NBSIR 84-2848

Technical Activities 1983 Center for Radiation Research

U.S. DEPARTMENT OF COMMERCE
National Bureau of Standards
National Measurement Laboratory
Center for Radiation Research
Washington, DC 20234

February 1984

U.S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

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TECHNICAL ACTIVITIES 1983
CENTER FOR RADIATION RESEARCH

Randall S. Caswell, Acting Director

U.S. DEPARTMENT OF COMMERCE
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U.S. DEPARTMENT OF COMMERCE, Malcolm Baldrige, *Secretary*
NATIONAL BUREAU OF STANDARDS, Ernest Ambler, *Director*

ABSTRACT

This report summarizes research projects, measurement method development, testing and data evaluation activities, carried out during Fiscal Year 1983 in the NBS Center for Radiation Research. These activities fall in the areas of radiation measurements, atomic and plasma radiation, nuclear radiation, radiation physics, radiometric physics, and radiation sources and instrumentation.

Key Words: Atomic radiation; nuclear radiation; plasma radiation; radiation instrumentation; radiation measurements; radiation physics; radiation sources; radiometric physics.

INTRODUCTION

This report is a summary of the technical activities of the NBS Center for Radiation Research (CRR) for the period October 1, 1982 to September 30, 1983. The Center is one of five 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 (visible) optical radiation, ultraviolet radiation, and ionizing radiation (x-ray, 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 nuclear radiation processes, and elucidate the interaction of radiation and particles (electrons, neutrons, and ions) with matter; collects, compiles, critically evaluates, and supplements the existing atomic, molecular, and nuclear data base in order to meet the major demands of the Nation for such data; participates in collaborative efforts with other NBS centers in the interdisciplinary applications of radiation.

The summary of activities is organized in six parts, one for the Office of Radiation Measurement, and one for each of the five Divisions in the Center: Atomic and Plasma Radiation, Nuclear Radiation, Radiation Physics, Radiometric Physics, and Radiation Sources and Instrumentation. Each Division 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 Bureau of Standards, Washington, D.C. 20234.

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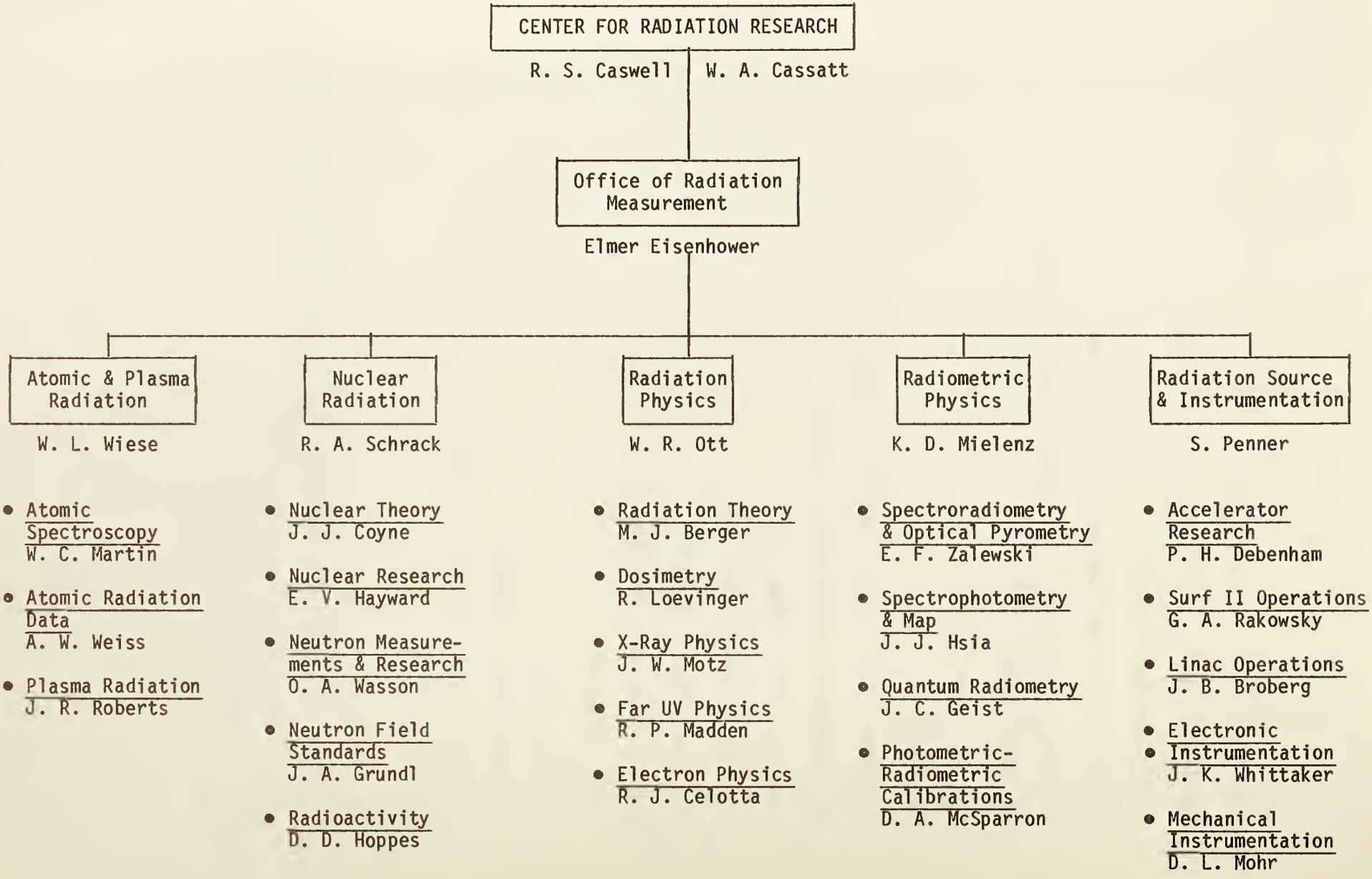
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TECHNICAL ACTIVITIES

530, Office of Radiation Measurement

Task No. 15201 - Radiation Standards Dissemination

The function of the Office of Radiation Measurement 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 that may be hazardous. The Office assists the technical organizational components of CRR in monitoring the radiation measurement needs of these national user groups, and in activities undertaken to meet national needs. The latter include methods for improving the consistency of field measurements with the national physical measurement standards. The Office maintains liaison with organizations that conduct measurement-intensive programs in the areas of radiation safety, energy, health, and environmental contamination. Examples are the Nuclear Regulatory Commission, Department of Energy, Food and Drug Administration, Environmental Protection Agency, Occupational Safety and Health Administration, and the Conference of Radiation Control Program Directors. The Office participates in collaborative programs with most of these organizations to satisfy specific measurement traceability and quality assurance requirements. Another function of the Office is to provide the secretariat and chairman for American National Standards Committee N43, concerned with equipment for non-medical applications of ionizing radiation.

Radon

The need for transfer standards for several different types of radon measurements, as well as other support services, continues to be expressed by state radiation control laboratories and other user groups. Based on the technical analysis and the study of user needs and NBS capabilities performed last year, more efforts have been directed toward developing the necessary transfer standards, and toward establishing informal measurement intercomparison and intercalibration networks. Some significant progress in these directions was made in the past year.

The Office continued to collaborate with and provide direct laboratory assistance to staff members of Division 532. A prototype regenerative radon-in-water standard has been developed and successfully demonstrated. The prototype consists of a radium-226 source which is deposited on an ion exchange filter, encapsulated into thin polyethylene, and immersed in water in an accumulation chamber. The water and radon-222 (which accumulates for known time periods) are transferred with mixing into a large syringe from which aliquots of a standard solution can be dispensed. This standard requires some further work on making it more rugged and convenient to use. Plans have already been made to distribute

a final version of the standard to four laboratories for independent testing and evaluation. Along similar lines, work has also begun on developing flow-through radon-in-air standards which are based on solid radium-226 sources. Several types of solid radium sources to be considered for a prototype standard have been prepared. To evaluate these sources, a new test facility for gas handling and radon monitoring using a flow-through scintillation cell has been constructed and tested. This test facility was incorporated into the existing radon chamber sampling and recirculation plumbing system. It is presently being used to evaluate a commercially-available radon source standard.

The Office continues to coordinate the interactions and measurement intercomparison activities between NBS and other radon measurement laboratories, such as the DOE Environmental Measurements Laboratory, two EPA laboratories at Montgomery and Las Vegas, the U.S. Bureau of Mines Denver Research Center, and national laboratories including Lawrence Berkeley Laboratory, Argonne National Laboratory, Oak Ridge National Laboratory, and Mound Laboratory. In particular, in the past year close interactions have been established with the DOE Technical Measurements Center (operated by Bendix in Grand Junction, Colorado) which is developing measurement protocols for DOE's remedial action programs. An informal measurement intercomparison network among many of these laboratories continues to receive NBS support and participation. In addition, the Office has recently participated in planning and developing an International Radon Intercalibration and Intercomparison Program which is now being organized by the Nuclear Energy Agency of the Organization for Economic Cooperation and Development (OECD).

Measurement Theory

Over the past several years, various aspects of measurement theory have been addressed by the Office. These studies consider the fundamental concepts of measurement, as well as the practical applications of these concepts. In particular, the Office's developed expertise in the treatment and reporting of measurement uncertainties has been useful to groups both within and external to NBS. In the past year, many individuals and groups have been assisted by the Office. More recently, the planned series of papers on detection limits and statistical hypothesis testing for the presence of activity is nearing completion; and work on developing more general measurement performance testing criteria continues. These latter studies are particularly important for use in performance testing programs such as that for personnel dosimetry.

Expression of Uncertainties in Measurement Results

As a result of requests and interest by other NBS groups, the Office, in collaboration with the Center for Applied Mathematics, edited and prepared an NBS Special Publication of reprints on the expression of the

uncertainties of final measurement results. An updated companion publication which presents the recently ratified CIPM (International Committee on Weights and Measures) recommendations for reporting uncertainties is also being prepared. This publication will discuss the recommendations in terms of the underlying philosophy or general approach, as well as provide discussion of some pro and con arguments for adoption of the recommendations by standardizing laboratories.

Regional State Laboratories

During its most recent meeting, the Executive Board of the Conference of Radiation Control Program Directors (CRCPD) adopted the principles and processes under which it will accredit state-operated laboratories that calibrate instruments used for measurement of ionizing radiation. Accreditation will be granted upon successful completion of the following process: submission of a request by the laboratory; evaluation of the laboratory's resources and procedures, including an on-site assessment; proficiency testing of the laboratory's performance by NBS; resolution of deficiencies; and technical evaluation and administrative review. The evaluation will be based on the "General Criteria for the Operation of State Regional Calibration Laboratories", which were developed in cooperation with the Office.

Over the past year, the regional laboratory in Springfield, Illinois, has gained experience by calibrating instruments used in the Illinois radiation control program. Based on this experience, a set of procedures has been developed for calibrations using x-ray beams. These documented procedures are required to satisfy the CRCPD accreditation criteria. A 3-curie cesium-137 source was installed recently, and the Office provided training on its use. The Illinois Department of Nuclear Safety has formally requested accreditation of the laboratory by the CRCPD. It is expected that the evaluation team, which will include a representative from the Office, will visit the laboratory in January 1984.

The calibration laboratory located at the University of Washington in Seattle has been gaining experience in use of its 3-curie cesium-137 source by calibrating University-owned instruments and those owned by the state radiation control program. Personnel from the Oregon radiation control program have used this source to calibrate their instruments under supervision of the laboratory staff. This is the first use of a state laboratory on a regional basis. Based on this operating experience, draft procedures for gamma-ray calibrations have been written. The capability of this laboratory will be extended to x rays next year when the x-ray machine recently ordered is installed. Accreditation by the CRCPD for gamma-ray calibrations is expected in mid-1984.

After delays due to building modifications and installation of radiation shielding, the x-ray machine is now operational in the South Carolina laboratory. An on-site training session on use of the machine and recommended calibration procedures has been completed. The measurements necessary to characterize this facility are presently being made. A 3-curie cesium-137 source will be obtained next year for this laboratory.

In fiscal year 1984, a regional laboratory will be developed in Sacramento, California, with funding support from FEMA. An existing state Office of Emergency Services laboratory, which now has gamma-ray calibration capability, will be expanded to include x-ray capability. Standards, technical guidance, and training will be supplied by our Office of Radiation Measurement.

Before a state-operated laboratory can be accredited by the CRCPD, it must satisfactorily participate in a performance test conducted by NBS. A commercial instrument has been purchased and is being evaluated for use as a transport standard in this test. The electrical evaluation is complete and the radiation evaluation is nearly complete, and the instrument should soon be available to conduct the first formal test of the Illinois laboratory.

Measurement Quality Assurance for the NRC

Under an interagency agreement with the Nuclear Regulatory Commission the Center for Radiation Research has evaluated six types of survey instruments used by NRC inspectors. The Office was involved in calibrating these instruments in three beta fields being established at NBS. The correction factors for the instruments were based on the certified output of the sources and corrections developed by NBS. The instruments were also calibrated in the 6- to 7-MeV photon beam developed with the positive-ion Van de Graaff. Calibration factors were determined for various depths in a plastic phantom from the corresponding readings for calibrated TLDs.

Another task specified in the interagency agreement is development of a measurement quality assurance (MQA) service for laboratories that calibrate survey instruments for NRC inspectors. The Office has assisted the Dosimetry Group in development of this service. The first round of MQA services is limited to photon radiation and is being made available to five calibration laboratories that serve NRC inspectors.

Committee Activities

For the 37th year, NBS served during 1983 as the secretariat of American National Standards Committee N43, Equipment for Non-Medical Radiation Applications. The secretariat and chairmanship functions are

performed by the Office. The Committee's purview includes 12 subcommittees, 15 standards projects, and 10 completed standards. Nine of the completed standards have been published as NBS Handbooks, and one is in the publication process. Six of the nine published standards are currently under review, as required by the procedures for maintenance of American National Standards. During the past year, significant progress was made on three new standards under development.

Since December 1982 a member of the Office staff has been serving as the Department of Commerce representative to the Interagency Working Group on Occupational Exposure Guidance. This group, consisting of representatives of 10 government agencies or departments, is assisting the Environmental Protection Agency in preparation of guidance which will replace that issued by the Federal Radiation Council in 1960. After concerted effort, new draft guidance is nearly ready for publication in the Federal Register.

Personnel Dosimetry

The laboratory accreditation program for processors of personnel radiation dosimeters was announced in the Federal Register on July 28, 1983. This program will operate under the procedures of the National Voluntary Laboratory Accreditation Program (NVLAP), using the University of Michigan as a contractor proficiency testing laboratory (PTL). Initial testing of the PTL will occur before the end of 1983, and accreditation of processors will begin in early 1984. The NRC is considering the issuance of regulations that would require its licensees to use only accredited processors. Technical support for this program has been supplied by several elements of CRR, including the Office and the Dosimetry Group. The Office continues to provide the chairmanship of an interagency committee that provides guidance and coordination for this and similar planned programs.

Other Activities

A cooperative agreement with the National Council on Radiation Protection and Measurements resulted in a handbook on measurement of neutrons generated by medical accelerators. The final report is undergoing review prior to publication by the NCRP.

Under another cooperative agreement, the CRCPD Committee on Radiation Measurements completed its revision of the 1979 publication entitled "Ionizing Radiation Measurement Criteria for Regulatory Purposes". The revised report includes more specific references to regulations that necessitate measurements, definitions of terms that are relevant to the measurement of ionizing radiation, principles of measurement quality assurance, and generic characteristics of various types of instruments.

