carlson, A.D., Wasson, O.A, Lisowski, P.W., Ullmann, J.L., and Hill, N.W., "A Study of the ^{235}U(n,f) Cross Section in the 3 to 30 MeV Energy Region," Proc. of the International Conference on Nuclear Data for Science and Technology, Mito, Japan, May 30-June 3, 1988, pp. 1029-1032.

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Caswell, R.S. and Coyne, J.J., "Effects of Track Structure on Neutron Microdosimetry and Nanodosimetry," Nuclear Tracks and Radiation Measurements (in press).

Coursey, B.M., Lucas, L.L., Grau Malonda, A., Garcia-Toraño, E., "The Standardization of Plutonium-241 and Nickel-63," Nuclear Instrum. and Meth. Part A. A279, 603 (1989).

Desrosiers, M. and Agric, J., "Gamma-Irradiated Seafoods: Identificationn and Dosimetry by Electron Parmagnetic Resonance Spectroscopy," Food Chem. 37, 96-100 (1989).

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Simic, M.G., and Jovanovic, S.V., "Mechanisms of Inactivation of Oxygen Radicals by Dietary Antioxidants and Their Models," in Antimutagenesis and Anticarcinogenesis Mechanisms II, Eds. Y. Kuroda, D.M. Shankel, M.D. Waters, Plenum, NY (1989).

Soares C.G. and Meulenberg, A. "A Simple GaAs Radiation Damage Monitor," in preparation for publication in IEEE Trans. Nucl. Sci.

Soares C.G., Devine, R.T., and Zeman, G.H., "Impact of Recent Data and Concepts on Personnel Dosimetry Testing Programs", in preparation for publication in Health Physics.

Srivastava, H.M. and Hubbell, J.H., "Certain Theorems on Bilateral Generating Functions Involving Hermite, Laguerre, and Gegenbauer Polynomial," J. Math. Analysis and Applications (in press).

Walker, M.L., "Some Recent Developments in Ionizing Radiation Chemical Dosimetry," to be published in the proceedings of the 1989 annual meeting of the National Organization for the Professional Advancement of Black Chemists and Chemical Engineers.

Wasson, O.A. and Schrack, R.A., "Determination of the Uniformity of Uranium Fission Deposits using Rutherford Backscattering Spectrometry and Alpha-Particle Scanning," submitted to Nucl. Instr. Meth. Phys. Res.

TECHNICAL AND PROFESSIONAL COMMITTEE PARTICIPATION AND LEADERSHIP

Division 536, Ionizing Radiation

Jacqueline M. Calhoun

EEO Coordinator, National Measurement Laboratory.

Member, Advisory Panel on Radiopharmaceuticals, U.S. Pharmacopoeia.

Member, U.S. Council for Energy Awareness (USCEA)-NIST Standards Program Committee.

Member of National Institute of Standards and Technology (NIST) Handicap Committee.

Member of the National Institute of Standards and Technology (NIST) Day Care Scholarship Committee.

Allan D. Carlson

Chairman, Standards Subcommittee, Cross Section Evaluation Working Group (CSEWG).

Member, Evaluation Committee of CSEWG.

Member, Data Status and Requests Subcommittee of CSEWG.

Co-Chairman, Program Committee and Co-Editor of the proceedings for Fifty Years with Nuclear Fission Conference held at NIST, April 25-28, 1989.

Chairman, Nuclear Energy Agency Nuclear Data Committee (NEANDC), Working Group on the $^{10}B(n,\alpha)$ Cross Section Standard.

Randall S. Caswell

Chairman, Science Panel, Committee on Interagency Radiation Research and Policy Coordination (CIRRPC), Office of Science and Technology Policy.

Alternate Member, Main Committee, CIRRPC.

Member, Consultative Committee for Ionizing Radiations (CCEMRI), Conférence Générale des Poids et Mesures, Paris, France.

Chairman, Section on Neutron Measurements (Section III), CCEMRI.

Randall S. Caswell (cont'd)

Member, National Council on Radiation Protection and Measurements (NCRP).

Member, Selection Committee for the Presidency of the NCRP.

Member and Secretary, International Commission on Radiation Units and Measurements (ICRU).

Sponsor, ICRU Report Committee on Stopping Power Protons and Alpha Particles.

Sponsor, ICRU Report Committee on Stopping Power for Heavy Ions.

Sponsor, ICRU Report Committee on Absorbed Dose Standards for Photon Irradiation and Their Dissemination.

Sponsor, ICRU Report Committee on Clinical Dosimetry for Neutrons (Physics).

Sponsor, ICRU Report Committee on In-Situ Gamma-Ray Spectrometry in the Environment

Bert M. Coursey

Advisory committee: International Conference on New Trends in Liquid Scintillation Counting and Organic Scintillators, Gatlinburg, TN, October 1989.

Member, International Committee for Radionuclide Metrology (ICRM) Life Sciences Working Group.

Member, ANSI Committee N42.2 on Nuclear Instruments, Procedural Standards for Calibration of Detectors for Radioactivity Measurements.

Member, Delegate to Section I, Consultative Committee for Ionizing Radiations (CCEMRI), Conférence Générale des Poids et Mesures, Paris, France.

Marc F. Desrosiers

Member, IAEA Coordinated Research Program on Electron Paramagnetic Resonance Dosimetry.

Editor, Magnetic Resonance Food Irradiation Newsletter.

Marc F. Desrosiers (Cont'd)

Program Chairman, Washington Electron Paramagnetic Resonance Discussion Group.

Member, Washington Chromatography Discussion Group.

Charles E. Dick

Member, Technical Organizing Committee, Industrial Applications, International Conference on the Applications of Accelerators in Research and Industry. Biannual Conference held in even numbered years at North Texas State Univ., Denton, TX.

Charles M. Eisenhauer

Member, CIRRPC Science Panel; Chairman, Subpanel on Predisaster Planning for Human Health Effects Research.

Member, Working Group 2, Reference Radiations Subcommittee 2, Technical Committee 5, International Standards Organization.

Member, National Council on Radiation Protection and Measurements (NCRP). Also Task Group on Atomic Bomb Survivor Dosimetry: SC-40 Biological Aspects of Radiation Protection Criteria.

Member, NAS-NRC Advisory Committee on the Radiation Effects Research Foundation; Advisory Dosimetry Subcommittee.

Member, ANS Standards Committee Working Group on Gamma-Ray Attenuation Data.

James A. Grundl

Member, NCRP Task Group SC-63 on Public Knowledge About Radiation Emergencies

Member, ASTM Subcommittee E10.05 on Nuclear Radiation Metrology.

Dale D. Hoppes

Secretary, International Committee for Radionuclide Metrology (ICRM).

Member, ICRM Beta- and Gamma-Ray Spectrometry Working Group.

Dale D. Hoppes (cont'd)

Member, U.S. Council for Energy Awareness (USCEA)-NIST Standards Program Committee.

Member, International Committee of Weights and Measures (BIPM), Consultative Committee on Standards for Measuring Ionizing Radiations, Subcommittee Section II: Radionuclide Measurements.

Member, ANSI Subcommittee N42.2 on Procedural Standards for Calibration of Detectors for Radioactive Materials.

Jimmy C. Humphreys

Secretary, ASTM E10.07 Subcommittee, Ionizing Radiation Dosimetry and Radiation Effects on Material and Devices.

Member, ASTM Subcommittee E10.01 Dosimetry for Radiation Processing.

Member, ASTM Subcommittee F1.11, Hardness Assurance of Electronics

Member, AAMI (Association for the Advancement of Medical Instrumentation) subcommittee task groups on dosimetry of gamma and electron beam sterilization of medical products and devices.

J. M. Robin Hutchinson

Chairman, International Committee for Radionuclide Metrology (ICRM) Subcommittee on Low-level Techniques.

Member, American National Standards Institute (ANSI) Committee on Nuclear Instruments and Detectors.

Secretary, ANSI Subcommittee N42.2 on Procedural Standards for Calibration of Detectors for Radioactivity Measurements.

Kenneth G. W. Inn

Member, ANSI N42.2, Quality Assurance for Radioassay of Environmental Samples.

Member, ASTM Committee C26.05.01, Methods of Test, Test Methods, Environmental Methods.

Member, ASTM Committee D19, Water, radioactivity Test Methods.

Wilfrid B. Mann

Member, ANSI-INMM Working Group INNM 8.04 Calibration Technique for the Calorimetric Assaying of Plutonium-Bearing Solids applied to Nuclear Materials Control.

Honorary Council Member, NCRP.

Chairman, NCRP Committee 18A, Standards and Measurement of Radioactivity for Radiological Use.

Life Member, ICRM.

Emmert D. McGarry

Member, ASTM Committee E10; Subcommittee E10.05, Nuclear Radiation Metrology.

Chairman, Awards Committee of ASTM Subcommittee E10.05.

Member, Planning Committee for the 9th ASTM-EURATOM Symposium on Reactor Dosimetry.

William L. McLaughlin

Technical Advisor Council of Europe Parliamentary Assembly, Work Group on Aerospace Physiology, Medicine, and Radiation Measurement.

Technical Advisor, Council of Europe Parliamentary assembly, Work Group on Space Biophysics.

Member, R & D Associates Committee on Irradiated Food Products.

Member, International Atomic Energy Agency (IAEA), Advisory Group on High Dose Measurement and Standardization for Radiation Processing.

Member, Association for Advancement of Medical Instrumentation, Subcommittee on Radiation Sterilization Dosimetry (Working Groups on Gamma Ray Sterilization and Electron Beam Sterilization).

Technical Advisor, National Council on Radiation Protection and Measurement, Scientific Committee 63, Radiation Exposure Control in a Nuclear Emergency.

Science and Technology Consultant, CIRRPC.

William L. McLaughlin (cont'd)

Chairman, Advisory Panel on Electron Beam Dosimetry for Industrial Radiation Processing, International Atomic Energy Agency.

Member Advisory Panel on Guidelines on Dosimetry for Industrial Radiation Processing, International Atomic Energy Agency.

Member of Organizing Committee and Chairman for Invited Speakers for International Workshop on Dosimetry for Radiation Processing, Ste-Adele, Quebec, Canada.

Member, Organizing and Program Committees and Editor of Proceedings, 2nd International Symposium on ESR Dosimetry and Applications, Munich 1988.

Chairman Program Committee, Member Organizing Committee, 3rd International Symposum on ESR Dosimetry and Application

Member ASTM Subcommittee E10.07 on Ionizing Radiation Dosimetry and Radiation Effects on Materials and Devices.

Member, ASTM Subcommitte E10.01, Dosimetry for Radiation Processing.

Member, Ad-Hoc Interdepartmental Committee on Food Irradiation (Secretariat, Department of Commerce).

Francis J. Schima

Research Associate Member, IAEA, Coordinated Research Program on Gamma-ray Standards for Detector Efficiency Calibration.

Member, ICRM Working Group on Gamma- and Beta-ray Spectrometry.

Scientific and Technical Consultant, CIRRPC.

Robert B. Schwartz

Member, ICRU Report Committee on Practical Determination of Dose Equivalent.

Chairman, Neutron Sub-Group, ISO TC 85/SC 2/WG 2.

Member, ICRU Report Committee on Practical Determination of Dose Equivalent.

Stephen M. Seltzer

Member, ICRU Committee on Stopping Power.

Consultant, ICRU Report Committee on Material Equivalent and Tissue Substitutes.

Collaborator, International Atomic Agency Advisory Group on Atomic and Molecular Data for Radiotherapy.

Michael G. Simic

Member of CAST (Council of Agricultural Science and Technology).

Secretary General of the Oxygen Society

Member of the Advisory Board Critical Reviews of Sulfhydryl Chemistry

Christopher G. Soares

Member of Health Physics Scientific Subcommittee Work Group for the revision of ANSI N13.11, "Personnel Dosimetry Performance - Criteria for Testing".

Michael P. Unterwerger

Member, ASTM Committee D22 on Sampling and Analysis of Atmospheres.

Oren A. Wasson

Member, Department of Energy Nuclear Data Committee

Executive Chairman, Conference entitled "Fifty Years with Nuclear Fission," held at NIST, April 25-28, 1989.

MAJOR CONSULTING AND ADVISORY SERVICES

536, Ionizing Radiation Division

R. S. Caswell participated as a member of a team reviewing the Radiological and Chemical Research program of the Pacific Northwest Laboratory at the request of the U.S. Department of Energy.

R. S. Caswell served as a member of a Review Panel evaluating candidates for the position of Director of the Office of Health and Environmental Research, U.S. Department of Energy.

C. E. Dick consulted with C. Richmond, Harry Diamond Labs., on coherence effects in Cherenkov radiation.

C. E. Dick consulted with Bill Lee, Eglin Air Force Base, on the evaluation of DRAM imagers for armament evaluation.

C. E. Dick consulted with L. Fagg, Catholic University. on design and calibration of high energy beam monitors for electron beams.

J. C. Humphreys provided on site advice and critical evaluation of dosimetry calibration and irradiation procedures for A. Nigro at Baxter Healthcare Corp., Round Lake, IL.

J.M.R. Hutchinson consulted with the U. S. Navy for the development of a new large area alpha-particle monitoring system.

K.G.W. Inn consulted with the National Physical Laboratory (and other major European Community national radiometrology laboratories) on the production of low-level radioactivity natural matrix standard reference materials.

K.G.W. Inn, L. Currie, and E. H. Eisenhower consulted with the management of the ORNL Health Physics Division on concepts and principles for their in-house quality assurance program.

E. D. McGarry provides consultation to Materials Engineering Branch of the Nuclear Regulatory Commission regarding benchmarking of pressure vessel surveillance dosimetry.

E. D. McGarry is now also providing consultation to the Materials Engineering Branch of the NRC with respect to radiation damage of structural components of commercial nuclear reactors. Current consultation deals with components of the TROJAN PWR reactor in Portland, Oregon.

Division 536, Major Consulting and Advisory Services

William L. McLaughlin, Jimmy C. Humphreys, and Jim Puhl conducted an extensive dosimetry intercomparision between NIST and UK National Physical Laboratory, Nordion International, Canada, Isomedix, Inc., NJ, and ATC International, MD, involving liquid chemical and radiochromic dosimeters.

William L. McLaughlin, worked extensively with Dr. S Kronenberg, Electronics and Radiation Command, US Army Fort Menmorth, NJ and C.R. Siebentritt Federal Emergency Management Agency, in designing and testing of emergency dosimetry systems, both electronic and radiochromic optical wave guide systems, in their response to mixed radiation fields (photons and neutrons).

William L. McLaughlin, worked with Dr. Helmut Schönbacher of the European Organization for Nuclear Research (CERN) to devise a radiochromic system especially designed for simplifying the routine monitoring or radiation damage of electrical and electronic components, including magnets, in high-performance, high-energy particle storage-ring facilities.

William L. McLaughlin, worked extensively with Dr. Dick William and Laura Streppel of North America Science Associates, Chicago, IL., on quality control measurements for the radiation sterilization of biological tissue implant immune-suppressions systems.

William L. McLaughlin, supplied Dr. Thomas Hugen of Stern and Stern Industries, New York, with radiation-damage data, computations and measurements on a number of plastic materials used as disposable medical devices.

William L. McLaughlin, designed, in collaboration with Dr. W.W. Chang, of Warner-Lambert Co. of Morris Plains, NJ., an experimental method for measurement quality assurance in the sterilization of pharmaceutical and drugs, including natural products.

William L. McLaughlin, worked with Dr. L.A. Harrah of PDA Engineering, Albuquerque to design a highly purified radiochromic system for use by DoD in the design of a tracheal dosimeter used in mixed radiation facilities.

William L. McLaughlin, consulted with Dr. R.J. Jaffee of TRW, on traceable methods for monitoring radiation effects on electrons in missiles and satellites.

William L. McLaughlin, worked with Dr. L.A. Sidney and Jeffry Mitchell of the 3M Co., St. Paul, MN, in the development of a new 3M radiochromic dosimeter film.

Division 536, Major Consulting and Advisory Services

William L. McLaughlin, collaborated with Dr. J. Sayeg of the University of Kentucky Medical Centers in the first use of Gaf Chromic^{TM} dosimetry film for brachytherapy treatment planning and β-ray dosimetry.

William L. McLaughlin, combined with Dr. A. Herrer of E-Beam Services Inc., to design a new large scale diagnostics system for wide-scan electron beam processing lines.

William L. McLaughlin, assisted Dr. P. Finn of Argonne National Laboratory in designing a long-term high-dose neutron dosimetry, with good neutron-to-gamma-ray discrimination.