A draft update of the 1980 NBS Special Publication entitled "Requirements for an Effective National Ionizing Radiation Measurements Program" has been prepared. The draft was circulated for review both inside and outside NBS, and many favorable comments were received. After minor revisions, the final update report will be published as an NBS Special Publication.

INVITED TALKS

Division 530, Office of Radiation Measurement

Collé, R., "Development of Transfer Calibration Standards for Radon Measurements," Indoor Radon Workshop, Environmental Measurements Laboratory, New York, New York, November 30, 1982.

Eisenhower, E. H., "Quality Assurance for Measurements of Ionizing Radiation," 1982 Workshop and Symposium of the National Conference of Standards Laboratories, Gaithersburg, Maryland, October 5, 1982.

Eisenhower, E. H., "Development of a Radiation Measurement Support System," Regional Radiation Control Training Conference, Park City, Utah, September 20, 1983.

PUBLICATIONS

Division 530, Office of Radiation Measurement

Collé, R., A Survey of Radon Measurement Needs and Activities in State Radiation Control Programs in the United States, Environmental International (in press).

Eisenhower, E. H., Traceability - A View from the NBS Center for Radiation Research, NBS Special Publication 609, 3-10 (1982).

Eisenhower, E. H., Ehrlich, M., Soares, C., Schima, F. J., and Seltzer, S., Qualtiy Assurance for Measurements of Ionizing Radiation (Annual Report for FY 1982), Nuclear Regulatory Comission Report NUREG/CR-3120 (in press).

Eisenhower, E. H., A National Quality Assurance Program for Personnel Dosimetry (14th Annual National Conference on Radiation Control) April 1983.

Heaton, H. T., Proceedings of a Meeting on Traceability for Ionizing Radiation Mesurements, NBS Special Publication 609 (1982).

Heaton, H. T., NBS Services for Ionizing Radiation Mesurements, NBS Special Publication 609, 45-58 (1982).

Heaton, H. T., A Review of Commerical Calibration Services for Survey Instruments, 12th Annual National Conference on Radiation Control (in press).

Kuyatt, C. E., Technical Activities 1981 - Center for Radiation Research, NBSIR 82-2468 (1982).

Kuyatt, C. E., Technical Activities 1982 - Center for Radiation Research, NBSIR 83-2654 (1983).

Lalos, G. T., and Heaton, H. T., Chapter 2, Calibration - An Overview, Calibration Handbook: Ionizing Radiation Measurement Instruments (in press).

TECHNICAL AND PROFESSIONAL COMMITTEE PARTICIPATION AND LEADERSHIP

Division 530, Office of Radiation Measurement

Ronald Collé

Delegate, Bureau International des Poids et Mesures (BIPM) Working Group on the Statement of Uncertainties.

Resource Person, Conference of Radiation Control Program Directors, Subcommittee on Radon Measurements.

Resource Person, Conference of Radiation Control Program Directors, Task Force on Criteria for an Adequate Radiation Control Program - Environmental Monitoring and Surveillance.

Member, Ad Hoc Committee on Interlaboratory Calibration of Radon and Radon Daughter Instruments.

Elmer H. Eisenhower

Alternate Representative, ANSI N44, Equipment and Materials for Medical Radiation Applications.

Chairman, ANSI N43, Equipment for Non-Medical Radiation Applications.

Chairman, Interagency Committee on Occupational Radiation Protection Measurements.

Resource Person, Conference of Radiation Control Program Directors, Committee on Radiation Measurements.

Department of Commerce Representative, Interagency Working Group on Occupational Exposure Guidance.

H. Thompson Heaton, II

Secretary, ANSI N43, Equipment for Non-Medical Radiation Applications.

Member, ANSI N43-3.4, Subcommittee for Gamma Irradiators.

Member, ANSI N43-8, Subcommittee for Electron Microscopes.

MAJOR CONSULTING AND ADVISORY SERVICES

Division 530, Office of Radiation Measurements

R. Collé advised personnel in the state radiation control programs of Wisconsin, Oregon, and Colorado on calibration procedures for radon measurements and radium assays.

R. Collé assisted Bechtel Corporation by providing background information and literature references on air quality in underground defense (Air Force) facilities.

R. Collé advised a Canadian environmental activist group on the interpretation of environmental radioactivity reporting requirements.

R. Collé advised and assisted staff members in various NBS divisions on the treatment and reporting of measurement uncertainties, and on the interpretation of measurement performance criteria.

R. Collé assisted the U.S. Department of Energy Technical Measurements Center (operated by Bendix Field Engineering Corp.) in the evaluation of several protocols for radon measurements.

R. Collé assisted in the planning and organization of an International Radon Intercalibration and Intercomparison Program being organized by the Nuclear Energy Agency of the Organization for Economic Cooperation and Development (OECD).

H. T. Heaton, II, advised the Department of Defense on several chapters in a calibration manual for ionizing radiation instruments for use in DOD calibration laboratories.

H. T. Heaton, II, assisted ISO Committee TC85 on development of a standard for x and γ reference radiations for radiation protection over an energy range of 8 keV to 1.3 MeV.

H. T. Heaton, II, assisted American National Standards Committee N42 on a draft standard for performance specifications of health physics instruments.

H. T. Heaton, II, assisted the NCRP by reviewing a report by Scientific Committee 60 on neutron leakage measurements for medical accelerators.

H. T. Heaton, II, advised the University of Arkansas on a calibration laboratory they are considering establishing.

TECHNICAL ACTIVITIES

Division 531, Atomic and Plasma Radiation

Task No. 15211 - Atomic Radiation Data and Standards
Task No. 15212 - Atomic Processes in Plasmas

The Atomic and Plasma Radiation Division carries out a broad range of experimental and theoretical research on atomic structure and atomic radiation in plasmas. The division determines a large variety of atomic radiation and collision data, encompassing wavelengths of spectral lines; atomic energy levels; ionization potentials; atomic transition probabilities; plasma line broadening parameters; ionization and excitation cross sections and rate coefficients, and dielectronic rate coefficients. Two data centers located in the division critically evaluate and compile atomic energy levels and transition probabilities. The division is also engaged in research on the interaction of atomic radiation with plasma environments, and it explores such effects for the development of new measurement techniques. Furthermore, well-defined atomic radiation sources are developed as radiometric standards or wavelength standards.

These activities support several areas of science and technology. A good deal of our work ties into magnetic fusion research, where atomic data are needed for studies of the effects of heavy ion impurities and where atomic radiation processes are utilizied as non-interfering plasma probes. Other areas of direct applications are space physics and vacuum ultraviolet and x-ray laser development, where atomic radiation data are one of the basic inputs. Our vacuum ultraviolet radiometry work is now, for the first time, providing small calibrated radiation source packages to allow radiometric calibrations on board spacecraft, which are used, for example, for accurate monitoring of the solar ultraviolet radiation.

The division consists of three technical groups: Atomic Spectroscopy, Atomic Radiation Data, and the Plasma Radiation Groups. The division has currently 21 professional physicists, among them 18 Ph.D.s, plus 1 postdoc. Also, during 1983 the division has had guest workers from Germany (2), Yugoslavia, France, Israel, and Spain (2).

During the past year several of our projects produced important accomplishments, as will be seen from the following discussion, where the principal work of the three technical groups during the last year is decribed.

I. Atomic Spectroscopy Group

(a) Vacuum-UV Spectra of Atomic Ions--The wavelengths, line identifications, and energy-level data obtained in this research have applications in high-temperature plasma diagnostics (controlled thermonuclear energy research), modeling of VUV laser schemes, space astronomy, etc. The work is also of basic atomic-physics interest, an accurate treatment of relativistic effects being necessary for meaningful calculations for these highly ionized species. The spectra obtained at NBS are excited in laser-produced plasmas, vacuum sparks, or sliding sparks, and observed with one of the NBS 10.7-m vacuum spectrographs. We have also recently observed spectra from the Texas Tokamak (TEXT). We have extended our work on the Cu isoelectronic sequence by completing the analyses (line identifications and energy levels) for eight copper-like ions, through Sn^{21+}. We obtained similar results for the $4d^9$-$4d^85p$ transitions in the Rh-like ions Xe^{8+}, Ba^{10+}, and La^{11+} and plan to extend this sequence through Nd^{14+}. We also recently made the first line identifications and derived energy levels for Cs^{3+}, Ba^{4+}, and La^{5+}.

Magnetic-dipole transitions between low-lying levels of highly ionized species are important features of tokamak spectra. We are obtaining the energy levels for predicting such lines by identifying transitions within the n=3 shell (M shell) in Aℓ-like through Cℓ-like ions of copper through arsenic. We have also theoretically predicted the wavelengths and transition rates of $3s^23p^n$ ground-configuration magnetic-dipole transitions for the ions of Cu through Mo. The predictions have been used to identify such lines in tokamaks. We continued our own search for magnetic-dipole lines at TEXT and identified six new lines of Kr ions (Kr^{19+} to Kr^{22+}). In collaborative work with the Institute for Spectroscopy, Moscow, we obtained the Kr^{9+} spectrum from which the $3d^9\ ^2D$ ground term splitting (needed for plasma diagnostics) will be determined.

We plan to extend our observations at TEXT to other elements of interest. We will also continue our identifications and energy-level analyses for ions of the Na, Aℓ-Cℓ, and Zn isoelectronic sequences.

(b) Laser Spectroscopy--We completed measurements of the ^{4}He 1s2p-1s3d lines (allowed and forbidden) using Doppler-free intermodulated fluorescence spectroscopy. The resulting wavenumbers, accurate to 5-7 parts in 10^9, allowed reevaluation of several term separations of interest for comparison with accurate theoretical calculations. The comparisons yielded predicted values of the Lamb shifts for these low terms more accurate than previous calculated values and also predicted Lamb shifts for three other terms having no calculated values. The ^{4}He-^{3}He mass-polarization isotopic shift of the 1s3d ^1D-^3D separation was

evaluated, and the pertinence of this effect for observed shifts previously regarded as anomalous was pointed out. If a thermionic-detection source of He metastable atoms with sufficiently low pressure and field strengths can be developed, we plan to extend this work to accurate determinations of high lsnd series members. This will give more accurate absolute energies for many low lsnℓ terms, which can be critically compared with theory and, in some cases, used to obtain more accurate Lamb-shift predictions.

We are now observing np, nf, and ng Rydberg states of Cs using resonantly-enhanced two-photon absorption. Measurements of selected fine-structure intervals have been completed, and we plan absolute wavenumber measurements of these series. The results should clarify discrepant values of the Cs ionization energy as recently reported and allow tests of the core-polarization theory of quantum defects.

Our longer-term goal is to apply state-selective and optical double-resonance techniques to selected complex atomic spectra. Toward this end, we will try to develop highly sensitive methods for detecting resonance absorptions using frequency modulation. Extension of such techniques to the detection of weak transitions in discharge sources would be an important step in laser spectroscopy of complex spectra.

(c) Atomic Inner-shell Photoabsorption--Our interpretation of the photoabsorption spectrum of neutral Cs (650-700 Å) as arising from transitions of the types $5p^6 6s\text{-}5p^5 6sns$ and $5p^6 6s\text{-}5p^5 6snd$ is in press. Using the high-resolution data from the NBS 10.7-m grazing-incidence spectrograph, we are making a theoretical study of the autoionizing broadening of these lines in collaboration with Prof. Klapisch of the Hebrew University. Our experiment to observe the Cs^+ spectrum above the principal ionization threshold is in preparation. We are trying laser-driven ionization techniques to observe this spectrum, which is of considerable interest because of the striking differences already observed between the corresponding isoelectronic Xe and Ba^{2+} spectra.

(d) Atomic Energy Levels Data Center--During the past seven years we completed new critical compilations of the energy levels for all 235 spectra of the iron-group elements K through Ni (Z = 19-28). The data were published separately by element. We are now updating and extending these compilations for a single-volume collection of the data for the entire iron group. New results for many of the spectra have been incorporated and extensive use of isoelectronic and other regularities are being made to increase the reliability of the data. We hope to complete this work during the next year.

Our compilation of energy levels for the fourteen Si spectra was published, including extensive experimental and theoretical results (some unpublished) assembled for the first time. The Si data are part of a project covering the Na-Ar group (Z = 11-18) and complete the series for Na-Si (Z = 11-14). We are now working on a similar compilation for the phosphorus spectra.

We monitor the literature on atomic energy levels, wavelengths, wavefunctions, etc., and the resulting reference files and published bibliographies are used by a wide clientele. During the coming year we will submit for publication the third supplement to our Bibliography on Atomic Energy Levels and Spectra, covering the literature from July 1979 through December 1983.

II. Atomic Radiation Data Group

The work of this theoretical group is divided into two major efforts, (1) theoretical studies of atomic structure and basic atomic processes and (2) a data evaluation and compilation program. The former is directed toward the development of new theoretical methods, the implementation of these methods to calculate data, and the interpretation of current experimental results. This work has concentrated on dielectronic recombination, the correlation problem in atomic structure, and the calculation of radiative transition rates. The critical evaluation and compilation of transition probability data is the main purpose of the Data Center on Atomic Transition Probabilities. In addition, the Data Center maintains an up-to-date bibliography of all ongoing work on transition probabilities.

(a) Theoretical Studies--This past year has seen the completion of a comprehensive and completely general computer program to compute total dielectronic recombination rates for highly stripped ions. Dielectronic recombination is a radiative recombination process that proceeds via a core-excited, or doubly excited state of the recombined ion. The total recombination rate is obtained by summing over the rates for all possible dielectronic states, and this program explicitly calculates all these component rates, using the distorted wave approximation along with a frozen core, independent particle model of the dielectronic state. Total recombination rates as a function of plasma temperature have been computed for highly stripped ions in the lithium and beryllium isoelectronic sequences as well as selected ions of scandium. The scandium data was computed at the request of the impurity modelling group of the Princeton Plasma Physics Laboratory. Total recombination rates have also been computed for the krypton ions Kr^{+24} through Kr^{+28}, under contract with the Theoretical Physics Division of Lawrence Livermore Laboratory. In order to facilitate their use in plasma modelling, these data have also been fit to a parametric formula.

A first version of the upgraded superposition of configuration program has been put into operation to calculate correlation corrections in atomic structures. The first problem addressed was the 4s-4p transition array in neutral argon. The calculations included LS-term dependent relaxations as well as 4-shell/3-shell intershell correlation, the final shifted LS-coupling energies and matrix elements being fed into a conventional intermediate coupling calculation. The calculations led to corrections in the component transition moments as large as 25%. The inclusion of 3s-4p correlation as well as 3p-4p however produced somewhat larger changes than expected in the energy levels, and this problem is still being investigated--the relative level shifts are of the order of 100-200 cm^{-1}. Calculations of correlation energies have also been made on highly stripped first row ions--carbon-like iron, Fe^{+20}, and boron-like ions. The idea here is to utilize non-relativistic correlation information to correct relativistic predictions of $\Delta n = 0$ excitation energies. Comparison with experiments for Fe^{+20}, where the calculations did not include intershell correlation, indicate the scheme is accurate to within 0.2%.

As with the dielectronic recombination programs, the atomic structure correlation programs represent only a first version of a theoretical tool. There are a number of avenues available for additional and significant improvements, and these are currently being actively investigated.

Our collaboration with the far UV group has continued, exploring the intricacies of 4f-shell collapse in various ions of barium. In this region of the periodic table, the 4f shell 'teeters' on the verge of collapse due to the nearly complete balance between electrostatic attraction and centrifugal repulsion and is therefore very sensitive to the detailed treatment of atomic structure.