William L. McLaughlin, supplied Dr. J. Jansen of Ames Research Laboratory, with detailed information on high-dose neutron dosimeters for use in the study of neutron damage effects on space vehicle components.

William L. McLaughlin, consulted with Dr. D. Bigbee of the FBI, on suitable radiation methods and sterility assurance approaches in the sterilization of medical and hospital waste.

William L. McLaughlin, assisted Dr. Robert White and Dr. Michael Beauregard of Industrial Drives, Inc., Radford, VA., in designing radiation measurements for quality control in the irradiation of machinery with minimal damage to sealants, seals, epoxies, plastics, lubricants, moving motor parts, and servo-motors.

William L. McLaughlin, Jimmy C. Humphreys, and Carol Croarkin (Standards Engineering Division) advised Joe Rothleder of the California Department of Food and Agriculture in the use of reference dosimeters and the setting up of radiation measurements and statistical procedures for regulation food irradiation in California.

R. B. Schwartz calibrated "Bubble Dosimeters" and "Bubble Spectrometer" tubes for the Oak Ridge National Laboratory.

S. M. Seltzer collaborated with scientists at the NASA Goddard Space Flight Center (and the US Geological Survey) on the theoretical and experimental development of a pattern-recognition approach to XRF analysis for the compositional classification of geological samples (with applications to the Mars Rover Mission), metal-alloys, and paints.

S. M. Seltzer performed a series of Monte Carlo calculations for electron transmission through, and energy-absorption in, Ti and Havar window foils proposed for use in Energy Sciences, Inc. (Woburn, MA) industrial electron accelerators.

Division 536, Major Consulting and Advisory Services

S. M. Seltzer provided close consultation to members of the Simulation Division, Sandia National Laboratory, Albuquerque, NM, on the incorporation of recently-developed electron-photon cross sections and sampling algorithms into their Monte Carlo codes.

S. M. Seltzer provided codes and cross-section databases, and instructions for their installation and use, to scientists requesting data and the tools for electron and photon transport calculations. Requests came from staff members of: IBM; the Israel Atomic Energy Commission; NASA's Marshall Space Flight Center; NASA's Goddard Space Flight Center; the National Research Council, Canada; the National Physical Laboratory, England; the Jet Propulsion Laboratory; the University of Saskatchewan's Chemistry Department; the Argonne National Laboratory; the Sandia National Laboratory; the University of Wisconsin - Madison Medical School; the University of Rochester Cancer Center; and the Lawrence Livermore National Laboratory.

JOURNAL EDITORSHIPS

Division 536, Ionizing Radiation

B.M. Coursey, Editor, International Journal of Radiation Applications and Instrumentation, Part A. Applied Radiation and Isotopes.

B.M. Coursey, Editor, International Journal of Radiation Applications and Instrumentation, Part B. Nuclear Medicine and Biology.

C.E. Dick, Member, Editorial Board, Industrial Metrology.

J.M.R. Hutchinson, Special Issue: "Environmental Radioactivity" in Environment International, 14, No. 4, 1988.

W.L. McLaughlin, Editor in Chief, North America, International Journal of Radiation Applications and Instrumentation, Part A. Applied Radiation and Isotopes.

W.L. McLaughlin, Editorial Board, Radiation Physics and Chemistry.

M.G. Simic, International Editorial Board, Free Radical Biology and Medicine.

TRIPS SPONSORED BY OTHERS

Division 536, Ionizing Radiation

David S. Bergtold, traveled to the Max Planck Institute, Mulheim, Germany, International Symposium, Free-radical-and radiation-induced damage to DNA, "Measurements of Biomarkers for DNA Damage and Repair" (September 1988). Sponsored by Max Planck Institute. Paid air fare.

David S. Bergtold, traveled to Society for Physiology, Montreal, Canada, "Oxy-radicals in the physiology of aging" (October 1988). Sponsored by American Physiological Society. Paid Travel, per diem and registration.

David S. Bergtold, American Gerontology Society, San Francisco, California, "Markers for DNA damage and repair and their relationship to aging" (November 1988). Sponsored by the Gerontological Society of America. They paid for air travel and subsistence.

Randall S. Caswell traveled to Paris, France to attend the Annual Meeting of the International Commission on Radiation Units and Measurements (ICRU). Round-trip air travel and partial subsistence were provided by the ICRU.

Randall S. Caswell traveled to Richland, Washington to serve as a member of a four-man team reviewing the Radiological and Chemical Research program of the Pacific Northwest Laboratory for the U.S. Department of Energy. Round-trip air travel and subsistence were provided by DoE.

Bert M. Coursey, traveled to Oxford, UK, for meetings with the publishers, Pergamon Press, of Applied Radiation and Isotopes, and to Coventry, UK, to attend the Executive Board Meeting of the International Radiation Physics Society. Air travel and one day subsistance were paid by Pergamon Press (April 30 - May 6, 1989).

Kenneth G. W. Inn, Lloyd Currie, and Elmer H. Eisenhower consulted with the management of the ORNL Health Physics Division on concepts and principles for their in-house quality assurance program. Air travel and two days subsistence were paid by Oak Ridge National Laboratory.
Lisa R. Karam traveled to l'Institute Jacques Monod - Paris, France, to develop M13 plasmid derivative for radiation bioeffects project. The l' Institute Jacques Monod paid for lodging and subsistence. (November 8 - December 12, 1988).

William L. McLaughlin, traveled to Oxford, UK for meetings with the Editorial Management Staff of the Pergamon Press, as a newly appointed Editor-in-Chief for North America, of the journal, Applied Radiation and Isotopes. Three days subsistence was paid by Pergamon Press. (September 24-27, 1988).

William L. McLaughlin, traveled to GAF Chemical Corporation, Wayne, NJ, to present invited talks at the GAF Seminar. All expenses were paid by GAF (November 10-11, 1988).

William L. McLaughlin, traveled to E.I DuPont & Nemours & Co., Clinton IO, to present invited talks and to teach a training courses at DuPont Polymers Products Department. All expenses were paid by the DuPont Co. (May 24-26, 1989).

William L. McLaughlin, traveled to the International Atomic Energy Agency, Vienna, Austria to give invited talks and to participate in the IAEA Advisory Group Meeting on High-Dose Dosimetry for Industrial Radiation Processing. Airline tickets and all subsistence was paid by IAEA. (September 16-21, 1989).

William L. McLauglin, traveled to CERN Nuclear Research Center, Geneva, Switzerland, to attend a meeting on Radiation Measurements for Radiation Effects on Materials. Airline tickets and two days subsistence was paid by CERN (September 22-23).

Robert B. Schwartz traveled to Schloss Elmau (near Munich), FRG, in October, 1988, to participate in a meeting of the ICRU Working Group on Practical Determination of Dose Equivalent. All expenses of the trip were paid for by the ICRU.

Michael G. Simic, Resonance DNA base radicals, Free Radical and Radiation Induced Damage to DNA, Max Planck Institute, Mulheim, Germany, September 26-30, 1988. Sponsored by Max Planck Institute. They paid partial air fare and subsistence expenses.

Michael G. Simic, Oxy radicals in Biology and Medicine, Symposium on Oxygen Stress and Aging, American Physiological Society, Montreal, Canada, October 9-14, 1988.

Michael G. Simic, New approaches in biological dosimetry. Conference on The Medical Basis for Radiation Accident Preparedness Oak Ridge, TN, October 20-22, 1988. Sponsored by DOE. They paid round trip air fare.

Michael G. Simic, Free radical processes in carcinogenesis, SFRR Japan Tokyo, November 27-30, 1988. Sponsored by Society for Free Radical Research. Furnished financial support.

Michael G. Simic, 18th European Environmental Society, Varna, Bulgaria. Lodging and subsistence for 3 days paid by Mutagen Society, Varna, Bulgaria.

Oren A. Wasson traveled to Darmstadt, Federal Republic of Germany, to participate in the International Atomic Energy Agency Advisory Group Meeting on "The Influence of Target and Sample Properties on Nuclear Data Measurements." The trip was sponsored and paid for by the International Atomic Energy Agency (September 5-9, 1988).

STANDARD REFERENCE MATERIALS

Division 536, Ionizing Radiation

Radioactivity Group Standards Issued - 1 August 1988 through 31 July 1989

SRM	Radionuclide	Principal Calibration Use
4417L-H	Indium-111	Activity measurement of radiopharmaceutical
4410H-N	Technetium-99m	"
4424	Sulfur-35	"
4407-M	Iodine-25	"
4401L-O	Iodine-131	"
4412L-N	Molybdenum-99	"
4415L-M	Xenon-133	"
4416 L-J	Gallium-67	"
4404L-L-K	Thallium-201	"
4400L-L-J	Chromium-51	"
4320	Curium-244	Chemical yield monitor
4926-C	Solution Source Tritiated H_2O	For the preparation of secondary standards for liquid scintillation counting
4369	Gadolinium-153	Irradiators for osteoporosis measurements
4275-C	Long-Lived Mixed Radionuclide Point Source	Germanium spectrometer systems in the energy range from 27 to 1596 keV
4276-C	Long-Lived Mixed Radionuclide Solution Source	Germanium spectrometer systems in the energy range from 27 to 1596 keV for user sources
4324	Uranium-232 Solution Sources	Chemical yield monitor

Total radioactivity SRM's distributed: 747

CALIBRATION SERVICES PERFORMED

Division 536, Ionizing Radiation Division

I. Radiation Interactions and Dosimetry Group

High-Dose Calibrations

	Customer Classification	Type of Service	No. of Customers	No. of Tests Performed	Service Fee Income
(1)	Industrial:	A	27	189	$ 52,312
	medical product	B	4	15	7,440
	sterilization	C	7	7	390
(2)	Industrial:	A	4	23	6,099
	electronic	B	4	25	10,895
	hardness testing	C	2	3	323
(3)	Industrial:	A	1	3	771
	polymer	B	0	0	0
	modification	C	0	0	0
(4)	National Laboratory:	A	0	0	0
	electronic	B	0	0	0
	hardness testing	C	0	0	0
(5)	Dept. of Defense:	A	2	10	2,815
	electronic	B	0	0	0
	hardness testing	C	0	0	0
(6)	Secondary	A	0	0	0
	Calibration	B	0	0	0
	Laboratory	C	0	0	0
(7)	University:	A	1	11	2,827
	research	B	0	0	0
		C	0	0	0
	Subtotals:	A	35	236	64,824
		B	8	40	18,335
		C	9	10	713
	Grand Totals:	XXX	52	286	83,872

Service Code	Type of Service	SP250 Number
A	Irradiate Dosimeters	49010C
B	Supply Transfer Dosimeters	49020C & 49030C
C	Special Measurements	49040S & 49050S

Division 536, Calibration Services Performed (cont'd)

Type of Service	Customer Type*	SP 250 Item No.	Number of Tests	Income
Calibration of x-ray and γ-ray measuring instruments, and irradiation of TL dosimeters	1-8	46010-50	328	$ 183 k
Calibration of γ-ray and β-particle sources	2-6	47010-40	23	33 k
Chemical dosimetry measurement assurance service for electron beam	2	48010-20	51	39 k
Instrument calibration	8	N.A.	1	20 k
			Total	$ 275 k

*Column 2: 1, calibration labs; 2, hospitals; 3, nuclear establishments; 4, industry; 5, US government labs; 6, DoD labs, 7, universities; 8 US government agencies.

II. Neutron Interactions and Dosimetry Group

Type of Service	Customer	Sp 250 Item No.	No. of Tests
Neutron Protection Instrumentation	Arkansas P&L	44060C	2
	Calvert Cliffs	44060C	18
	Carolina P&L	44060C	1
	Omaha Public Power	44060C	7
	Lackland AF Base	44060C	1
	Redstone Arsenal	44060C	10
	WPPSS	44060C	8
	AFRRI	N/A	4
	Illinois Power	44060C	4
	M. D. Anderson Hosp.	44060C	1
		Total	56
Neutron Source Calibration	Oak Ridge National Lab	44010C	1
	U.S. Army	44010C	2
	Perry Nuclear Plant, Ohio	44010C	1
		Sub Total	4
	In-house (NIST) Sources	N/A	6
		Total	10

Division 536, Calibration Services Performed (cont'd)

III. Radioactivity Group

August 1, 1988 to August 1, 1989

	Scheduled Calibrations		Non-scheduled Tests	
	Number of Sources	Total Fee $k	Number of Sources	Total Fee $k
Category				
Alpha-particle Sources SP-250 Nos. 43030C	13	9.4	1	1.
Beta-Particle Solutions and Gases (^{85}Kr)	--	--	4	3.7
Gamma-ray Solutions, Point Sources, and Xe Isotopes	1	1.1	9	9
	14	10.5	14	13.7

*SP-250 numbers refer to scheduled calibrations

SPONSORED SEMINARS AND COLLOQUIA

Division 536, Ionization Radiation

L. Zuppiroli, Laboratorie des Solides Irradies, Ecole Polytechnique, Palaiseau, France, "Organic Conductors and Ceramic Materials for MegaGray Dosimetry Measurements," September 28, 1988.

Etsuo Niki, University of Tokyo, Tokyo, Japan, "Physiological Antioxidants (Mechanisms of Action of Vit. E., Carotene, Uric Acid, Ascorbate)," November 4, 1988.

Rudiger Jahr, Physikalisch Technische Bundesanstalt, Braunschweig, West Germany, "The PTB Reactor Division--Research Highlights," November 7, 1988.

David J. Brenner, Columbia University School of Medicine, New York, New York, "Neutron Doses and RBE's at Hiroshima," December 8, 1988.

Arne Miller, Risø National Laboratory, Roskilde, Denmark, "Standard Reference Dosimetry Applied to Industrial Radiation Processing," January 30, 1989.

Arthur Ainsworth, Amersham International, Amersham, UK, "Preparation and Calibration of Amersham Ophthalmic Applicator Sources," March 6, 1989.

Stephen J. Goetsch, University of Wisconsin-Madison, Department of Radiology, "Ophthalmic Applicator Measurements at the University of Wisconsin," March 6, 1989.

Donald Haskard, Royal Adelaide Hospital, Australia, "The Use of Ophthalmic Applicators in Australia," March 6, 1989.

Joseph Sayeg, University of Kentucky, School of Medicine, Louisville, KY, "A new method for characterizing ophthalmic applicator sources," March 6, 1989.

Johannes Zoetelief, Radiobiological Institute TNO, Rijswijk, The Netherlands, "Dosimetrical Aspects of Mammography," March 9, 1989.

H. M. Vriesendorp, Johns Hopkins University Hospital, Baltimore, Maryland, "Radio-Labeled Anti-Ferritins for Treatment of Human Malignancies," March 16, 1989.

Harald H. Rossi, Nevis Laboratories, Irvington, New York, "The Role of Physics in Radiobiology," April 20, 1989.

John B. Czirr, Brigham Young University and Bicron Corporation, "Neutron Spectroscopy for Cold Neutrons,", May 1, 1989.

Dieter Seeliger, Technical University of Dresden, East Germany, "Neutron Measurements at Dresden," May 1, 1989.

Miroslav Radman, Institut Jacques Monod, Paris, France, "Activation of Genetic Recombination Between Species," May 15, 1989.

Robert Katz, University of Nebraska-Lincoln, Lincoln, Nebraska, "Track Physics: Perspectives, Problems, and Progress," June 1, 1989.

Michael P. R. Waligorski, Institute of Nuclear Physics, Krakow, Poland, "Radiosensitivity Parameters for Cancer-like Endpoints in Cell Cultures," June 15, 1989.

Gabor Foldiak, Hungarian Academy of Sciences, Budapest, Hungary, "Competitive Reactions in the Radiolysis of Hydrocarbons," June 23, 1989.

Marshall R. Cleland, Radiation Dynamics, Inc., "New Developments in Radiation Processing," July 20, 1989.

Motoji Ikeya, Osaka University, Toyonaka City, Japan, "ESR Dosimetry and Microscopy," August 7, 1989.

Eiping Quang, University of Michigan, Ann Arbor, Michigan, "Neutron Capture Cross Section Measurements for U-238," August 10, 1989.

David Werst, Argonne National Laboratory, Argonne, Illinois, "Time-Resolved Magnetic Resonance Methods Used in Pulse Radiolysis Studies," August 11, 1989.

D. Schulte-Frohlinde, Max Planck Institute, Mulheim, West Germany, "Mechanism of Laser-Induced Damage to DNA and Model Compounds," August 16, 1989.