The first problem addressed was that of the subshell excited states $4d^9nf$ of Ba^{+2}, where the orbitals, in the Hartree-Fock approximation, are known to be radically term dependent. Calculations were performed on these states in the multi-configuration Hartree-Fock (MCHF) approximation, including the expected dominant correlation configuration $5p^55d^2$. This was followed by an intermediate coupling calculation which made full allowance for orbital relaxation and configuration interaction. The ground state correlation $4d^8nf^2$ was also included in the f-value calculations. The results reproduced remarkably well the discrete structure oscillator strength distribution as well as relative level positions observed in UV photoabsorption experiments. A second f-shell collapse problem addressed by these methods was that of the nf series in the 'normal' spectrum of Ba^+ (4d-shell not excited). Here the doublet splittings are large and anomolous in that the 5f splitting is larger than

4f. The qualitative behavior of these spin-orbit splittings was reproduced in the frozen core H-F approximation, the relaxed core H-F and the MCHF, including $5p^5 5d^2$ correlations, with agreement with experiment improving with increasing level of sophistication. The f-orbitals themselves were signficantly different for the different approximations. Relativistic effects, via the Dirac-Fock method, led to still more drastic changes in the nf wave functions, and we are continuing our study of the relativstic problem.

We have also applied the MCHF method of treating correlation to calculate the mass polarization contribution to the isotope shift of several transitions in neutral carbon. The somewhat limited correlation corrections included in these calculations led to significant improvement in the shift for those transitions where it is known experimentally.

(b) Data Center--The revision of atomic-transition-probability tables for allowed lines of the elements scandium through nickel, which were published in past issues of J. Phys. Chem. Ref. Data is nearing completion. Several new publications containing large amounts of data appeared in the literature in 1982 and 1983 and were included in our tabulations. While the new papers filled some critical data gaps and thus improved the tables significantly, these additional data also slowed down the pace of our compilation work. Work is in progress on evaluating and compiling tables of transition probabilities for forbidden lines of the iron-group elements. Data terminals for communication with the HP-1000 Computer were installed in the Data Center. It is planned to have the design work for an atomic spectroscopic database initiated in FY 1984 by an employee of OSRD who has been hired and who will be in close consultation with our staff.

After work on the iron-group elements is completed, the next major project to be undertaken is the critical evaluation and compilation of transition probabilities for the elements hydrogen through neon in all stages of ionization. This compilation will replace Volume I of our series "Atomic Transition Probabilities," which is now seriously out of date.

Two separate critical reviews and tabulations of Stark widths and shifts of non-hydrogenic spectral lines were completed, one for neutral atoms and the other for ionized species. This work was undertaken in collaboration with Drs. N. Konjevic and M. S. Dimitrijevic of the Institute of Physics, Belgrade, and it is now being prepared for automatic typesetting.

The bimonthly newsletter "Atomic Data for Fusion," which we prepared in collaboration with Oak Ridge National Laboratory, has been discontinued. However, we continue to submit bibliographic references for inclusion in the "International Bulletin on Atomic and Molecular Data for Fusion", published by the International Atomic Energy Agency. A comprehensive compilation of wavelengths, energy levels and transition probabilities for iron in all stages of ionization has also been prepared, based on existing compilations, for the Department of Energy.

III. Plasma Radiation Group

(a) Collisional Rate Coefficients with the 50kJ Theta Pinch--A paper entitled "Measurement of Ionization Rates of Ti IX, Ne VI, Ne VII and O VI was accepted for publication in Physical Review A. In this paper the measured ionization rates were reported to be a factor of two higher than ground state ionization rates and this difference was attributed to the possible contribution of stepwise excitation-ionization. Further experimentation on O VI excited levels revealed that the levels above the collision limit have very small populations. This supported the earlier conclusion that the levels above collision limit are depopulated by the excitation-ionization process and thus brought the measured and theoretical rates into agreement. These results and a proposed laser resonance fluorescence experiment to understand this process more thoroughly were presented at the APS Topical meeting on "Atomic Processes in High Temperature Plasmas" held at Princeton, N.J. on April 13-15, 1983.

Presently, we are measuring the excitation rates of Ti X to compare with the theoretical values predicted by $\bar{g}$-approximation. This is accomplished by injecting titanium into a theta pinch plasma utilizing a coaxial discharge gun and measuring the absolute emissivities of the spectral lines of Ti X. The plasma electron temperature and density are measured by the Thomson scattering technique and the collisional excitation rates are deduced by using the corona model.

(b) Tokamak Spectroscopy--The first experimental results on magnetic dipole transitions of highly ionized Kr, Ge, Ga and As have been published in the Physical Review. Wavelengths, predicted by a semiempirical method, have not only been observed with instruments on the TEXT tokamak, but also on the PLT tokamak at Princeton. These new results will allow radial distribution of Doppler ion temperature measurements to be extended into the 1 to 5 keV range.

A new detector system to observe spectra in the XUV and VUV spectral regions has also been tested on instruments on the TEXT tokamak operated by our NBS group. The 66 ms snapshot exposures of spectral features with 0.3 Å resolution have been obtained with the new channel electron multiplier array (CEMA) detector. These observations will allow complete temporal and spectrally resolved line profiles for Doppler ion temperature measurements.

(c) Theory of Plasma Potentials and Spectral Shifts--We have developed a model to estimate the "mean field" plasma potential in the vicinity of a plasma ion. The model explicitly takes into account the influence of the bound electrons and physical constraints on the plasma electrons. The results are expressed in terms of a Debye potential plus corrections which become increasingly important close to the ion. These potentials can be used to compute thermodynamic properties such as partition functions and degree of plasma ionization. They can also be used to estimate quasistatic shifts in energy of bound ion levels. However, we have recently shown that such quasistatic shifts are not realistic estimates of actual shifts in the transition energies of spectral lines due to collisions with plasma electrons and ions. Efforts are currently in progress to develop a valid dynamical theory for plasma shifts of spectral ion lines.

(d) Resonant Multi-photon Ionization of Hydrogen--We have observed for the first time resonance enchanced 4-photon ionization of hydrogen and studied in detail the laser power density dependence of the width, shift and shape of the resonance photo-ionization profile. Careful characterization of the spatial and temporal structure of the laser beam was necessary to compare our results with a recent theory for this highly nonlinear process. Because the tunable dye laser we used for this experiment has several longitudinal modes, it was also necessary to construct a normalized model for the influence of mode beating on the temporal behavior of the laser pulse. In the next year we plan to carry out the study of this process one step further by constructing a tunable dye laser with a single longitudial mode. This will afford a more model-free comparison of experiment with the basic theory.

(e) Stark Effect on Autoionization Resonances--Results on Sr (high field) and Gd (low field) have been submitted for publication. The gadolinium results are thoroughly understood in terms of field mixing with Rydberg autoionizing levels. The measured broadening of strontium by the electric field is five times larger than predicted by our simple model. Several possible reasons why the model may be unsatisfactory have been considered, but the answer remains unclear. Further theoretical work is in progress, in collaboration with D. Harmin, U. Fano, and P. Lambropulos. Also, in collaboration with J. Cooper and E. Saloman, we are starting up an experiment in Ba to investigate Stark structure predicted by a new theory of D. Harmin.

(f) Rayleigh Scattering--We have constructed a barium plasma source, which consists of a heat-pipe oven driven by laser resonant ionization with the laser tuned to the barium resonance line. The ionization process is believed to be very efficient, provided enough barium vapor population and laser intensity are present. Spatial and temporal measurement of the ionization is achieved through a near-resonance Rayleigh scattering measurement with a probe laser tuned to the Ba^+ resonance line.

Early results show inefficient barium ion production for an observable resonance scattering measurement. This may be due to the heat-pipe oven design. Geometrically, this heat-pipe has a non-uniform temperature distribution because of the scattering observation ports. Therefore, we are redesigning the heating configuration of the oven to avoid any cooling effect near the scattering center. The presence of a buffer gas causes significant collisional cooling which inhibits the ionization process. We have found that argon buffer gas causes condensation of the barium vapor and therefore enhances the non-resonant scattering. We are studying the functional dependence of this enhanced scattering on the incident light polarization and the barium density.

(g) Vacuum Ultraviolet Radiometry with Plasmas--A new model of a portable low-powered (15W) rf-excited dimer lamp was designed and constructed as a radiance standard according to our recommendations. Prior to this model these lamps could only be used as irradiance standards. One of these newly designed lamps has been calibrated for use on the FOS (faint object spectrograph) space shuttle experiment. We also evaluated and calibrated a space-qualified Pt-Cr-Ne hollow cathode lamp for use on the FOS.

We have been investigating an irradiance source of highly pure Lyman-α radiation (121.6 nm) which does not utilize a monochromator. A preliminary report on this source was presented at the October 1982 annual meeting of the Optical Society of America.

We are presently involved in selecting and calibrating a deuterium lamp to be flown on the SUSIM (solar ultraviolet spectral irradiance monitor) space shuttle experiment as an in-flight calibration source. As a part of this project our calibrations of a set of these lamps were compared with calibrations carried out at NPL (England) to ensure highest reliability of the irradiance scales.

Also, we have begun the investigation of a new source to provide radiance and/or irradiance calibrations in the 20-200 nm range. This source is a pulsed plasma created by a focused laser beam striking a heavy metal target. A target chamber has been placed in operation, and some data have been obtained with a grazing incidence spectrograph. Measurements are in progress to determine the suitability of this source as a radiometric standard.

Finally, an argon arc operated at a much higher power than the mini-arc has been designed, constructed, and calibrated. This arc was supplied to Goddard Space Flight Center to enable calibrations to be performed at a level comparable to the solar irradiance in the near UV range (250-350 nm). The irradiance of this arc is ≈30 times that of the mini-arc.

(h) Stark Broadening, Shifts of Hydrogenic and Non-hydrogenic Ion Lines.--We have completed our work on the widths and shifts of Stark broadened He II ion lines. These lines included the He II P_α line at 4686 Å and the VUV H_α line at 1640 Å. The electron density in the pulsed plasma arc source was measured using a He-Ne laser interferometer allowing us to compare the line profiles with widely varying theoretical estimates for the width and shift of hydrogenic ion lines. We have also begun measurements of non-hydrogenic ion lines as well. This includes the first and second ionization stages in Ne, Ar, Kr, Xe and N. Some 230 lines have been observed in this experiment. With the aid of an independent measurement of the plasma electron density using the He-Ne laser interferometer, the systematic trend of Stark broadening in the rare gas homologus sequence is being investigated.

SPONSORED CONFERENCES

Division 531, Atomic and Plasma Radiation

DOE Review Panel, 2-day DOE Review of NBS Work on Atomic Data Pertinent to Magnetic Fusion Research, NBS, Gaithersburg, Maryland, W. L. Wiese, June 9-10, 1983.

INVITED TALKS

Division 531, Atomic and Plasma Radiation

Clark, C. W., "Negative Ion Resonances in Electron Scattering by Noble Gases," University of Chicago Chemical Physics Symposium, October 6, 1982.

Clark, C. W., "The Diamagnetism of Rydberg Electrons," 1983 Annual Joint Meeting of APS/AAPT (American Physical Society and American Association of Physics Teachers), New York City, New York, January 27, 1983.

Clark, C. W., "Negative Ions of the Noble Gases," University of Maryland Chemical Physics Seminar, February 16, 1983.

Clark, C. W., "Orbital Contraction in Transition Regions," 15th National Atomic and Molecular Physics Conference, The University of Manchester, England, April 8, 1983.

Clark, C. W., "The Lowest Resonance States of the Negative Ions of Krypton and Xenon," 15th National Atomic and Molecular Physics Conference, The University of Manchester, England, April 6, 1983.

Clark, C. W., "Low Energy Electron Scattering on a Magnetic Field," International Symposium on Collisions in Strong Fields, Bielefeld, West Germany, July 25, 1983.

Kelleher, D. E., "Plasma Spectroscopy," Massachusetts Institute of Technology, Cambridge, MA, January 20, 1983.

Kelleher, D. E., "Plasma Spectroscopy," SUNY, Stony Brook, NY, March 14, 1983.

Reader, Joseph, "Atomic Spectroscopy at the National Bureau of Standards," Lebedev Physical Institute, Moscow, USSR, May 18, 1983.

Reader, Joseph, "Atomic Spectroscopy at the National Bureau of Standards," Institute of Physics of the Lithuanian Academy of Sciences, Vilnius, Lithuania, USSR, May 24, 1983.

Reader, Joseph, "Atomic Spectroscopy at the National Bureau of Standards," Institute of Spectroscopy, Moscow, USSR, May 26, 1983.

Reader, Joseph, "Atomic Spectroscopy at the National Bureau of Standards," State Committee on Standards, Moscow, USSR, May 27, 1983.

Division 531, Invited Talks (cont'd.)

Reader, Joseph, "Atomic Spectroscopy at the National Bureau of Standards," Ioffe Physical-Technical Institute, Leningrad, USSR, June 2, 1982.

Roszman, Larry, "Dielectronic Recombination Rates of Some Ionized Elements," Fourth Topical Conference on Atomic Processes in High Temperature Plasmas, APS, Princeton, NJ, April 1983.

Roszman, Larry, "Problems in Dielectronic Recombination," Workshop on Indirect Processes in Electron-Ion Scattering, Oak Ridge National Laboratory, Oak Ridge, Tennessee, June 1983.

Weiss, A. W., "Correlation Effects in Highly Ionized Atoms," Working Group on Highly Ionized Atoms, Los Alamos National Laboratory, Los Alamos, New Mexico, October 1982.

Wiese, W. L., "Atomic Spectroscopy Data for Gas and X-Ray Laser Transitions," International Conference on Lasers, Canton, Peoples Republic of China, September 7, 1983.

Wiese, W. L., "Topics in Atomic and Plasma Radiation Research," Fudan University, Shanghai, Peoples Republic of China, September 22, 1983.

Wiese, W. L., "Emission Spectroscopy of Argon," Kyoto, Japan, September 27, 1983.

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Division 531, Atomic and Plasma Radiation

Clark, C. W., The Isotope shifts of C I spectral lines and their application to radioactive dating by laser assisted mass spectrometry, Optics Letters (in press).

Clark, C. W., Low-energy electron-atom scattering in a magnetic field, Phys. Rev. A 28, 83 (1983).

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Jones, D. W., Musiol, K., and Wiese, W. L., Regularities of Stark Widths and Shifts in an Ar I Transition Array, in The Physics of Ionized Gases, (Invited Lectures, Review Reports and Progress Reports of SPIG-82), edited by G. Pichler (Institute of Physics, Zagreb, Yugoslavia, 1983), pp. 457-464.

Kaufman, V., The Spectrum of Neutral Sulfur (S I) in the Vacuum Ultraviolet, Phys. Scr. 26, 439-442 (1982).

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Kelleher, D. E. and Lombardi, G. G., Effect of Electric Fields on Autoionizing Resonances, J. Phys. (Paris), Colloq. C2, 11, 439 (1982).

Kelleher, D. E., The Effect of Electric Fields on Autoionization Resonances, in Spectral Line Shapes, edited by B. Wende, (Walter de Gruyter, Berlin • New York, 1981), pp. 281-292.

Konjevic, N., Dimitrijevic, M. S., and Wiese, W. L., Experimental Stark Widths and Shifts for Non-Hydrogenic Spectral Lines of Ionized Atoms, J. Phys. Chem. Ref. Data (in press).

Konjevic, N., Dimitrijevic, M. S., and Wiese, W. L., A Critical Review of Experimental Stark Width and Shift Data for Spectral Lines of Non-Hydrogen Atoms (for the period 1976 to 1982), J. Phys. Chem. Ref. Data (in press).

Lombardi, G. G., Feynman's Disk Paradox, Am. J. Phys. 51, 213 (1983).