TECHNICAL ACTIVITIES

Division 530.01, Nuclear Physics Group

(A) EXPERIMENTAL ACTIVITIES:

During FY89, electromagnetic nuclear physics experiments by the group have again been carried out exclusively in the user mode. Work is going on at a number of laboratories: the University of Saskatchewan cw linac/pulse stretcher ring; the University of Lund microtron; the MIT/Bates Linear Accelerator Lab; SLAC; the Berkeley 88" Cyclotron; and CEBAF (planning only). The Saskatchewan and Lund machines are among the few operational cw electron accelerators in the world.

The work at Saskatchewan is in collaboration with researchers from that lab, and from the University of Maryland. The experiment is a search for evidence for three body forces in the exclusive three-body breakup channel of ^3He. We use a bremsstrahlung beam and two plastic scintillator dE-E telescopes for proton detection. The data which have been taken are being analyzed. We see evidence for the presence of excess cross section compared to calculations based on binary interactions only. A new detector has been designed to permit out-of-the-reaction-plane data to be taken. Such kinematics are most sensitive to three-body effects and will allow new probes of the reaction mechanism. Measurements are planned for spring 1990. [Dodge, Lightbody, O'Connell]

The work at Bates is continuing on several fronts. We have completed data analysis of the (e,e'fission) data taken for $^{233,238}U$. Radiative corrections to the data and checks of normalizations have been carried out. We find in comparing the exclusive fission cross section (e,e'f) compared to the total (e,e') cross section in the quasi-free (QF) and delta resonance regions that there are apparent differences in the reaction mechanisms for the two regions. In the QF knockout region, the residual nucleus is left in a rather low energy state of excitation (about 20-25 MeV), while in the delta region the residual energy is about 40 MeV. These energies are not easily reconciled with nuclear binding energy effects based on position of the QF nucleon knockout and delta production peaks relative to free nucleon peaks, and may require consideration of momentum dependent potentials for the struck nucleons. Despite substantially different fission branching ratios, using known fission probabilities for the two targets, we obtain the same residual energies in the case of the two QF and delta peaks. Previous studies of binding effects based on inclusive measurements led to substantially different residual energies. [Dodge, Lightbody, O'Connell]

We are still in the planning stages of polarized electron beam experiments at Bates. Our deuteron breakup measurement d(e,e'p)n must await development of a larger acceptance magnetic spectrometer capable of out-of-plane operation. The experiment proposed seeks to make a proof-of-principle test of the form of a newly discovered structure function related to the spin-orbit part of the N-N potential. In the meantime we have developed an electron polarimeter for these measurements. The polarimeter has been tested and will be used in a measurement of the neutron charge form factor, a very high priority experiment which makes use of a polarized ^{3}He target as well as a polarized beam. [Dodge, Lightbody, O'Connell]

At SLAC, our approved experiment to measure the ^{4}He(e,e'p) cross section at high momentum transfer awaits scheduling. A new segmented focal plane detector has been designed and built by our group for the 8 GeV magnetic spectrometer which we will use in the experiment. We have made new and improved estimates of the accidental coincidence rates which now make the experiment appear practical. The motivation behind our experiment is to search for medium modifications of the struck-nucleon structure functions, and is related to study of the fundamental quark confinement process. In waiting for beam, our detector has been used in another SLAC experiment to measure nucleon charge and magnetic form factors at high momentum transfer. [Dodge, Lightbody, O'Connell]

This year we participated in a collaborative experiment with Duke University at the Berkeley 88" cyclotron. We studied the radiative capture reaction ^{30}Si(p,gamma) with polarized protons. The form of the angular distribution should permit clean and unambiguous determination of the quadrupole absortion strength in ^{31}P, and evidence for giant quadrupole resonances built upon excited states. This work makes use of the same experimental setup (large, high quality NaI detectors) used to study the d-d capture process and the alpha particle d-state. [Dodge, Hayward]

In other work, we are collaborating with the group from Lund University (Sweden) in making photon scattering measurements from ^{16}O. We are attempting to observe both the elastic and inelastic scattering cross section angular distributions. This information together with total absorption data will reveal the multipole absorption strength for oxygen, as well as new nuclear structure information. [Hayward]

Polarizability of the nucleon remains a quantity of fundamental importance relating to basic predictions of QCD, and we are continuing plans for the experimental study of both the electric and magnetic polarizability using the new generation cw electron machines.

Difficulties persist in reconciling total absorption and scattering data, which conclude that the electric polarizability is ten times the magnetic polarizability. The theoretical resolution to this problem might lay in a proper treatment of retardation effects. Experimentally, the magnetic polarizability should be better determined. One possiblility is to use a linearly polarized photon beam and measure the scattering intensity along the polarization direction. New theoretical studies by researchers in the US, USSR, and elsewhere, of the scattering of such polarized photons have been motivated based on a careful evaluation of existing data. [Hayward, Maximon]

Finally, we continue to be very actively involved in planning CEBAF experiments and equipment. The 400 M$ CEBAF project has recently been reaffirmed by the Nuclear Science Advisory Committee, and by the community-wide Long Range Planning Committee, as the highest priority project in nuclear science. We are spokespersons on two major letters-of-intent, which will be submitted as proposals in Fall 1989. The two experiments are multinucleon knockout, (e,e'2p), and pion electro production, (e,e'pi). The bases for the measurements are study of nucleon-nucleon correlations in nuclei, and study of the pion content in nuclei. We are involved in development of a magnetic spectrometer focal plane detector package for the latter, and development of the large acceptance, torroidal spectrometer, trigger system for the former. Our designs and ideas will be part of the Conceptual Design Report submitted to DOE by CEBAF. Our two experiments were chosen by the lab for presentation to the two Technical Advisory Panels for Halls B and A, respectively, as central elements of the core research programs. [Dodge, Lightbody, O'Connell]

(B) <u>THEORY ACTIVITIES</u>:

Theory activities of our group have changed only in detail in FY89. The program now includes: (1) elementary particle physics work relating to searches for glueballs, hybrids, etc., mass spectra of composite systems, mass mixing matrices and the quark mass spectrum, processes involving 'beauty' and 'charmed' mesons (and studies at proposed B-factories), formation of quark-gluon plasmas, and quantum field theory; (2) calculation of three-body bound state and continuum wave functions using a separable potential expansion of the NN interaction, and related studies of the few-body problem; (3) polarized photon scattering, and polarization phenomena in off-axis bremsstrahlung and tagging; (4) modeling electron, proton, neutron, and pion yields from electron and photon induced reactions; (5) study of binding effects in quasielastic electron scattering; and (6) muon catalyzed and cold fusion studies.

The FY89 elementary particle work continues to focus on spectroscopic issues, including search for particles with large gluon content, and a description of the quark and lepton mass spectrum based on BCS theory. Large collaborations for new experiments at CERN and elsewhere continue detector development for glueball (gluon composites) and hybrid (quarks, antiquarks, and gluons) particle searches. New work has been started on computing cross sections for processes involving beauty and charmed meson interactions with protons. This effort is in response to possible construction of new high accelerator construction projects being discussed in the US and Europe, including the SSC and proposed B-meson factories. [Meshkov]

In a related area of high energy nuclear physics, nucleons and mesons are predicted to make a phase transition to a quark-gluon plasma at nuclear matter densities 3-10 times normal nuclear matter density. It is believed that the early universe passed through this phase transition once. We also believe that such conditions are produced in central, heavy ion collisions. The RHIC (Relativistic Heavy Ion Collider) accelerator will permit collisions of heavy ions each with energies of 100 GeV/nucleon. It appears that this project will go forward, based on NSAC review and prioritization of nuclear science activities. The search for signatures of the transition from confined quarks to the quark-gluon plasma is under study by our group and is clearly a very high priority subject. [Danos and collaborators]

The theory program is continuing exploration of the underlying quark substructure of nucleons, and its manifestations on the nucleon-nucleon interaction. It is felt that for the short range of the NN force, it is particularly important to include explicit quark degrees of freedom. In addition, work is continuing on understanding the quark confinement problem in QCD. It is speculated that confinement, in analogy with superconductivity, results from the existence of a physical vacuum which is removed from the remainder of the spectrum by an energy gap, which exhibits a Meissner-Ochsenfeld effect, and which can not be described by perturbative quantum field theory. More particularly, it is believed that these characteristics of the physical vacuum result from the infrared properties of QCD. Utilizing these considerations, an attempt is underway to construct a model of the QCD vacuum with the techniques developed in the context of BCS superconductivity theory. [Danos and collaborators]