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Pittman, T. L. and Fleurier, C., Red Shift of the He II H_α and P_α Lines, in Spectral Line Shapes, Vol. 2, edited by K. Burnett (Walter de Gruyter & Co., Berlin • New York, 1983), pp. 87-100.

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Roberts, J. R., Kaufman, V., Sugar, J., and Rowan, W. L., Magnetic-dipole transitions observed in highly ionized Ga, Ge, As, and Kr, Phys. Rev. A 27, 1721-1723 (1983).

Roszman, L. J., and Weiss, A. W., Effects of Configuration Interaction on Dielectronic Recombination of Fe (XXIV), J. Quant. Spectrosc. Radiat. Transfer 30, 67-71 (1983).

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TECHNICAL AND PROFESSIONAL COMMITTEE PARTICIPATION AND LEADERSHIP

Division 531, Atomic and Plasma Radiation Division

Victor Kaufman

Chairman, 1984 and member, 1985 William F. Meggers Award Committee, Optical Society of America.

Georgia A. Martin

Chairperson, National Academy of Sciences--National Research Council Committee on Line Spectra of the Elements--Atomic Spectroscopy.

Invited Participant, NAS-NRC Panel on Current Trends in Atomic Spectroscopy (October 1982).

William C. Martin

Chairman, Working Group on Structure of Atomic Spectra, Commission 14 of International Astronomical Union.

Member, National Academy of Science-National Research Council Committee on Line Spectra of the Elements--Atomic Spectroscopy.

Member, IAEA Network of Atomic Data Centers for Fusion.

Invited Participant, NAS-NRC Panel on Current Trends in Atomic Spectroscopy (October 1982).

Joseph Reader

Invited Participant, NAS-NRC Panel on Current Trends in Atomic Spectroscopy (October 1982).

James R. Roberts

Chairman-Elect, the TEXT Users Organization (TEXT = Texas Experimental Tokamak, a national plasma research facility).

Jack Sugar

Member, 1985 William F. Meggers Award Committee, Optical Society of America.

Division 531, Technical and Professional Committee Participation and Leadership (cont'd.)

Wolfgang L. Wiese

Member of Organizing Committee, International Astronomical Union, Commision 14.

Chairman, International Astronomical Union, Commission 14, Working Group on Atomic Transition Probabilities.

Member, IAEA Network of Atomic Data Centers for Fusion.

Member of International Organizing Committee of Colloquium on EUV and X-Ray Spectroscopy.

MAJOR CONSULTING AND ADVISORY SERVICES

Division 531, Atomic and Plasma Radiation

1. J. Z. Klose performed numerous evaluation tests and calibrations of a Pt-Cr-Ne hollow cathode lamp and five rf dimer lamps this year as part of contract work for Martin Marietta Aerospace. His work involved close consultation with Martin Marietta personnel concerning the results of each test and plans for successive tests and calibrations. Klose is presently involved in selecting and calibrating a deuterium lamp to be flown on the SUSIM (solar ultraviolet spectral irradiance monitor) space shuttle experiment as an in-flight calibration source. This process requires his close consultation with our contractor, the Naval Research Laboratory. The staff at Ball Aerospace Systems Division is using argon arcs supplied by us under contract for the calibration of instruments for solar UV measurements in space. J. M. Bridges has had several consultations concerning the proper application of the arcs in these calibrations. Klose and Bridges also answer requests from a variety of callers for information on radiance and irradiance calibrations in the vacuum ultraviolet spectral region.

2. The Data Centers on Atomic Energy Levels and Transition Probabilities routinely fill requests for atomic data or literature information submitted by scientists in a wide range of research areas. The requests average about 15 per week. On occasion, special reports are prepared for particular user groups. Thus, W. C. Martin and W. L. Wiese write updates on atomic data of interest for the astrophysical community for the IAU Transactions, and give review reports at the General Assemblies of the International Astronomical Union.

3. J. R. Roberts serves as Chairman-Elect for the TEXT users organization (TUO). TEXT stands for Texas Experimental Tokamak and is a national plasma users facility. The TUO steering committee considers the special needs of off-site user groups and has then provided advice and perspective on the users program to the TEXT managers and the Office of Fusion Energy at DOE.

4. L. J. Roszman serves as a consultant with the Theory Group at Lawrence Livermore Laboratory on problems concerning the effects of dielectronic recombination on high temperature plasmas.

5. A. W. Weiss was invited by DOE to participate in the Highly Ionized Atom Working Group at the Los Alamos National Laboratory in New Mexico in October 1982. The schedule included an invited presentation followed by a round table discussion.

JOURNAL EDITORSHIPS

Division 531, Atomic and Plasma Radiation

J. Reader, Editor, Fine Spectra of the Elements, Handbook of Chemistry and Physics, CRC Press.

W. L. Wiese, Associate Editor, Journal of Quantitative Spectroscopy and Radiative Transfer.

TRIPS SPONSORED BY OTHERS

Division 531, Atomic and Plasma Radiation

J. M. Bridges traveled to Boulder, Colorado for consultation with Ball Brothers concerning calibration work. Entire trip paid by Ball Brothers. (July 1983)

Charles W. Clark traveled to Warrington and Manchester, England. He attended the meeting "Ionization by Electron and Photon Impact," sponsored by Collaborative Computational Project, Daresbury Laboratory. He also attended the 15th National Conference on Atomic and Molecular Physics at the University of Manchester and presented two papers. The entire trip was paid for by the Science Research Council of Daresbury Laboratory in Warrington. (March 23-April 11, 1983)

Charles W. Clark attended the international symposium "Collisions in Strong Fields," Bielefeld, Germany and presented a contributed paper at the 13th International Conference on the Physics of Electron and Atomic Collisions. Partial support was provided by the satellite meeting held in Bielefeld, West Germany. (July 21-August 4, 1983)

J. R. Roberts traveled to Los Alamos National Laboratory, New Mexico, for consultation with Dr. Franz Jahoda on far infrared laser diagnostics on LANL ZT-40. The trip was paid by LANL. (May 1983)

L. J. Roszman traveled twice to Lawrence Livermore Laboratories in California as a consultant with the theory group under Dr. J. Weisheit. Entire trip was paid by LLL. (January and September, 1983)

C. J. Sansonetti traveled to Los Alamos National Laboratory to serve on a committee formed to review the design of a high-resolution Fourier spectrometer planned by the Chemistry Division. Entire trip was paid for by LANL. (August 1-2, 1983)

CALIBRATION SERVICES PERFORMED

Division 531, Atomic and Plasma Radiation

Type of Service	Customer	SP 250	No. of Tests	Income
Dimer Lamp	Martin Marietta	Contract	2	$15k
Hollow Cathode Lamp	Martin Marietta	Contract	1	7.5k
Deuterium Lamp	Naval Research Lab.	Contract	4	27.5k
Argon Arc	Goddard Space Flight Center	Contract	2	3k
Deuterium Lamps	Goddard Space Flight Center	7.6 D	2	1k
Deuterium Lamps	Canon	7.6 D	1	0.5k

TECHNICAL ACTIVITIES

Division 532, Nuclear Radiation

Task No. 15221 - Neutron Radiation Safety
Task No. 15222 - Nuclear Structure and Standards
Task No. 15223 - Nuclear Radiation Research
Task No. 15225 - Neutron Field Standards
Task No. 15226 - Radioactivity Standards
Task No. 15227 - Neutron Measurements and Resarch
Task No. 15602 - Physical/Technological Property SRM Research
Task No. 15645 - Computerization of Standard Reference Bases

The Nuclear Radiation Division encompasses a broad range of activities including both fundamental and applied research. It includes five groups designated as Nuclear Theory, Nuclear Research, Neutron Measurements and Research, Neutron Field Standards, and Radioactivity. Of these the first two are mostly basic nuclear research, and the last three are mostly applied research. Photonuclear data collection, located in the Nuclear Research Group as part of the Photon and Charged Particle Data Center, is being phased out.

Activities of the Division support important national areas of concern: medicine (e.g. radioactivity standards for nuclear medicine and dosimetry standards for neutron radiation therapy), fission and fusion nuclear power (neutron cross sections, fission rate measurements in power reactors, environmental radioactivity standards), environment (environmental radioactivity in natural matrices), occupational safety (neutron personnel monitoring), and science (nuclear structure and dynamics through electromagnetic interactions, and molecular physics with eV neutrons).

We continue to attract many guest workers. Some of our scientific colleagues who have come to NBS for extended stays are: Dennis Skopik, University of Saskatchewan; Prabha Durgapal, George Washington University; James O'Brien, Montgomery College; William Stapor and Miles McCord, Catholic University of America; Elisa Wolynec and Marcos Martins, University of Saõ Paulo, Brazil; Li Linpei, National Institute of Metrology and Yang Dongliang, Institute of Atomic Energy, Peking, China; Mauro Dias, Instituto de Pesquisas Energêticas e Nucleares, Saõ Paulo, Brazil; Bernd Siebert, Physikalisch-Technische Bundesanstalt, Braunschweig, West Germany; Augustin Grau Malonda, Junta de Energia Nuclear, Madrid, Spain; Johann Rafelski, University of Frankfurt, West Germany; Sunaryo Wiryosumarto, National Atomic Energy Agency, Republic of Indonesia; Rezsoe Jedlovszky, National Office of Measures of Hungary; and Tae-Soon Park, Korean Standards Research Institute.

Division 532, Technical Activities (cont'd)

Members of the Nuclear Radiation Division staff on extended stays elsewhere include Leonard Maximon and Michael Danos, Centre d'Etudes Nucléaires de Saclay, France; Michael Danos, Centre d'Etudes de Bruyères-le-Chatel, France; J. Joseph Coyne, Physikalisch-Technische Bundesanstalt, Braunschweig, West Germany; Evans Hayward, Max-Planck Institut für Chemie, Mainz, West Germany; Sydney Meshkov, University of California, Los Angeles; and Bert Coursey, Central Bureau for Nuclear Measurements, Geel, Belgium.

Dosimetry Standards for Neutron Radiation Therapy. This program, supported by the National Institutes of Health, has been continued to improve the accuracy and consistency of absorbed dose measurements for neutron therapy through provision of national dosimetry standards and improved theoretical information on neutron interactions with tissue and tissue-equivalent materials. A longer term goal is to develop a calibration facility at NBS where neutron dosimeters can be calibrated.

The major work performed for this program in the past year was participation in an international intercomparison of neutron dosimetry performed at the National Physical Laboratory (NPL), Teddington, England, and sponsored by the Bureau International des Poids et Mesures. Measurements were made in a 15 MeV collimated neutron beam to determine the neutron and gamma-ray tissue kermas in free air 3 cm in front of a 30-cm cubic water phantom, and to determine the neutron and gamma-ray absorbed doses at depths of 5, 10, and 15 cm in the phantom. The NBS dosimeters employed to make the measurements consisted of two tissue-equivalent ionization chambers to determine the total (neutron plus gamma-ray) kermas and absorbed doses, two magnesium-walled ionization chambers with argon gas filling to assess the gamma-ray components of the mixed fields, and a photon-energy compensated Geiger-Müller counter also to assess the gamma-ray components. All dosimeters were calibrated in a known ^{137}Cs gamma-ray beam at NPL prior to making measurements in the neutron beam so that all neutron beam values reported by the participants will be based on a common calibration source. The NBS calibrations with the NPL ^{137}Cs beam agreed with the values obtained using the NBS standard ^{137}Cs beam within 2.2%.

Participation in this international intercomparison is important to NBS to establish the relation between NBS neutron dosimetry standards currently under development and the neutron standards being developed at other standards laboratories. Valuable experience was gained concerning the instrumentation and procedures used at another prominant standards laboratory for generating and measuring high energy neutron beams.

Last year's annual report described studies made of the neutron and gamma-ray tissue kerma rates produced in free air by a ^{252}Cf radiation source. A report describing this work has been published as "Dosimetry of a Lightly Encapsulated ^{252}Cf Source" in the journal Radiation Protection

Dosimetry. This work demonstrated that the proportional counter can provide valuable information for mixed-field dosimetry and, accordingly, tissue-equivalent plastic and graphite-walled proportional counters were acquired for future use.

One of the methods to be used to establish neutron dosimetry standards at NBS consists of comparing neutron kerma rates at 15 MeV neutron energy using ionization chambers and using a ^{235}U double-foil, pulse ionization fission chamber. A preliminary comparison was made last year but suffered from inaccurate measurements of distance from the neutron-producing target to the dosimeter. This difficulty will be overcome in a planned future comparison by use of a horizontal cathetometer (distance-measuring telescope) which has been acquired for this purpose.

The 15 MeV neutron field produced by the NBS 3 MV Van de Graaff accelerator was used to investigate various characteristics of the neutron dosimeters such as ion recombination, polarity effects, wall attenuation and scattering, and stem scattering. These measurements are not only important for future work with 15-MeV neutrons at NBS, but they also provided essential data for the NPL intercomparison project.

I. Nuclear Theory Group

This group works on high energy theory, nuclear theory, Coulomb interactions, neutron standards theory, and theoretical neutron dosimetry, relating particularly to the experimental nuclear research and neutron standards research programs in the Division.

Elementary Particle Physics. Our present theory of the strong interactions, Quantum Chromodynamics (QCD), describes hadrons as composed of colored quarks and antiquarks with the strong force between them mediated by the exchange of massless colored gluons. QCD implies that a new form of matter should exist, namely composites of two or more of these gluons, called glueballs. These particles contain no quarks and are colorless.

A major activity of the NBS elementary particle program is the study of glueballs, i.e., setting criteria for their existence, production, and decay in experiments such as those under way at SPEAR (colliding electron-positron beams) and at Brookhaven National Laborarory (BNL). Critical reviews of the status of various glueball candidates have been given in a series of invited talks at international conferences, the most recent at the Experimental Meson Spectroscopy Conference at BNL. Summarizing the available data it was concluded that the most viable glueball candidates at present are those $\phi\phi$-states produced in the reaction $\pi^- p \to \phi\phi n$ at BNL. Various experimental tests to check the glueball characteristics of these states have been proposed; some of these are now underway.

In recent years many attempts have been made to unify the strong, weak, and electromagnetic interactions. All of them have used as a basis, the "standard model" i.e., $SU(3)^{color} \times SU(2)^{weak} \times U(1)^{Y}$. It has been extremely successful in recent confrontation with experiment, i.e., the discovery of the $W^{\pm}$ and Z_0 bosons at their predicted masses.

The standard model can be summarized in terms of a set of particles determined by a few simple principles. Together with P. Fishbane of U. Va. and P. Ramond of the Univeristy of Florida, Gainesville, a systematic search has been carried out for the possible existence of other sets of fermions which satisfy these principles and do not violate any current experimental limits.

Various sets of such particles have been found; this work is currently being submitted for rapid publication under the title "Standard Model Constraints on Fermions".

Nuclear Theory. In the past, nuclear forces have been treated in terms of meson exchanges between point nucleons, although it was realized that these nucleons were not point particles but in fact occupied a large part of the volume of nuclei. Now the origin of nuclear forces must be rethought in terms of the underlying quark structure. The model available for this treatment is the bag model. However, two-nucleon interactions in this model have six quarks in the bag, and if an exchanged meson is included then there are seven quarks and an antiquark. There are many-body correlations among the quarks. A program to investigate these forces has been started.

The current hadron bag model treats the confinement problem in a purely ad hoc, unphysical, manner, i.e., by imposing a scalar boundary condition on the quark wave function. However, no scalar fields exist in the QCD Lagrangian, which could serve to take up the momentum transfer implied by the boundary condition. In order to eliminate this drawback, and to put the description of the hadrons on a more physical basis a reformulation of the quark bag model for the nucleon in terms of the methods of NBS Monograph 147 has been initiated. The first steps, in progress at this time, consist of rewriting the QCD Hamiltonian in the Schrödinger picture, and of computing the specific QCD matrix elements not contained in 147.