A strong collaboration between the theory group at George Washington University and our group continues work on the few body problem. In particular, work is proceeding on development of approximation methods which will permit continuum three-body wave function calculations. This subject is of great importance to the nuclear science community at this time, for the MIT/Bates and CEBAF programs, and for the hadron facilities. Our experimental group is now performing exclusive three-body breakup measurements which require such calculations in a search for nuclear three-body forces. In related work, low energy n-d scattering data can now be understood on firm theoretical grounds for the first time. This activity has a high priority in nuclear science. [Maximon]

New radiation theory work has been carried out in support of photon scattering activities worldwide, but with particular relevance with respect to polarizability of the nucleon. The cross section for scattering of linearly polarized photons from protons has been calculated for energies below pion threshold, but without approximation in photon energy. This work is essential to the interpretation of experiments now being planned at the new cw electron facilities. In addition, development of photon tagging schemes (based on off-axis bremsstrahlung) which will produce polarized photons are under consideration. The theory behind these schemes is an active area in which the group is involved, and in fact playing a lead role. [Maximon]

We have continued to refine our work on reaction product yields for high energy electron and photon induced processes. The codes which we developed are now in common use at all the major US electron facilities, where accidental coincidence rates set fundamental limits on which processes can be studied in a practical sense. [Lightbody, O'Connell]

Last year we reported that a result of earlier experimental studies, including some by our group, was observation of a q-dependence of the separation energy inferred from single-arm electron scattering in the quasi-free region. This q-dependence can be understood on the basis of momentum dependent optical potentials experienced by both nucleons and deltas within the nucleus. This work has continued in a collaboration between our group and the University of Virginia experimetnal group. In particular, the UVA group has new data from SLAC which confirms the usefulness of the momentum dependent optical potential in explaining the observed spectra. [O'Connell and collaborators]

Finally, our group has participated in the cold fusion study brought about by the University of Utah and Brigham Young University groups. We have served as advisors internally, and done independent calculations of the process itself. Also this year, we continued to be involved in muon catalyzed fusion studies, through a grant from DOE. This subject bears on long term energy production mechanisms. [Danos]

This year marks a 40 year presence of the nuclear physics group at NBS, and now NIST. Electromagnetic nuclear physics has deep roots at NBS. What is both remarkable and rewarding is that this field has played an important role in nuclear science for so many years. Today, with continuing vigor, electromagnetic nuclear physics stands as the number one priority in nuclear science. Our group has been important to the field through development and operation of numerous accelerator facilities, through our nuclear and radiation theory effort, and, more recently, through our user mode activities.

INVITED TALKS

Division 530.01, Nuclear Physics Group

Danos, M.,"Nuclear Stopping Power, QCD Showers and Density Fluctuations," Hadronic Matter in Collision Conference, Tucson, AZ, Oct. 5-12, 1989.

Danos, M., "Coulomb Assisted Fusion," NATO Summer School, Peniscola, Spain, May 26-31, 1989.

Danos, M., "Accuracy Weighted Variational Principle for Degenerate Continuum States," Workshop on Muon-catalyzed Fusion, Oxford, UK, September 1989.

Dodge, W., "Philosophy and Methodology of Particle Identification Schemes relevant to the Hall A Spectrometers", Bates MIT Linear Accelerator Laboratory, Middleton, MA, April, 1989.

Dodge, W., "4 GeV Spectrometer Scintillation Planes and Cherenkov Detectors," NSAC Town Meeting at CEBAF, Newport News, VA, June, 1989.

Hayward, E., three lectures on "Nuclear Photon Scattering," University of Lund, Sweden, Nov. 1988.

Hayward, E., Seminar on the "Polarizability of the Nucleon," University of Genoa, Italy, Nov. 1988.

Hayward, E., Seminar on the "Polarizability of the Nucleon," University of Uppsala, Sweden, Nov. 1988.

Hayward, E., Seminar on the "Polarizability of the Nucleon," Max Planck Institute, Mainz, Germany, March 1989.

Hayward, E., Seminar on the "Polarizability of the Nucleon," Erice Summer School, Sicily, July 1989.

Lightbody, J.W. Jr.,"Multinucleon Knockout Studies with the LAS; presentation to Technical Advisory Panel," CEBAF, January, 1989.

Lightbody, J.W. Jr.,"Preliminary Results from ^{3}He(gamma,2p) Experiment," University of Saskatchewan, NSERC Visiting Committee, February 1989.

Lightbody, J.W. Jr.,"Deuteron Breakup Study with Polarized Electrons," MIT/Bates Laboratory Program Review Committee, April 1989.

Lightbody, J.W. Jr.,"Two-nucleon Knockout Studies Using the CEBAF STAR Spectrometer," University of Illinois, Hall-C Workshop, April 1989.

Maximon, L.C., "Theoretical Aspects of Tagged Photon Facilities," 7th Seminar on Electromagnetic Interactions of Nuclei at Low and Medium Energies, Moscow, USSR, Dec. 12-14, 1988.

Meshkov, S., "BCS Mass Matrices," 2nd International Symposium on the Fourth Family of Quarks and Leptons, University of California, Los Angeles, Feb. 23-35, 1989.

Meshkov, S., "Quark and Lepton Masses," Florida International University, Miami, Florida, Colloquium, March 28, 1989.

Meshkov, S., "Quark and Lepton Masses," Coral Gables, Florida, Colloquium, March 30, 1989.

Meshkov, S., "Quark and Lepton Masses," University of California, Riverside, April 13, 1989.

Meshkov, Sydney, "Quark and Lepton Masses," Ecole' Polytechnique, Paris, France Seminar, June 21, 1989.

Meshkov, Sydney, "Total Cross Sections of Beauty and Charmed Mesons on Protons," Workshop on B-Factories, Blois, France, June 27, 1989.

Meshkov, Sydney, "Quark and Lepton Masses," Aspen Center for Physics, Aspen, CO, August 31, 1989.

O'Connell, J.S., "Pion knockout reactions," to Hall A collaboration, University of Virginia, Charlottesville, VA, Oct. 25, 1988.

O'Connell, J.S., "Electrofission in the quasifree and delta regions," Massachusetts Institute of Technology, Middleton, MA, Dec. 6, 1988.

O'Connell, J.S., "Deuteron breakup with polarized electrons," to the MIT-Bates PAC, Middleton, MA, Dec. 8, 1988.

O'Connell, J.S., "Particle identification in the Hall A spectrometers," CEBAF, Newport News, VA, Jan. 30, 1989.

O'Connell, J.S., "Electrofission in the quasifree and delta regions," University of Pittsburgh, Pittsburgh, PA, March 22, 1989.

O'Connell, J.S., "Phenomenolgy of deltas in nuclei," George Washington University, Washington, DC, March 31, 1989.

O'Connell, J.S., "Understanding Hadronic Dynamics with Electromagnetic Probes," MIT Townhall Meeting, Middleton, MA, April 12, 1989.

O'Connell, J.S., "Phenomenological Interpretation of the Delta Resonance," American Physical Society Meeting, Baltimore, MD, May 2, 1989.

O'Connell, J.S., "Nonprotonic Knockout Reactions in Hall A," CEBAF Users Meeting, Newport News, VA, June 7, 1989.

O'Connell, J.S., "Nonprotonic Knockout Reations in Hall A," CEBAF Technical Advisiory Panel, Newport News, VA, June 28, 1989.

PUBLICATIONS

Division 530.01, Nuclear Physics Group

Danos, M., Biedenharn, L.C., and Stahlhofen, A.A., Comprehensive Theory of Nuclear Effects on the Intrinsic Sticking Probability: I in Muon Catalyzed Fusion, AIP Conference Proceedings 181, AIP New York, p. 308 (1989).

Danos, M. Biedenharn, L.C., and Stahlhofen, A.A., Comprehensive Theory of Nuclear Effects on the Intrinsic Sticking Probability: II in Muon Catalyzed Fusion, AIP Conference Proceedings 181, p. 320, AIP New York (1989).

Danos, M. Stahlhofen, A.A., and Biedenharn, L.C., Comprehensive Theory of Muon-Catalyzed Fusion, A. Phys. Soc., NY 192 158 (1989).

Danos, M. Rafelski, J, Nuclear Stopping Power: QCD Showers and Density Fluctuations in Hadronic Matter in Collision 1988, P. Carruthers and J. Rafelski, eds; World Scientific, Singapore (1989) p. 332.

Hayward, E., Weller, H.R., Whitton, R.M., Langenbrunner, J., Dodge, W.R., Kuhn, S., and Tilley, D.R., The Energy Dependence of the Polarization Observables in the $^2H(d,\gamma)^4He$ Reaction, Phys. Lett. 213, 413 (1988).

Hayward, E., On the Polarizability of the Proton, Phys. Lett. 223, 133 (1989).

Hayward, E., Comment on "Feasibility of measurement of the electromagnetic polarizability of the bound nucleon," Phys. Rev. C 40, 467, (1989).

Kaus, P. and Meshkov, S., A BCS Quark Mass Matrix," Mod. Phys. Lett. A3, 1251 (1988)' ibid (errata), 4, 603 (1989).

Kaus, P. and Meshkov, S., A BCS Quark Mass Matrix, Proceedings of the XXIV International Conference on High Energy Physics, Munich, FRG, Springer-Verlag, p. 576.

Kaus, P., and Meshkov, S., "BCS Mass Matrix," in Proceedings of the Fourth Family Conferences, UCLA, February 23-25, 1989. (Publication of the New York Academy of Sciences)

Maximon, L.C., Lehman, D.R., and Friar, J.L., Coulomb Effects in Asymptotic Normalization Constants: A Soluble Model, Phys. Rev. C 37, 336 (1988).

Maximon, L.C., Asai, J, Caplan, H.S., Skopik, D.M., and Del Bianco, W., Cross Section and Linear Polarization of Tagged Photons, Canadian Journal of Physics 66, 1079 (1988).

Maximon, L.C., Scattering of Polarized Photons By Protons, NISTIR 88-3877, October 1988.

Maximon, L.C., Theoretical Aspects of Tagged Photon Facilities, Proc. of 7th Seminar On Electronmagnetic Interactions of Nuclei at Low and Medium Energies, Moscow, USSR, Dec. 12-14, 1988.

Maximon, L.C., Scattering of Polarized Photons By Protons, Phys. Rev. C 39, 347 (1989).

Maximon, L.C., Lehman, D.R., and Gibson, B.F., Long-Range Behavior of the Nucleon-Deuteron Interaction, in Contributed Papers from Few Body XII, 12th International Conference on Few-Body Problems in Physics, edited by B.K. Jennings (TRIUMF, TRI-89-2, 1989), p. D51.

Maximon, L.C., and Heddle, D.P., Differences in Straggling for Positrons and Electrons, Phys. Rev. C 40, (1989).

Meshkov, S., Glueballs, Advances, Problems, Mysteries, in Proceedings of the BNL Workshop on Glueballs, Hybrids and Exotic Hadrons, Upton, New York, August 27-September 1, 1988. (AIP Publication)

O'Connell, J.S. and Schima, F.J., Muon-induced radioactivity in underground detectors, Phys. Rev. D 38, 2277, (1988).

O'Connell, J.S. and B. Schroder, Quasifree electron scattering on nucleons in a momentum-dependent potential," Phys. Rev. C 38, 2447 (1988).

PUBLICATIONS IN PREPARATION

Division 530.01, Nuclear Physics Group

Danos, M., Coulomb Assisted Fusion, Conference Proceedings of NATO Summer School entitled Nuclear Equation of State, May 26-31, 1989, Peniscola, Spain (submitted).

Danos, M., Accuracy-Weighted Variational Principle for Degenerate Continuum States, Journal of Mathematical Physics (submitted).

Danos, M., Coulomb Assisted Cold Fusion in Solids, Nature (submitted).

Danos, M., Intrinsic Sticking in dt Muon-Catalyzed Fusion: Interplay of Atomic, Molecular and Nuclear Phenomena, Annals of Physics (submitted).

Fridman, A., and Meshkov, S., Total Cross Sections of Beauty and Charmed Mesons on Protons, Physics Letter (submitted).

Kaus, P., and Meshkov, S., Quark and Lepton Masses, in Proceedings of the Symposium on the 60th Birthday of Professor M. Gell-Mann, Caltech, January 27-28, 1989.

Kaus, P., and Meshkov, S., Quark and Lepton Masses, Physical Review (submitted).

Dodge, W.R., Lightbody, J.W. Jr., O'Connell, J.S.; Electrofission in the Quasifree and Delta Regions, Physical Review C (submitted).

Dodge, W.R., Lightbody, J.W. Jr., and large MIT/Bates lab collabortaion; Quasielastic (e,e') from ^{3}H and ^{3}He (in preparation).

Lightbody, J.W. Jr., with L.C. Cardman et al.; Elastic Electron Scattering from ^{12}C (in preparation).

O'Connell, J.S., Phenomenological Interpretation of the Delta Resonance in Electron-Nucleus Scattering, Physical Review C (submitted).

TECHNICAL & PROFESSIONAL COMMITTEE PARTICIPATION & LEADERSHIP

Division 530.01, Nuclear Physics

Hayward, E.

Executive Committee for the 50 Years with Fission Conference, NIST, April 26-28, 1989.

Hayward, E.

Program Committee for the 1989 Spring American Physical Society Meeting, Chairman, Baltimore, MD, May 1-4, 1989.

Lightbody, J.W. Jr.

CEBAF User Group Board of Directors

Lightbody, J.W. Jr.

University of Saskatchewan Linear Accelerator Laboratory, Program Advisory Committee

Lightbody, J.W. Jr.

Program Director, Intermediate Energy Nuclear Physics, National Science Foundation

Maximon, L.C.

Vice-Chairman, 1990 Gordon Research Conference on Photonuclear Reactions

Meshkov, S.

Aspen Center for Physics:

Advisory Board
  Chairman, Organizing Committee, 1989 Aspen Winter Conference on Elementary Particle Physics, January 1989
Organizing Committee, 1990 Aspen Winter Conference on Elementary Particle Physics, January 1990
Chairman, Public Lecture Series, 1989, 1990
Chairman, 1990 Aspen Winter Physics Conferences (Elem. Particles, Astro Physics, Condensed Matter)
Building and Grounds Committee

Meshkov, S. (cont'd.)

Interagency Seminar Series (Washington)

O'Connell, J.S.,

Co-Chairman of the MIT Bates Review - Nonmagnetic Detectors, June 21-23, 1989.

TRIPS SPONSORED BY OTHERS

Division 530.01, Nuclear Physics Group

Danos, M., Saclay Laboratory, Paris, France, to collaborate with Drs. Gillet, Gogny, and Iracane, October 18-November 26, 1989, partially paid for by Saclay Laboratory, Paris, France.

Danos, M., Duke University, Durham, NC, to consult with Drs. Biedenharn, Weller, Bilpunch, March 30-31, 1989, by DoE.

Danos, M., NATO Advanced Study Institute, Peniscola, Spain, attended meeting on the Nuclear Equation of State and presented a paper, May 27-June 1, 1989, partially paid for by NATO Advanced Study Institute.

Hayward, E., University of Lund, Sweden, (October, November, and June, to continue photo scattering experiments and data analysis with B. Schroeder, M. Schumacher, and students at the University of Lund by the University of Lund, Sweden.

Hayward, E., University of Uppsala, Sweden, to present seminar on the Polarizability of the Nucleon, Nov. 1988, by University of Uppsala.

Hayward, E., University of Genoa, Italy, to present seminar on the Polarizability of the Nucleon, Nov. 1988, by University of Genoa.

Lightbody, Jr., J.W., University of Saskatchewan, Saskatchewan, Canada, to participate in collaborative research effort and to serve on a Ph.D. Examing Committee, December 11-14, 1988, by the University of Saskatchewan.

Lightbody, Jr., J.W., University of Saskatchewan, Saskatchewan, Canada, to participate in a collaboration research effort and to give a talk to visiting committee on progress of experiment, January 28-February 1, 1989, by the University of Saskatchewan.

Lightbody, Jr., J.W., CEBAF, Newport News, VA, to attend CEBAF User Group Board of Directors Meeting, by CEBAF.

Lightbody, J.W. Jr., Numerous trips to conferences, meetings, national labs, university labs, and other university site visits, for NSF Intermediate Energy Nuclear Physics Program oversight, under auspices of NSF.