To replace the ad hoc boundary conditions of the bag model by a correct description of the hadron-vacuum interface in fact requires a solution, or at least a semi-quantitative understanding, of the confinement problem. It is widely believed that the confinement in QCD, in analogy with superconductivity, results from the existence of a physical vacuum which is removed from the remainder of the spectrum by an energy density

gap, which exhibits a Meissner-Ochsenfeld effect, and which can not be described by the methods of 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 superconductivity theory.

A new emerging field of nuclear physics concerns the question of explicit manifestations of QCD effects in nuclear reactions. A promising approach is the observation of a quark-gluon plasma in the collision of two heavy nuclei. Diverse aspects of this are being explored.

A vexing problem of nuclear physics is the apparent isospin impurity of the α-particle, which manifests itself in the ratio $\sigma/(\gamma,p)/\sigma(\gamma,n)$ which does not equal unity. This experimental fact has lead to speculation that the nuclear force itself may not be isospin invariant. A program has been started to test whether the Coulomb interaction itself, contrary to previous calculations, can explain the observed cross section ratio.

Electron Scattering and Photonuclear Theory. The most important probes for experimental nuclear research at intermediate and high energies are provided by electron accelerators in the form of well collimated beams of electrons with good energy resolution, and by quasimonochromatic photon beams produced when these electrons collide with a suitable target. The increased accuracy of present-day high energy electron scattering experiments, resulting from increasing energy resolution and improved detection systems calls for a reinvestigation of the theoretical expressions used in the analysis of these experiments. This will be needed even more for the analysis of experiments currently being planned for CW electron accelerators in the energy region of 200 MeV - 2 GeV now under construction. Theoretical work has concentrated on the expressions commonly used by experimenters for the radiative tail from elastic and inelastic electron scattering. A number or reports on this subject, for use by experimenters, are being prepared.

In collaboration with physicists at George Washington University, theoretical work on the photodisintegration of few body systems continues. Experimenters at M.I.T. have already used this work in the analysis of their experiments on the photodisintegration of ^{3}He.

Theoretical Neutron Dosimetry. A theoretical program on Neutron Interactions with Biological Tissue is being carried out with joint support from NBS, the Office of Health and Environmental Research, Department of Energy, and recently from the Armed Forces Radiobiology Research Institute (AFRRI). The objective of this program is to obtain information

about neutron interactions with tissue through secondary charged particles using theoretical calculations whose input includes neutron cross section data; range, stopping power, and straggling information; and geometrical properties. These calculations include what is usually called microdosimetry, but extend further in the basic physics. These results apply to physics, radiation biology, radiation protection of workers, and standards for neutron dose measurement.

There is increased interest in studying very small cavity sizes (of the order of nanometers). For these cavity sizes our analytical calculations will not be valid because of the importance of delta rays and straggling, or track structure in general. For this reason, and because it will be needed to improve calculations at high neutron energy, we are developing a Monte Carlo code to calculate energy deposition spectra for fast neutrons. The first version has been designed so as to duplicate the results of the analytic code. This code is now operating successfully and gives identical results to the analytic code within the Monte-Carlo statistics. Preliminary studies have been completed on how to include straggling and delta-ray effects. As a first step we are using the "Landau" straggling, which is valid for small thicknesses of material--certainly the case for nanometer cavities.

The analytic code used for neutron energy deposition studies has been extended in two ways: (1) use of bin-averaged cross sections so that arbitrary neutron spectra may be calculated, useful even for "monoenergetic" neutron sources since they are seldom completely monoenergetic, and also for distributed-energy neutron sources such as cyclotrons with either protons or deuterons on beryllium as the neutron-producing reaction; and (2) calculation of ionization yield spectra for small sites which are more directly comparable to the experimentally-measured spectra obtained with walled and wall-less tissue-equivalent proportional counters. We are now preparing tables of initial and slowing-down spectra for neutrons up to 15 MeV using new nuclear data for low neutron energies and stopping powers furnished by Martin Berger of the Radiological Physics Division.

Kerma factors have been calculated for 44 compounds and mixtures encompassing a large number of materials of interest to radiation biology, radiation therapy, neutron protection, dosimetry, and radiation chemistry. These results have now been published in the International Journal of Applied Radiation and Isotopes (IJARI).

Neutron Personnel Monitoring. Under contract with the NRC we have reviewed measurements made inside of containment at nuclear power plants in order to recommend optimum procedures for evaluating the radiation dose received by workers in those plants. We found that measurements of neutron dose equivalent with remmeters often differed from those deduced from multisphere ("Bonner" sphere) measurements by as much as a factor of

two. Discrepancies were due partly to the harsh temperature and humidity conditions under which measurements were made, and partly due to inherent shortcomings of the remmeters. Measurements with neutron albedo dosimeters were capable of predicting neutron dose equivalent to within about 40%, provided that they were calibrated with an appropriate neutron source, such as a D_2O-moderated ^{252}Cf source. However, dosimeters calibrated with fission sources such as unmoderated ^{252}Cf were incorrect by factors of 20 or 30. Measurements with other types of instruments were also reviewed. We recommended continued use of both remmeters and albedo dosimeters together with improved calibration procedures for these instruments.

We analyzed a recent experiment that measured the effect of neutrons reflected from the floor of a calibration room, on the fission rate of a ^{235}U foil. In an early paper (1965) we predicted that, for a point source and point detector above a flat surface, the fluence of neutrons reflected from the surface would vary inversely as the square of the distance from the detector to the image source created by viewing the surface as a mirror. This prediction was borne out by the experiment--even for configurations for which the ^{235}U fission rate from reflected neutrons was as much as three times the rate from source neutrons.

We are preparing an invited article for a special issue of Radiation Protection Dosimetry on the subject of recommended calibration procedures for neutron personnel monitors. At a recent meeting of International Standards Organization Technical Committee 85 at NBS we provided information that will be incorporated in an international standard on calibration procedures for neutron personnel monitors.

Under contract with the Armed Forces Radiobiological Research Institute (AFRRI), we reviewed calculations and measurements made for them by another laboratory, for the purpose of understanding the neutron fields in their irradiation facilities. Values of neutron tissue kerma inferred from measurements with activation foils were in good agreement with values inferred from calculated neutron spectra.

Reactor Dosimetry. Scattering corrections for a recent remeasurement of the neutron cross section of ^{235}U in a ^{252}Cf spontaneous fission spectrum were reviewed. Corrections for scattering in the NBS fission chamber were based on Monte Carlo calculations by P. Soran of LANL. These calculations have reduced the uncertainty in the correction for chamber scattering. The uncertainty (0.4%) in the correction for scattering in the ^{252}Cf source capsule is now the largest uncertainty of those associated with scattering corrections.

II. Nuclear Research Group

The study of the interactions of high energy photons and electrons with nuclei is leading to new understandings of how nucleons behave inside complex nuclei, i.e. in what form they exist and how they interact with each other. Activities of the Nuclear Research Group cover experimental and theoretical investigations of many different electromagnetically induced nuclear reactions. This includes high energy electron and photon scattering from nuclei, electrodisintegration experiments in which nuclear reaction products are studied, and electroactivation studies in which integrated reaction cross sections are studied via induced radioactivities.

The photon scattering work was terminated in August 1981 to make room for construction of the NBS microtron. Before this time, however, work was completed on the scattering of high energy photons from ^{16}O at several angles. These data along with similar data on ^{12}C have been analyzed to yield the E2 strength in these nuclei. A paper on this work has been published in Physical Review C.

A new photon scattering experiment has now been performed in Mainz, Germany in collaboration with B. Ziegler of the Max Planck Institute. Using the tip of the bremsstrahlung spectrum photons were scattered through 115° from the delta resonances of ^{12}C and ^{208}Pb. This experiment is the first of its kind and is important because the results and the problems uncovered will determine the course of future work in this field. Much larger cross sections were found than can be explained by coherent scattering alone. While a paper is in preparation on this work, we are trying to decide which next step will teach us the most.

The electron scattering program has encompassed several different activities. A precision measurement of the ^{4}He radius has been made by comparing it to that of ^{12}C. This work led to the PhD of W. Stapor of Catholic University. A similar measurement of the proton radius is now being planned and will form the basis of the thesis of M. McCord. Maruyama has continued in his study of stretched configurations in collaboration with the group at the University of Massachusetts; the measurements are made at the Bates Laboratory. Lightbody and Maruyama are also engaged in a collaboration at Bates to investigate the convection and magnetization current contribution to the transverse cross section of the first excited state of ^{52}Cr. They are in another collaboration at the Amsterdam laboratory to study magnetic transitions in ^{52}Cr.

O'Connell organized a collaboration with a group of physicists from Lund, MIT, American University, and NBS to investigate the apparent failure of the Coulomb sum rule. At the Bates Laboratory, we measured the spectra of electrons scattered through 20° by six targets at four electron energies. During the course of the measurements we found an instrumental

background produced by the electrons striking the interface between the spectrometer and the scattering chamber and established a procedure for subtracting it off. Within the uncertainties in the experiment our results are consistent with the sum rule and it is now believed that the discrepancy found in previous experiments stemmed partly from the instrumental problem. These results have appeared in Physical Review C.

The electrodisintegration experiments performed in collaboration with E. Wolynec and M. Martins of São Paulo have continued. The work on the isochromat of the electric dipole virtual photon spectrum for zirconium has been completed and a paper published in the Physical Review. We now plan to study the (e,α) and (e,p) cross sections for Zr and complete the interpretation of the ^{63}Cu(e,n) cross section.

A major effort of the Nuclear Research Group during the past year was the preparation of a proposal requesting funds to support nuclear physics research using the 200 MeV CW microtron now under construction. The physics was described as well as the instrumentation required to do it. The proposal also outlined a plan to use the 200 MeV accelerator as an injector for a much larger 1 GeV microtron. The experiments to be done with this machine were also described.

III. Neutron Measurements and Research Group

This group is concerned with measurements of neutron interactions which depend strongly on the neutrons' energy. The interactions include both nuclear and molecular effects and require neutron spectroscopic capability from 0.005 eV to 50 MeV--over ten decades of energy. The largest program is devoted to a continuing international effort to push the accuracy of reference neutron cross sections into the ±1% (1 SD) range. Other programs are concerned with the development and exploration of analytical techniques based on the unique features of the neutron's interaction with matter. Both the standards and analytical studies require a significant component of fundamental neutron research. The NBS facilities used are the 100 MeV linac, 3 MV positive-ion Van de Graaff, and nuclear reactor.

The nuclear data measurements by the group during this period concentrated on the ^{235}U neutron-induced fission cross section standard in the low MeV energy region. The neutron sources were the linac 200-m time-of-flight facility, the ^{252}Cf neutron spectrum, and the 2.6-MeV associated-particle facility at the Van de Graaff. The analysis of the measurement from 0.3 to 3 MeV using the Black Detector as a neutron flux monitor on the linac is nearly complete. The investigation proved to be more time consuming than originally anticipated due to the large number of separate runs which had to be carefully compared for consistency and a major effort to examine each aspect of the experiment in detail so as to reduce the

uncertainties to a minimum. Analysis is nearly complete of a similar measurement from 1 to 6 MeV which used the dual thin scintillator as a neutron flux monitor. The ^{235}U cross sections deduced from these two different experiments agree within their common neutron energy region. This confirms the validity of the neutron flux measurement component in the experiments.

Significant progress was made in an experiment at 2.5 MeV using the time-correlated associated-particle technique with the $D(d,n)^3He$ reaction at the Van de Graaff. Suitable TiD targets have been obtained which permit a reasonable separation of the associated ^3He particles from the elastically scattered deuterons by using foil absorption. The primary effort is now to optimize the D_2^+ beam current and to study the spatial distribution of the neutron beam. Preliminary results have been obtained.

The NBS has participated in a new international intercomparison of neutron flux measurement capability sponsored by the International Bureau of Weights and Measures (BIPM). The intercomparison which will include eight international laboratories is by means of a large ^{235}U fission ionization chamber which was supplied by the Harwell laboratory. This chamber will allow both linac and Van de Graaff neutron facilities to participate whereas only Van de Graaffs participated in previous tests. We were the first laboratory to complete the measurements which were done at a neutron energy of 500 keV on both the linac and Van de Graaff using the Black Detector flux monitor. A useful by-product of this intercomparison will be a new international measurement of the $^{235}U(n,f)$ cross section with a common ^{235}U deposit.

Development and calibration of the dual thin scintillator (DTS) detector for flux measurements in the 1-15 MeV region have been completed. A paper describing the detector and its calibration was submitted for publication in Nuclear Instruments and Methods. Calibrations of the detector at 2.45 and 14.0 MeV using the associated particle technique have an accuracy of 1.5% and 0.7%, respectively. The detector efficiency has been extended throughout the 1-15 MeV region using a Monte Carlo code with a precision of $\leq$ 1.5%. This detector is also potentially useful as a neutron spectrometer. Operating in a coincident mode between the two scintillators, the detector exhibits a response function peaked at the neutron energy throughout the 1-15 MeV range. Such a response function should provide a significant improvement for spectrum unfolding techniques. Work on using the DTS detector as a neutron spectrometer is just beginning.

Initial detector developments were done to establish the $^3He(n,p)$ reaction as a useful standard in the keV energy range. Presently there is no single reaction which is suitable for flux measurements throughout the keV range (0.5 to 2000 keV). Both $^6Li(n,\alpha)$ and $^{10}B(n,\alpha)$ change so rapidly

or become so small in the higher energy region that neither is suitable at higher energies. For $^{235}U(n,f)$ the opposite situation obtains; the structure below 100 keV causes the reaction to be useless for standards purposes. However, the $^{3}He(n,p)$ reaction is smooth throughout and is relatively flat from 300 to 3000 keV. Three problems have restricted the use of this standard: (1) the absence of a detector with suitable geometry for standards measurements, (2) large uncertainties in the cross section, and (3) relatively low counting rates. The problem of counting rates has disappeared as neutron source intensities have increased over the years. The detector selected to implement this standard is a low pressure gas scintillator. The chamber has been constructed and initial testing will take place with the assistance of the Physics Department at Duke University.

Further studies were conducted to improve the two-dimensional position resolution characteristics of the microchannel plate neutron detector. Experiments and Monte Carlo calculations indicate that the major limitation on resolution is the scattering of photons in the fiber optic faceplate. These studies show that microchannel plate systems could be improved greatly by the addition of extramural absorptive material in the fiber optic matrix to attenuate the photons that take diagonal paths.

The studies of inelastic neutron scattering in the eV energy region have continued with concentration on detector development. Since the low energy neutron resonances used to detect the scattered neutron are primarily capture resonances in heavy nuclei and since the γ rays from such capture are highly internally converted, a strong x-ray signal will be present. To exploit this fact a measurement using a high purity intrinsic Ge detector to detect the x rays following Au neutron capture was attempted. The results of the measurement indicate that a significant improvement in the signal to background can be made using this technique. Further measurements are planned using the WNR facility in collaboration with LANL personnel. In addition, a BGO detector to measure capture γ rays is being developed for use in this program.

The effect of neutron energy loss on neutron moderation problems through the excitation of electronic states in atoms and molecules was investigated. Initial studies using Monte Carlo based simulation and the theoretical probabilities for such electronic excitation indicated a very small effect on neutron moderation. An analytic approach based on an approximation to the average logarithmic energy decrement was subsequently developed. From this technique the fractional correction to the logarithmic energy decrement was calculated to be on the order of 10^{-4} for neutron moderation in light elements. In practice this small increase will probably not be significant for neutron moderation problems.