Meshkov, S., University of California, Los Angeles, CA, Dec. 1988 - June 1989, Visiting Professor, by UCLA.

Meshkov, S., Florida International University, Miami, Florida, to present a colloquium and discuss current research, March 27-31, 1989 by Florida International University.

O'Connell, J.S., March 24, 1989, University of Pittsburgh, Pittsburgh, PA, to present a talk entitled "Electrofission in the Quasifree and Delta Regions by the University of Pittsburgh.

O'Connell, J.S., June 20-23, 1989, to attend Planning Workshop at MIT-Bates Laboratory, Middleton, MA by Massachusetts Institute of Technology, Middleton, MA.

O'Connell, J.S., June 27-28, 1989, to give a presentation entitled "Nonprotonic Knockout Reactions in Hall A," to the Technical Advisory Committee at CEBAF, Newport News, VA, by CEBAF.

O'Connell, J.S., August 9-10, 1989, to visit CEBAF, Newport News, VA, and to consult with Ingvar Blomqvist, by CEBAF.

SPONSORED SEMINARS AND COLLOQUIA

Division 530.01, Nuclear Physics Group

Michael Danos, NIST, "Fusion Right or Wrong!" April 14, 1989.

Karl Van Bibber, Stanford Linear Accelerator, "The PEGASYS Project at SLAC," April 21, 1989.

Marcella Sanzone, Instituto di Scienze Fisiche, Universita di Genova, "Photon Scattering off the Proton in the Delta Region," July 11, 1989.

Gerald Feldman, Duke University, "Search for the Isovector Giant Quadrupole Resonance in ^{31}P via Polarized Proton Capture," September 14, 1989.

LIST OF ACRONYMS

AAMI	Association for the Advancement of Medical Instrumentation
ac	alternating current
ACR	Absolute Cryogenic Radiometer
AFALT	Air Force Armament Testing and Materials
AFRRI	Armed Forces Radiobiology Research Institute
AIP	American Institute of Physics
ANS	American Nuclear Society
ANSI	American National Standards Institute
ANVIS	Aviator Night Vision Imaging System
ARPES	Angle Resolved Photoelectron Spectroscopy Package
ASSI	Airglow Solar Spectrometer Instrument
ASTM	American Society for Testing and Materials
BB	blackbody
BBU	beam break-up
BCS	Bandeen-Cooper-Schneifer
BNL	Brookhaven National Laboratory
BRDF	Bidirectional Reflectance Distribution Function
BSDF	Bidirectional Scattering Distribution Function
c	speed of light
CAD	Computer-aided Design
CAM	Computer-aided Mechanical
CAMAC	Computer Automated Measurement and Control
CCG	Calibration Coordination Group
CCPR	Consultative Committee on Photometry and Radiometry
CEBAF	Continuous Electron Beam Accelerator Facility
CEN	Center for Nuclear Research (France)
CERN	European Center for Nuclear Research
CIRRPC	Committee on Interagency Radiation Research and Policy Coordination, OSTP
CORM	Council for Optical Radiation Measurements
CRCPD	Conference of Radiation Control Program Directors
CRR	Center for Radiation Research
CT	computed tomography
cw	continuous wave
dc	direct current
DNA	Deoxyribose nucleic acid
DoC	Department of Commerce
DOD	Department of Defense
DOE	Department of Energy
EEC	European Economic Community
ENDF	Evaluated Nuclear Data File
EPA	Environmental Protection Agency
ESR	Electron spin resonance

FAA	Federal Aviation Administration
FAD	FASCAL Absolute Detector
FASCAL	Facility for Automatic Spectroradiometric Calibrations
FEMA	Federal Emergency Management Agency
FEL	Free Electron Laser
FIMS	Fissionable Isotope Mass Standards
fL	femtolumens
FRG	Federal Republic of Germany
FTP	File Transfer Protocol
FY	Fiscal Year
fw	femtowatts
GPIB	General Purpose Instrumentation Bus
GRT	Germanium Resistance Thermometers
Gy	gray
H	Hungary
HDL	Harry Diamond Laboratories
HFIR	High Flux Isotope Reactor
HP	Hewlett Packard
IAEA	International Atomic Energy Agency (Vienna)
ICRU	International Commission on Radiation Units and Measurements
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IR	Infrared
ISCC	Inter-Society Color Council
ITT	International Telephone and Telegraph
kCi	kilocurie
LBIR	Low Background Infrared
LET	Linear Energy Transfer
LLNL	Lawrence Livermore National Laboratory
LMRI	Laboratoire de Metrologie des Rayonnesments Ionisants (France)
LWR-PV	Light Water Reactor Pressure Vessel
LWR-PV-SDIP	Light Water Reactor Pressure Vessel Surveillance Dosimetry Improvement Program
MAT	Measurement Assurance Program
MIDAS	Modular Interactive Data Acquisition System
MIT	Massachusetts Institute of Technology
MODIL	Manufacturing Operations Development & Integration Laboratory
MPU	Micropole undulators
MR2	Measurement Room 2 (FEL User Area)

NASA	National Aeronautical and Space Administration
NATO	North Atlantic Treaty Organization
NBS	National Bureau of Standards
NCRP	National Council on Radiation Protection and Measurements
NDT	nondestructive testing
NIM	Nuclear Instrumentation Module
NIST	National Institute of Standards and Technology
NISTIR	National Institute of Standards & Technology Internal Report
NMR	Nuclear magnetic resonance
NOAA	National Oceanographic Atmospheric Administration
NPL	National Physical Laboratory (U.K.)
NRC	National Research Council
NRL	Naval Research Laboratory
NSAC	Nuclear Science Advisory Committee
NSERC	National Science and Engineering Research Counsel
NSF	National Science Foundation
NVIS	Night Vision Imaging System
OAEP	Office of Atomic Energy for Peach (Thailand)
PEGASYS	PEP Gasjet Spectrometer System
PEP	Position Electron Physics
PTEF	Polytetrafluoroethylene
PUD	Paired uranium detectors
PV	pressure vessel
PWS	Primary Working Standards
QA	Quality assurance
OCD	Quantum Chromodynamics
QED	Quantum Efficient Device
QF	quas-free
rf	radio frequency
RHIC	Relativistic Heavy Ion Collider
rms	root-mean-square
RTM	Racetrack Microtron
SCK-CEN	Studiecentrum voor Kernenergie-Centre d'Etude de l'Energie Nucleaire (Belgium)
SDC	Strategic Defense Command
SEM	Scanning Electron Microscope
SEMPA	Scanning Electron Microscopy with Polarization Analysis
SLAC	Stanford Linear Accelerator Center
SLPM	Standard Liters per Minute
SOLSPEC	Solar Spectrometer
SOLSTICE	Solar Stellar Irradiance Comparison Experiment
SPEAR	Stanford Positron Electron Accelerator Ring

SPIE	The International Society for Optical Engineering
SRM	Standard Reference Material
SSBUV	Shuttle Solar Backscatter Ultraviolet Radiometer
SSC	Super-conducting Super-collider
SSRL	Stanford Synchrotron Radiation Laboratory
SSTR	Solid State Track Recorder
SURF	Synchrotron Ultraviolet Radiation Facility
SUSIM	Solar Ultraviolet Spectral Irradiance Monitor
TCAP	Time-correlated associated Particle
TEM_{00}	Transverse electromagnetic
TEPC	Tissue Equivalent Proportional Counter
TEXT	Texas Experimental Tokamak
TLD	Thermoluminescent Detector
TN	Technical Note
TR	Transformer/Rectifier
TRIUMF	Triangle Universities Meson Facilities
TUO	TEXT Users Organization
UCLA	University of California, Los Angeles
UK	United Kingdom
UMD	University of Maryland
UNH	University of New Hampshire
UPS	Ultraviolet Photoemission Spectroscopy
URPs	Unique radiolytic products
USDA	U.S. Department of Agriculture
UV	Ultraviolet
UVA	University of Virginia
VENUS	Belgian LWR-PV Benchmark Experiment
VV	Variable-voltage

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This report summarizes research projects, measurement method development, calibration and testing, and data evaluation activities that were carried out during Fiscal Year 1989 in the NIST Center for Radiation Research. These activities fall in the areas of radiometric physics, radiation sources and instrumentation, ionizing radiation, and nuclear physics.

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