Division 532, Technical Activities (cont'd)

A review paper on "Standard Cross Section Data" was completed during this year. This document will be published in a special issue of Progress in Nuclear Energy devoted to Cross Section Data for Nuclear Reactor Analyses. The standards paper contains information on the need for standards, properties of standards, applications and measurement techniques for the standards, comparisons of experimental data, comparisons of evaluations, and the status of the standards. Light element, capture, and fission standards are considered. Significant effort has gone into graphical plots of recent experimental data and evaluations. A comprehensive bibliography is included.

A feasibility experiment to determine the amount of ^{235}U in waste material from nuclear facilities was completed. The amount and distribution of ^{235}U in waste material is a concern in the control of material in the nuclear safeguards program. The incinerator ash from a nuclear materials facility was simulated with various concentrations of ^{235}U in a range of container sizes.

The use of resonance neutron radiography as a means of monitoring the amount of uranium in the waste material was investigated. Positron-sensitive proportional counters were used as detectors in an experimental setup at the NBS linac facility. A matrix material simulating incinerator ash was innoculated with ^{235}U in concentrations ranging from 4.8×10^{-4} g/cm^3 to 4.6×10^{-3} g/cm^3. The observed uncertainty in the results agreed well with the predicted uncertainty obtained from an analytic model.

Tests were also made of the effect of matrix and ^{235}U inhomogeneity on measurement accuracy. The observed results of inhomogeneity also agreed well with predicted results. The technique thus provides a method for investigating measurement problems on low concentration waste samples that is well understood and capable of uniquely determining the concentration and distribution of any isotope (and isotopic concentration) in a waste material sample ranging from 2-liter containers to 55-gallon drums.

A standard 6-7 MeV photon field has been developed at the 3 MV Positive Ion Van de Graaff Accelerator. This field is produced by the $^{19}F(p,\alpha\gamma)^{16}O$ nuclear reaction. This field has been characterized in terms of the absolute emission of the photon source and its energy spectrum. Backgrounds have been identified and reduced. This field was used to calibrate radiation detectors consisting of thermoluminescence detectors and active survey meters for the Nuclear Regulatory Commission. Radiation detectors may be calibrated with uncertainty of 5% (1 standard deviation). These measurements were done in collaboration with the Radiation Physics Division and the Office of Radiation Measurement.

A Rutherford Backscattering Facility is being established on a new beam line at the Van de Graaff laboratory. This facility, which is being constructed in collaboration with scientists from the Center for Materials Science, will be used for studies of the properties of thin films and ceramic surfaces. The accelerator, which was modified to produce helium ion beams in addition to the hydrogen and deuterium beams used for the neutron experimenters, has provided energy analyzed beams of both He^{+} and He^{++} ions. Additional staff will be provided from the Center for Materials Science in order to use the facility approximately 25% of the time.

Studies of neutron-induced fission cross section systematics for a wide range of nuclei continued in the MeV energy region. The present work involves the prediction of the fission cross sections of short-lived nuclides based on the properties of the nearby long-lived nuclides. The status of the fast fission cross section ratios is also being maintained for a Cross Section Evaluation Working Group (CSEWG) subcommittee. The final measurement of the fission cross section ratios done at Lawrence Livermore National Laboratory was published.

The group has also made significant contributions to national nuclear data committees. Wasson is a member of the Department of Energy Nuclear Data Committee, and is on the General Program Advisory Committee for the 1985 International Conference on Nuclear Data for Basic and Applied Science. Behrens supplies status reports on fast fission cross sections relative to ^{235}U to a subcommittee of the Cross Section Evaluation Working Group and is a member of the Transuranic Task Force of the Isotopes and Radiation Division of the American Nuclear Society. Carlson has assumed important time-consuming responsibilities to CSEWG. He is the chairman of the Standard Subcommittee while also serving on the Evaluation Committee and the Data Status and Requests Subcommittee.

Carlson's involvement in CSEWG activities has significantly increased as a result of the standards evaluation process for the ENDF/B-VI evaluation. The focus of CSEWG activities is on the standards subcommittees since the standards evaluations must be completed before other evaluations can begin. The procedures for evaluating the standards have been established. A number of different approaches are being used so that consistency of the various results can be checked. A substantial effort is being directed toward a simultaneous evaluation of the H(n,n)H, $^{6}Li(n,t)^{4}He$, $^{10}B(n,\alpha)^{7}Li$, $^{197}Au(n,\gamma)^{198}Au$, and $^{235}U(n,f)$ cross sections. This set was selected since a large number of ratio measurements of standards to standards exist within it. Correlations among data sets will be taken into account while the shapes and normalizations will be evaluated separately. In addition, an R-matrix analysis of the $^{6}Li+n$ and $^{10}B+n$ systems will be done. Individual evaluations for each of the standards

will also be performed. The evaluation procedure should provide consistent cross sections in which all the available experimental information, including correlations, is more properly used.

In addition to taking a strong leadership role in the ENDF/B-VI evaluation process, NBS has initiated a cooperative program among the standards committees of the International Nuclear Data Committee (INDC), the Nuclear Energy Agency Nuclear Data Committee (NEANDC), and CSEWG. An important result of this program could be internationally accepted neutron standard cross sections. Carlson also attended and chaired a session at the IAEA Consultants' Meeting on the ^{235}U Fast Neutron Fission Cross Section and the ^{252}Cf Fission Neutron Spectrum which was held in March 1983 at Smolenice, Czechoslovakia.

This program has benefited for the last two years from guest workers who were supported by their home institutions. Mr. Mauro Dias developed the dual-thin scintillator neutron flux monitor and used it for a ^{235}U cross section measurement. He returned to the Instituto de Pesquisas Energeticas e Nucleares in São Paulo - Brazil in April 1983 to complete his Ph.D. studies. Mr. Li Linpei participated in the ^{235}U cross section measurements at 2.6 MeV and with the ^{252}Cf neutron source. He returned to the National Institute of Metrology in Peking, People's Republic of China in August 1983.

The status of our facilities remained essentially unchanged with all facilities providing useful beams and intensities. The NBS Center for Radiation Research has commissioned a further study of neutron research at the NBS. This study, which also includes the related fields of high-LET radiation and analytical chemistry, will soon be presented for consideration by the NBS management.

IV. Neutron Field Standards Group

The objectives of this group are to provide neutron dosimetry standardization and neutron source and detector calibrations for energy generation technology and radiation exposure monitoring. Activities are divided between response to calibration and measurement service requests and the application of existing standard neutron fields and related capabilities to neutron reaction-rate measurement standardization. Strong interactions with outside organizations, both in the federal and private sector, continue to be the main programmatic characteristics of this group's activities.

Concern for neutron field measurements in nuclear technology is on the increase as was noted last year. Neutron field calibration and related measurements continued at a high level this year in order to improve the level of standardization for personnel neutron dosimetry, for

materials performance under stress of irradiation, and for advanced power reactor development. Fission chamber experiments in a variety of circumstances continue to be of importance. Measurements in neutron flux intensities which differ by orders of magnitude and operations in neutron fields associated with tokamak fusion experiments are examples.

Neutron personnel dosimetry activities involved dosimeter and dosimetry instrumentation calibrations in five different standard neutron fields. Clients ranged from nuclear utilities and dosimetry vendors to DoE laboratories participating in dosimetry improvement programs. Dosimetry for materials performance focused on preparing and evaluating the documentation describing reactor pressure vessel (RPV) mock-up measurements at ORNL. Experimental characterization of the neutron field in the RPV mock-up at ORNL rests largely upon neutron reaction rate measurements that were referenced to fission neutron standard fields at NBS. The industry problem behind this effort, steel embrittlement under stress of radiation in a reactor vessel, continues to be an important component of our program. The new impetus arising from the recognition of thermal shock potential in older pressure vessels as a result of post-TMI changes in emergency reactor-shutdown procedures is still a problem for the industry, the NRC, and even the media. The option of making cavity dosimetry measurements in operating power plants was taken up this year. NBS personnel were on-site for the installation of a dosimetry capsule in Main Yankee in Connecticut, and a measurement standardization surcharge arrangement was worked out for a Westinghouse contract to perform cavity dosimetry measurements and calculation for Diablo Canyon in California.

The CESWG Subcommittee on Standards explicitly recognizes the fission-spectrum-averaged cross section of ^{235}U in the ^{252}Cf fission spectrum as a basic normalization measurement for the ^{235}U fission cross section. Remeasurement of this normalization quantity is now largely complete. The present value from the new data is 1231 mb. Error components are being evaluated in terms of known improvements associated with the new measurements. A preliminary estimate of the total error for the new determination is ± 2.0% (1 std. dev.). It is expected that the final error will be about one third less. The major error reductions come about from (1) revision of the mass scale for NBS fissionable deposits (error reduced to ± 0.75%); (2) new detailed Monte-Carlo scattering calculations for the fission chamber and the fissionable deposit backings carried out at Los Alamos; and (3) reduction of the error assigned the source strength of NBS-1, the National Standard Neutron Source (error reduced to ± 0.9%). An important part of the program was the measurement of room-return neutrons by a guest worker from the People's Republic of China.

Division 532, Technical Activities (cont'd)

The development of a thermal-neutron-autoradiography facility for diagnostic irradiations of art works continued in cooperation with the Reactor Division and the Smithsonian Institution. Substantial preliminary modifications at the thermal column, fabricated and installed by our group, deliver a high intensity flux of thermal neutrons over a large area. The design also makes possible rapid recovery of irradiated paintings so that short-lived activities can be included in the post-irradiation diagnostic procedures. Design of a large semi-movable shield for a permanent art work irradiation facility is complete.

Comprehensive publication of fission cross sections measured in the ISNF and two fission standard neutron fields took place this year. Eight fissionable isotopes were included in the reported information. This work is part of our on-going program of neutron field standards measurements and is subject to periodic review and updating. The next revision of masses for the fissionable isotope mass standards is not likely to occur in less than three years. The cross sections should remain within their stated error estimates indefinitely since all known error components have been investigated. Some representative results for ISNF, and their agreement with ENDF/B-V, are as follows: ^{235}U: 1606 mb ± 5.0% (calculated-to-experimental = 0.977 ± 5.0%); ^{232}Th: 38.4 mb ± 3.2% (calculated-to-experimental = 0.878 ±3.8%). A characteristic of this result which identifies it as coming from a standard neutron field is the inclusion of a component in the C/E ratio error for the propagated effect of ISNF spectrum uncertainties. Each physical and nuclear parameter of ISNF has been subject to a spectrum variational analysis which is subsequently propagated to a set of spectrum-associated errors for each species of reaction rate measurements. Thus, calculated-to-observed ratios are an unambiguous check of the corresponding energy-dependent cross section.

The testing of neutron personnel dosimetry instrumentation, which continued at a high level, made notable and proper institutional use of the filtered beams, the thermal column, and the D_2O-moderated fission spectrum irradiation facility. Systematic performance tests have now been performed on essentially all types of passive dosimeters used in the United States. Calibration of active neutron dosimetry instrumentation (remmeters and BF_3 counters) served the needs of a variety of agencies, laboratories, and commercial vendors, and also met the calibration requirements of an increased number of power reactor operators.

Personnel from the Naval Surface Weapons Center, in collaboration with CRR personnel, did extensive testing of the Navy's shipboard area monitoring system. The energy and angular response of the monitor system was determined using all three of our monoenergetic filtered beams plus a thermal beam from the reactor thermal column. In addition, the 144 keV beam was used for testing various detector tubes which may be used in the shipboard monitor. The 144 keV beam is especially useful for these tests,

since it is a convenient high-intensity source of neutrons with relatively little gamma contamination. The energy response of a new type of dosimeter developed at Yale University, also investigated with the filtered beams, shows promise of having close to tissue-equivalent response and it may be inexpensive as well.

The cavity fission source was redesigned in order to allow irradiated neutron fluence standards to be removed separately from the highly radioactive fission source disks which now remain inside the thermal column after irradiation. The fission chamber monitor also was remounted on the insertion stem close to the source detector assembly and two new shielding arragements were designed and built to accomodate the new source. A 7" dia. lead cylinder on a rolling platform allows the fission source disks to come out of the thermal column into a shield that is hand carried to a larger lead storage channel. Various operations and inspections can now be done with the highly radioactive fission source disks. Personnel exposures involved with the handling of sources have been substantially reduced.

The cavity fission source, with these operational modifications in place and with final neutron scattering corrections, is now a convenient standard neutron field for routine use. The ^{235}U fission neutron flux density at the midplane between the fission source disks is 1.8×10^{10} n/cm^2s. For individual irradiated foils this flux is established to ± 2.6% based on neutron flux transfer from the NBS ^{252}Cf Irradiation Facility.

The cavity fission source produced a substantial number of fission neutron fluence standards for reactor dosimetry applications. In three primary irradiations, titanium, nickel and iron foils were exposed to fission neutron fluences of between 4.5 and 7×10^{10} n/cm^2. These fluence standards have been distributed to various dosimetry measurement laboratories in this country and abroad. A major effort was undertaken to formulate a test report for neutron fluence standards that is user oriented and adequately descriptive. Major error components for these standards are (1) flux transfer from the ^{252}Cf fission neutron irradiation facility: ± 2.3%; (2) neutron scattering corrections: ± 0.6% and (3) gradient and positioning uncertainties: ± 0.85%. The total error for the new fluence standards is ± 2.6%.

The stack of activation foils in the cavity fission source involves perturbation of the activation rate in each foil because of neutron scattering in the same foil or in nearby foils. Monte Carlo calculations were made for us by Los Alamos National Laboratory to determine this effect. It was found that the flux gradient over the foil stack is small enough that corrections can be effected on the basis of separation distance alone. The Monte Carlo calculations also provide corrections for the entire cavity fission source detector assembly.

Division 532, Technical Activities (cont'd)

A test of the helium-accumulation fluence monitor (HAFM) technique has been carried out by irradiation of ^{6}LiF, ^{10}B, and natural boron samples in the NBS Intermediate-Energy Standard Neutron Field (ISNF). More than forty HAFM samples were provided for the irradiation by Rockwell International. The neutron fluence was determined by means of six pairs of gold and indium activation foils, which were positioned among the nine tubes supporting the HAFM samples. A total fluence of about 1.3×10^{14} neutrons/cm^2 was delivered to the samples. A background run was also made with the fission drivers removed from the ISNF facility. Both Au and Ir foils were irradiated with the HAFM detectors to provide run-to-run monitoring which will correct the HAFM irradiations based on a subsequent ^{235}U fission rate determination.

A major intercalibration measurement campaign was undertaken at the Nuclear Energy Center (SCK/CEK) in Mol, Belgium. Three group members were at the BR-1 reactor in Belgium on staggered assignments for a period of six weeks. Measurement goals included a flux transfer from the ^{252}Cf fission neutron standard field at NBS to the ^{235}U cavity fission source at SCK/CEN, and a fission cross section determination for fissile materials in the ^{235}U fission spectrum. A considerable logistics effort was involved in transferring fission chambers, electronics, a data acquisition computer, and fissionable materials. One shipment of irreplaceable NBS fissionable isotope mass standards that did not arrive on time in Belgium was later found in Bombay, India.

Miscellaneous measurement and related activities make poor material for accomplishment reporting, but do constitute a substantial part of our Neutron Field Standards Group effort. A sampling of these activities in FY-83 are as follows: (1) preparation of a subsection on "Data Analysis Methods--Examination of Individual Detector Responses" for NUREG Report #4, "Power Reactor Surveillance Physics--Dosimetry Compendium"; (2) participation in fission rate measurement at the VENUS reactor pressure vessel mockup; (3) completed report on iron shell measurements of neutron penetration parameters; (4) source calibration tutorial for Livermore Radiation Lab. staff; (5) consultation with INEL staff on higher actinide fission cross section measurements in the CFRMF Facility; (6) completed revision of the "Compendium of Benchmark Neutron Fields for Reactor Dosimetry;" and (7) furnished calibrated ^{235}U deposit to ANL for international intercomparison of fissionable deposits.

Specific reference is made here to last year's narrative of technical activities (Annual Report 1982; Div. 532). Much of the information provided there is applicable to this year's activities. Ten publications and reports were part of the group's activities this year; the total for FY-82 and FY-83 is 20.

Division 532, Technical Activities (cont'd)

Meetings and committee work continue to occupy a prominent place in our program. We provide a secretary for the ASTM Subcommittee on Radiation Metrology which presently is engaged in the development of 19 standards for reactor pressure vessel irradiation surveillance and steel embrittlement prediction. Participation at symposia and program reviews in radiation personnel dosimetry continued and the effort to draft a new IAEA Manual on Neutron Dosimetry Calibrations moved forward. Formal program review meetings for the NRC-sponsored LWR-Pressure Vessel Dosimetry Irradiation Surveillance Program and the DoE-sponsored Personnel Dosimetry Upgrading Program require active participation spread out among 5 staff members.

V. Radioactivity Group

A. Standard Reference Materials and Calibration Services

The following table highlights some of the significant efforts of the group to provide a basis for consistent and accurate radioactivity measurements in the U.S.:

Standards and Calibration Services	No. of Units	K$
Standard Reference Materials	727	174.5
Atomic Industrial Forum program for nuclear medicine	272	----
Scheduled Calibrations (OPMS)	34	20.4
Special Measurements (NBS 94)	75	36.0
Traceability tests, including EPA, FDA, NRC, and commercial firms	173	----

The last item, which can use all of the other listings as mechanisms to check the measuring ability of participating laboratories, propagates accurate activity calibrations with minimum NBS expense. The participation of commercial standards suppliers, equipment manufacturers, and testing laboratories is now established, and the regulatory agencies also have programs for checking their quality control laboratories.

Among the Standard Reference Materials (SRMs) made available during the past year are ^{90}Sr (significant for environmental monitoring), ^{14}C-hexadecane (especially suitable for the calibration of liquid scintillation counters), a mixed-gas standard in glass spheres, and a renewal of the well-received mixture of long-lived radionuclides for calibrating

germanium gamma-ray-spectrometry systems. The contemporary ^{14}C-oxalic acid reference material, which serves as the international benchmark in carbon dating, was elevated to an SRM after further evaluation of the data from laboratories that participated in the calibration.

^{228}Ra standards, significant for compliance with requirements for drinking water monitoring, have been prepared.

The monthly issuance of radiopharmaceutical activity standards continues to serve as an economic and safety reference point for the industry and workers in nuclear medicine.

A quantity of Irish Sea sediment with relatively high radioactivity concentration has been sterilized, freeze-dried, diluted with Chesapeake Bay sediment, pulverized, homogenized, and bottled in preparation for radioactivity calibration as an SRM. A scrubber hood suitable for perchloric acid fuming and high temperature fusions was installed to aid in the chemical separations required for some environmental samples.

B. Basic Activity and Nuclear Data Measurements

Most of the basic calibrations for gamma-ray-emitting radionuclides are retained on stable ionization chambers or germanium-spectrometry systems. This permits routine service calibrations or SRM production with minimum repetitious use of the more complex direct calibration techniques. These techniques can be used instead to produce calibrations for new radionuclides of growing significance. Spectrometry systems which are used to check the purity and accuracy of all x- and gamma-ray-emitting radionuclides are also used to measure accurately probabilities per decay for some radiations, in order to relate emission rate and activity measurements. Half lives are measured in order to prolong the accurate application of SRM's, and new techniques for measurement are pursued in order to improve or expand our measuring abilities. Recent examples of these follow.

Production of ^{135}Xe with the linear accelerator, and methods of standardization, were investigated.

The technique of comparative liquid scintillation counting, with calculated responses to give an accurate ratio to ^{3}H or ^{14}C, was applied to a series of iodine radioisotopes (^{123}I, ^{125}I, ^{129}I, and ^{131}I). Liquid-scintillation counting was also used to calibrate SRMs of ^{89}Sr and ^{90}Sr.

A new calibration of ^{75}Se was developed, using a pressurized proportional counter in anticoincidence with gamma-ray detectors. Extending dead times up to 40 ms were used to measure directly the contribution of a 17-ms state as 6.0%. Probabilities per decay were measured for the major gamma rays of ^{75}Se.

The decay of 76-s ^{82}Rb was studied with material eluted from a medical generator and in equilibrium mixtures with the parent, 25-d ^{82}Sr, also containing large amounts of ^{85}Sr. Preliminary values of pertinent decay quantities were established and techniques for measuring the activity and the impurity ratio were developed and checked.

The technical feasibility of placing environmental radioactivity measurements on an "atom counting" basis was investigated. A new instrument developed by a commercial firm was evaluated. The instrument uses the mechanism of sputtering from a solid source with ionized argon atoms, followed by laser resonance-ionization spectrometry and mass spectrometry. The basic conclusion is that certain environmental radionuclides have concentrations and other characteristics which allow direct assay but others do not, at the present stage of development.

A careful investigation of ^{228}Ra-^{228}Ac mixtures, with repeated chemical separations to remove progeny, demonstrated that simple discriminator extrapolations could lead to results 7 or 8% high in the assay of ^{228}Ac with high-efficiency counters. The energy added by conversion electrons in coincidence with the ^{228}Ac beta particles effectively created a spectrum almost empty of particles below 50 keV. Normally an almost horizontal extrapolation through the region obscured by the low-energy electrons from the ^{228}Ra decay would be assumed.

C. Other Agency Programs

A radon counting system has been developed to measure the exhalation rate of radon sources accurately. The objective of the program is to provide a reliable radon-in-air standard and to check such present commercial standards. A prototype radon-in-water standard has been developed. The system is being made more rugged and simpler to use.

Thermoluminescent dosimeters and survey instruments were calibrated in atmospheres of ^{133}Xe of known activity concentrations.

A spectrometry system for analysis of xenon radioisotopes was constructed and tested. Conversion electrons from isomeric decays are detected in a near-4π silicon detector system in anticoincidence with a surrounding NaI(Tl) well counter. Gamma rays following beta decays are detected in the well counter in coincidence with beta particles detected in the silicon detector system.

A series of calibrated radionuclide solutions for testing the quality of radiobioassays was supplied to an NRC contractor. Advice on the testing program was also given.

Several hundred calibrated ampoules of ^{230}Th and ^{228}Ra were supplied to EPA to use in their calibration and testing programs.

Division 532, Technical Activities (cont'd)

D. International Activities

Just as accurate U.S. radioactivity measurements are anchored on NBS standards, our results must be checked on an international basis. Techniques and calibrations are exchanged and compared with the corresponding laboratories in other nations, and with international organizations. These sometime involve working visits or formal intercomparisons. Some of our international activities in the past year are given below.

Papers were given at an International Committee for Radionuclide Metrology (ICRM) seminar on Alpha-Particle Spectrometry and Low-Level Measurements; the group also participated in the organization of the seminar. Three papers were also given at the ICRM Seminar on Applied Radionuclide Metrology, and W.B. Mann edited the proceedings, which were subsequently dedicated to him on his 75th birthday.

Samples of calibrated ^{201}Tl, ^{137}Cs, ^{85}Sr, ^{82}Sr-^{82}Rb, and ^{22}Na were sent to the International Bureau of Weights and Measures (BIPM) for registration on their reference system, and ^{133}Ba samples for a forthcoming BIPM intercomparison were prepared and tested. Samples of ^{14}C were intercompared with the National Physical Laboratory, U.K. and VNIIFTRI, U.S.S.R. A solution of ^{22}Na was sent to Indonesia and one of ^{60}Co was supplied to Korea for bilateral comparisons. ^{75}Se activity calibrations were compared with OMH, Hungary, and a pile-up-rejector designed and constructed in their laboratory was tested at NBS. A set of eight scintillators was also supplied to OMH. ^{210}Pb solution was supplied to PTB, F.R.G., for intercomparison.

A guest worker from the People's Republic of China is cooperating in activity measurements and spectrometry at NBS for a year, and workers from Korea and OMH came for short visits. An NBS chemist has started a year's stay at the Central Bureau for Nuclear Measurements, the European Community laboratory in Belgium. An NBS physicist spent a week at OMH.

The group is participating in an ICRM test of efficiency-interpolation methods for germanium spectrometry and in further investigations into low-level environmental sampling techniques. BIPM advisory panel activities include participation in the ^{133}Ba intercomparison and the working party on coincidence measurements.

SPONSORED CONFERENCES

Division 532, Nuclear Radiation

ICRM Seminar on Alpha-Particle Spectrometry and Low-Level Measurements, Harwell, England, J. M. R. Hutchinson, May 10-13, 1983.

Symposium on New Techniques and Potential Applications of Ultrasensitive Mass Spectrometry, NBS, Gaithersburg, Maryland, J. M. R. Hutchinson, May 31, 1983.

INVITED TALKS

Division 532, Nuclear Radiation

Ayres, R. L., "Quantitative Measurement of Radioactivity and the Physics of Radiation Detectors", George Washington University, Washington, D.C., October 15, 1982.

Ayres, R. L., "Description of Storeroom Microcomputer", Second NBS/ADABSE Analytical Workshop, National Bureau of Standards, Washington, D.C., October 26, 1982.

Behrens, J. W., "Inferred ^{238}Pu(n,f) Cross Section in the MeV Range", American Nuclear Society, Washington, D.C., November 17, 1982.

Behrens, J. W., "Neutron Transmission Measurements to Determine Isotopic Content of Spent Fuel", American Nuclear Society, Detroit, Michigan, June 12-16, 1983.

Carlson, A. D., "NBS Neutron Flux Measuring Techniques", Physikalisch-Technische Bundesanstalt, Braunschweig, West Germany, April 5, 1983.

Carlson, A. D., "NBS Measurements of the ^{235}U Fission Cross Section", International Atomic Energy Agency Consultants' Meeting on the Uranium-235 Fast Neutron Fission Cross Section and the Californium-252 Fission Neutron Spectrum, Smolenice, Czechoslovakia, March 28-April 1, 1983.

Carlson, A. D., "Evaluation Procedures for the ENDF/B-VI Standards", International Atomic Energy Agency Consultants' Meeting on the Uranium-235 Fast Neutron Fission Cross Section and the Californium-252 Fission Neutron Spectrum, Smolenice, Czechoslovakia, March 28-April 1, 1983.

Caswell, R. S., "Measurement Quality Assurance for Ionizing Radiations in the U.S.", C.S.N., Casaccia, Rome, Italy, May 23, 1983.

Caswell, R. S., "Interaction of Neutrons with Tissue and Tissue-like Materials", C.S.N., Casaccia, Rome, Italy, May 23, 1983.

Caswell, R. S., "Interaction of Neutrons with Tissue and Tissue-like Materials", Atomic Energy of Canada, Ltd., Chalk River, Ontario, Canada, October 18, 1983.

Coursey, B. M., "Calibration of Liquid-scintillation Counters", Radiopharmaceutical Chemistry Division, George Washington University Medical School, Washington, D.C., October 19, 1982.

Division 532, Invited Talks (cont'd)

Coursey, B. M., "Liquid Scintillation and the NaI(Tl) Counting of Iodine-129", Biology and Medicine Technical Group, American Nuclear Society, Washington, D.C., November 18, 1982.

Danos, M., "Conditions for Formation of Quark-gluon Plasma in High Energy Nuclear Collisions", CERN, Geneva, Switzerland, December 6, 1982.

Danos, M., "Conditions for Formation of Quark-gluon Plasma in High Energy Nuclear Collisions", Quark-gluon Plasma Workshop, Brookhaven National Laboratory, Upton, New York, December 17, 1982.

Danos, M., "The Nucleus: Solid, Liquid, or Gas?", combined University-Technical University Nuclear Physics and Theoretical Physics Colloquium, Münich, Germany, May 27, 1983.

Danos, M., "Melted Nucleons, a New Phase of Matter", combined University-Technical University Nuclear Physics and Theoretical Physics Colloquium, Münich, Germany, May 27, 1983.

Eisenhauer, C. M., "Analysis of Personnel Dosimetry and Portable Instrument Measurements of Determining Neutron Dose Equivalent at Nuclear Power Plants." 10th International Neutron Dosimetry Workshop, Acapulco, Mexico.

Fuller, E. G., "The Deuteron and Other Problems (?) in Photonuclear Reactions", Triangle Universities, Nuclear Laboratory, Duke University, Durham, North Carolina, December 9, 1982.

Gerstenberg, H., "Comparison of Experimental with Theoretical Photon Attenuation Cross Sections Between 10 eV and 100 GeV", International Conference on Nuclear Data for Science and Technology, Antwerp, Belgium, September 9, 1982.

Hayward, E. V., "Elastic Photon Sacttering from ^{12}C and ^{16}O in the Energy Range 20-40 Mev", Strahlenzentrum Universität Giessen, Giessen, West Germany, October 11, 1982.

Hayward, E. V., "Elastic Photon Scattering from ^{12}C and ^{16}O in the Energy Range 20-40 MeV", Département de Physique Nucléaire Centre d'Etudes Nucléaires de Saclay, 91190 Gif-sur-Yvette Cedex, France, October 13, 1982.

Hayward, E. V., "Photon Scattering from the Delta Resonance", Nuclear, Radiological and Accelerator Physics Seminar, NBS, Rm. C-301, Building 245, Washington, D.C.

Inn, K. G. W., "Preparation of Reference Materials by NBS for the Evaluation Program of the ANSI Draft Standard N13.30", 28th Annual Bioassay, Environmental and Analytical Chemistry, Natick, Massachusetts, October 13, 1982.

Division 532, Invited Talks (cont'd)

Inn, K. G. W., "Development of NBS Natural Matrix Radioactivity Materials", 28th Annual Bioassay, Environmental and Analytical Chemistry, Natick, Massachusetts, October 14, 1982.

Johnson, R. G., "Neutron Inelastic Scattering Measurements in 1-15 eV Region", Los Alamos National Laboratory, Los Alamos, New Mexico, October 26, 1982.

Lightbody, J. W., Jr., "Recent Development iningle Arm Electron-Nucleus Scattering Experiments and Future Prospects", 7th Conference on the Application of Accelerators in Research and Industry, Physics Department, North Texas State University, Denton, Texas, November 9, 1982.

Lightbody, J. W., Jr., "The RMS Charge Radius of the Proton", Staff Research Seminar Series, NBS, Gaithersburg, Maryland, September 15, 1983.

Maximon, L. C., "Radiative Tail in High-Energy Electron Scattering," University of Trondheim, Trondheim, Norway, September 16, 1983.

Meshkov, S., "Glueballs", University of Nebraska, Lincoln, Nebraska, November 9, 1982.

Meshkov, S., "Glueballs", University of California-Irvine, Irvine, California, December 2, 1982.

Meshkov, S., "Glueballs", Orbis Scientae Conference, Coral Gables, Florida, January 17-21, 1983.

Meshkov, S., "Glueballs", 18th Recontre de Moriond, La Pagne, Savoie, France, January 23-29, 1983.

Meshkov, S., "Glueballs", University of California-Berkeley, Berkeley, California, February 7, 1983.

Meshkov, S., "Glueballs", Ohio State University, Columbus, Ohio, April 5, 1983.

Meshkov, S., "Review of Glueballs", 7th International Conference on Experimental Meson Spectroscopy, Brookhaven National Laboratory, New York, April 14-16, 1983.

Meshkov, S., "Glueballs", California Institute of Technology, Pasadena, California, May 9, 1983.

Meshkov, S., "Glueballs", University of California-Davis, Davis, California, May 26, 1983.

Meshkov, S., "Glueballs", University of Santa Barbara, Santa Barbara, California, May 31, 1983.

Division 532, Invited Talks (cont'd)

Meshkov, S., "Glueballs", University of California-Irvine, Irvine, California, June 9, 1983.

Meshkov, S., "Glueballs", LAMPF II Workshop, Los Alamos, New Mexico, July 26, 1983.

Meshkov, S., "Glueballs", Aspen Center for Physics, Aspen, Colorado, August 4, 1983.

O'Connell, J. S., "Use of Electron Rings in Nuclear Physics Research", University of Lund, Lund, Sweden, October 5, 1982.

O'Connell, J. S., "Electron Scattering and the Coulomb Sum Rule", Netherlands Institute for Nuclear and High Energy Research, Amsterdam, The Netherlands, October 11, 1982.

O'Connell, J. S., "Electron Scattering and the Coulomb Sum Rule", University of Mainz, Mainz, West Germany, October 14, 1982.

O'Connell, J. S., "Interpretation of Coincidence Form Factors in Electron Scattering", Corcoran Hall, George Washington University, Washington, D.C., December 11, 1982.

O'Connell, J. S., "Electron Nucleus Scattering", Lewes Center for Physics, Lewes, Delaware, June 14, 1983.

PUBLICATIONS

Division 532, Nuclear Radiation

Ayres, R. L., and Hirshfeld, A. T., Radioactivity Standardization of ^{99m}Tc and ^{99}Mo, Int'l. J. Appl. Rad. and Isot. 33, 835-841 (1982).

Behrens, J. W., Preparation of Accelerator Targets by Painting, Nucl. Instrum. Methods 200, No. 1, 67-70 (1982).

Behrens, J. W., Inferred $^{238}Pu(n,f)$ Cross Section in the Mev Range, Transactions American Nuclear Society 43, 722-723 (1982).

Behrens, J. W., Johnson, R. G., and Schrack, R. A., Neutron Transmission Measurements to Determine Isotopic Content of Spent Fuel, Trans. Am. Nucl. Soc. 44, 204-205 (1983).

Behrens, J. W., Fast Neutron Ratio of Pa-223, U-234, U-236, Np-237, and Pu-242 Relative to U-235, Status Report for BNL-NCS-51123 (August 1983).

Behrens, J. W., Inferred Fission Cross Sections in the MeV Range for the Transuranics, Trans. Am. Nucl. Sci. (in press).

Behrens, J. W., Measurement of the Subthreshold Neutron-Induced Fission Cross Section of Plutonium-240 Relative to Uranium-235 from 5 to 300 keV, Nuclear Science and Engineering (in press).

Behrens, J. W., Schrack, R. A., and Carlson, A., Resonance Neutron Radiography for Nondestructive Evaluation and Assay Applications, Proceedings of International Conference on Nuclear Cross Sections for Technology (in press).

Bowman, C. D., and Johnson, R. G., Measurements of Inelastic Scattering of eV Neutrons, IPNS Symposium on Neutron Scattering, AIP Conference Proceedings No. 89, 84-86 (1982).

Bowman, C. D., and Johnson, R. G., Neutron Induced Atomic Excitation and Neutron Moderation, Proceedings of International Conference on Nuclear Data for Science and Technology, September 6-10, 1982, Antwerp, Belgium, 971-973 (1983).

Bowman, C. D., and Johnson, R. G., Measurement of Inelastic Neutron Scattering in the eV Range, Proceedings of Seminar/Workshop on Thermal Reactor Benchmark Calculations, Techniques, Results, and Applications, NP-2855, 7-1 to 7-7 (1983).

Division 532, Publications (cont'd)

Bowman, C. D., Schrack, R. A., Behrens, J. W., and Johnson, R. G., Neutron Resonance Transmission Analysis of Reactor Spent Fuel Assemblies, Proceedings of the World Conference on Neutron Radiography (in press).

Broadhurst, M. G., Ben, A. J., and Schwartz, R. B., The Effect of Neutron Irradiation on Electric Conductivity in Cellulose Acetate, Rad. Prot. Dos. 3, No. 1/2, 107-108 (1982).

Burt, P. E., Fagg, L. W., Crannell, H., Sober, D. I., O'Brien, J. T., Maruyama, X. K., Lightbody, J. W., and Lindgren, R. A., Electron Scattering Study of the 10.32 MeV Transition in ^{40}Ca, Physical Review C 25, No. 5, 2805-2809 (1982).

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Carlson, A. D., NBS Measurements of the ^{235}U Fission Cross Section, Proceedings of IAEA Consultants' Meeting on the U-235 Fast Neutron Fission Cross Section and the Cf-252 Neutron Spectrum, 1983 (in press).

Carlson, A. D., Standard Cross Section Data, Progress in Nuclear Energy, (in press).

Carlson, C. E., Coyne, J. J., Fishbane, P. M., Gross, F. and Meshkov, S., Hadronic Decays of Low-Lying Glueballs, Nuclear Physics (in press).

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Caswell, R. S. and Coyne, J. J., Kerma Values, Neutron, Encyclopaedia of Physics and Its Applications, Pergamon Press (in press).

Division 532, Publications (cont'd)

Cavallo, L. M., National Standards for Radioactivity Measurements, NBS Special Publication 609, 31-37 (1982).

Coursey, B. M., Hoppes, D. D., and Unterweger, M. P., Standardization of ^{18}F for Use in Positron-Emission Tomography, Int. J. Appl. Radiat. Isot. 34, No. 8, 1181-1189, (1983).

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Dodge, W. R., Hayward, E., and Wolynec, E., Experimental Test of Virtual Photon Theory, Physical Review C 28, No. 1, 150-158 (1983).

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Fishbane, P. M., Horn, D., Karl, G., and Meshkov, S., Flavor Symmetry and Glueballs, Nuclear Physics B (in press).

Fishbane, P. M., Karl, G., and Meshkov, S. M., Iota (1440) and Theta (1670) Glueball Candidates, Physics Letters (in press).

Friar, J. L., Fallieros, S., Tomusiak, E. L., Skopik, D., and Fuller, E. G., Electric Polarizability of the Deutron, Physical Review C 27, No. 3, 1364-1366 (1983).

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Goodman, L. J., Coyne, J. J., and Caswell, R. S., The NBS Program in Dosimetry Standards for Neutron Radiation Therapy, Proc. of IAEA Advis. Grp. on Advances in Dosimetry for Fast Neutrons & Heavy Charge Part. for Ther. Appl. (in press).

Grundl, J. A., National Standards for Neutron Mesurements, NBS Special Publication 609, 39-43 (1982).

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Grundl, J. A. and Gilliam, D. M., Fission Cross Section Measurements in Reactor Physics and Dosimetry Benchmarks, American Nuclear Society Transactions, 44, 533 (June 1983).

Hoppes, D. D. and Schima, F. J., Nuclear Data for the Efficiency Calibration of Germanium Spectrometer Systems, Int'l J. Appl. Rad. and Isot. 34, No. 2, 491-492 (1983).

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Hutchinson, J. M. R., and Mullen, P. A., "Pin-Well"-NaI(Tl) Counting of 59.5-keV Gamma Rays in the Decay of Americium-241, Int'l J. Appl. Rad. and Isot. 34, No. 2, 543-546 (1983).

Hutchinson, J., Noyce, J., and Kolb, W., Radiochemical Isolation of Radium-228 and Its Calibration By Liquid-Scintillation Counting and Gamma-Ray Spectrometry, J. Analytical Radiochemistry (in press).

Hutchinson, J. M. R., Mullen, P. A., and Collé, Development of a Regenerative Radon-in-Water Radioactivity Standard, Nucl. Inst. Meth. (Proc. of ICRM Seminar) (in press).

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Lamaze, G. P., McGarry, E. D., and Schima, F. J., Integral Reaction Rate Measurement in ^{252}Cf and ^{235}Fission Spectra, Nuclear Data for Science and Technology, 425-428 (1982).

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Lightbody, J. W., Jr., Belicard, J. B., Cavedon, J. M., Frois, B., Huet, M., Leconte, Ph., Nakada, A., Xuan Ho, Phan, Platchkow, S. K., Turck, S., de Jager, C. W., Lapikas, J. J., and de Witt Hubert, P. K. A., Elastic and Inelastic Electron Scattering from ^{50,52,54}Cr, Physical Review C 27, No. 1, 113-132 (1983).

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Mann, W. B., An International Reference Material for Radiocarbon Dating, Radiocarbon 25, No. 2, 519-527 (1983)

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O'Connell, J. S., Neutrino Reactions in the Fermi Gas Model, Proceedings of the Los Alamos Neutrino Workshop, Los Alamos National Laboratory, Los Alamos, NM, 37-42 (1982).

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Division 532, Publications (cont'd)

O'Connell, J. S., Use of Electron Rings in Nuclear Physics Research, Proceedings of the Workshop on Use of Electron Rings for Nuclear Physics Research in the Intermediate Energy Region, Lund, Sweden October 5-7, 1982, I, 1-3 (1983).

O'Connell, J. S., Scaling Variables for Coincident Electron Scattering, Physics Letters (in press).

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Schwartz, R. B., Eisenhauer, C. M., and Grundl, J. A., Experimental Verification of the D_2O-Moderated ^{252}Cf Source Spectrum, Nuclear Regulatory Commission Report (in press).

Siebert, B. R. L, Caswell, R. S., and Coyne J. J., Calculations of Quality Factors for Fast Neutrons in Materials Composed of H, C, N and O, Proceedings of the 8th Symposium on Microdosimetry (Euratom) September 27-October 1, 1982, Jülich, Federal Republic of Germany, 1131-1140, (1983).

Stapor, W. J., Crannell, H., Lightbody, J. W., Maruyama, X. K., and O'Brien, J. T., A Flowing Gas Target System for Precision Electron Scattering Measurements, Nuclear Instruments and Methods 203, 97-100 (1982).

TECHNICAL AND PROFESSIONAL COMMITTEE PARTICIPATION AND LEADERSHIP

Division 532, Nuclear Radiation

James W. Behrens

Member of CSEWG Subcommittee to monitor status of important cross sections. His function is to supply status reports on fast fission ratios relative to U-235.

Member of Transuranic Task Force (TRU) of the Isotopes and Radiation Division of the American Nuclear Society.

Allan D. Carlson

Member, Cross Section Evaluation Working Group (CSEWG).

Member, Evaluation Committee of CSEWG; Chairman, Standards Subcommittee of CSEWG.

Member, Data Status and Requests Subcommittee of CSEWG.

Randall S. Caswell

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

Chairman, Section on Neutron Measurements (Section III), CCEMRI, Conférence Générale des Poids et Mesures, Paris, France.

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

Chairman, NCRP Ad Hoc Committee on SI Units.

Chairman, NCRP Ad Hoc Committee on Publications.

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

Sponsor, ICRU Report Committee on Stopping Power.

Sponsor, ICRU Report Committee on Absolute and Relative Dosimetry at High Doses.

Sponsor, ICRU Report Committee on Specifications and Quality Assurance of Scintillation Cameras.

Division 532, Technical and Professional Committee Participation and Leadership (cont'd)

Randall S. Caswell (cont'd)

Member, Radiation Research Accelerator Facility (RARAF) Scientific Advisory Committee, Columbia University.

Bert M. Coursey

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

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

Member, Executive Committee, Biology and Medicine Technical Group, American Nuclear Society.

J. Joseph Coyne

Member, National Nuclear Data Center (NNDC), Panel on Reference Nuclear Data.

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

Michael Danos

Member, Program Review Committee for the Saclay Electron Linac, Saclay, France.

Charles M. Eisenhauer

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

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

Member, NAS-NRC Advisory Committee on the Radiation Effects Research Foundation; and subcommittee: Panel on the Reassessment of A-Bomb Dosimetry.

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

Leon J. Goodman

Consultant, American Association of Physicists in Medicine, Task Group 18: Fast Neutron Beam Dosimetry Physics.

Division 532, Technical and Professional Committee Participation and Leadership (cont'd)

Leon J. Goodman (cont'd)

Member, International Commission on Radiation Units and Measurements, Committee on Clinical Dosimetry for Neutrons.

James A. Grundl

Co-chairman, Steering Committee for Developing ASTM Standards for Reactor Dosimetry, NBS, March 1985.

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

Evans V. Hayward

Member, The Program Committee for the American Physical Society.

Vice Chairman, Executive Committee of the Nuclear Physics Division, the American Physical Society.

Chairman, Program Committee for the Nuclear Physics Division of the American Physical Society.

Member, Maryland Governor's Science Advisory Council.

Member, Search Committee for the Southeastern Universities Research Association.

Member, Argonne Universities Association Special Committee for the Medium Energy Electron Accelerator Facility.

Member, Board of Trustees of the Southern Universities Research Association.

Dale D. Hoppes

Member, International Committee for Radionuclide Metrology (ICRM) Alpha-, Beta-, and Gamma-Ray Spectrometry Working Group.

Member, Atomic Industrial Forum (AIF)-NBS 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, Calibration Advisory Group, NBS.

Division 532, Technical and Professional Committee Participation and Leadership (cont'd)

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, American Society for Testing and Materials (ASTM) Committee C26.05 Environmental Methods Task Group on Nuclear Fuel Cycle.

Member, Methods of Radiochemical Analysis in Water and Water Deposits, Committee D19.04.

George Lamaze

Secretary, American Society for Testing and Materials (ASTM), on Subcommittee E10.05, Nuclear Radiation Metrology.

Member, ASTM Committee E10, Nuclear Technology and Applications.

J. W. Lightbody, Jr.

Member, National Advisory Board of the Southern Universities Research Association.

Member, Program Advisory Committee for MIT/Bates Accelerator Laboratory.

Wilfrid B. Mann

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

Member, DoE Half-Life Evaluation Committee for Pu Isotopes Physical Constants.

Member, ANSI-INMM Subcommittee N15.8 on Calibration Techniques for Nuclear Material Control.

Member, ANSI-INMM Work Group INMM 8.04 on Calibration Techniques for Calorimetric Assay of Plutonium-Bearing Solids.

Division 532, Technical and Professional Committee Participation and Leadership (cont'd)

Wilfrid B. Mann (cont'd)

Chairman, National Council on Radiation Protection and Measurements (NCRP) Committee 18A on Standards and Measurement of Radioactivity for Radiological Use.

X. K. Maruyama

Counselor, EEO Program.

Clerk, Bates Linear Accelerator Users Group, Inc.

Emmert D. McGarry

Member, Organizing Committee for the Fifth ASTM-Euratom Symposium Reactor Dosimetry, NBS, March 1985.

Member, Steering Committee for Developing ASTM Standards for Reactor Pressure Vessel Irradiation Surveillance.

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

Committee Member and a Technical Coordinator for the Standard Dosimetry Measurement Facility (SDMF) Test in support of NRC Program for the Improvement of Radiation Surveillance Dosimetry of Nuclear Reactor Pressure Vessels.

Sydney Meshkov

Member, Board of Advisors, Aspen Center for Physics, Aspen, Colorado.

Member, Board of Advisors, Lewes Center for Physics, Lewes, Delaware.

Member, LAMPF II Planning Committee, Los Alamos, New Mexico.

Visiting professor, University of California, Los Angeles, California.

J. S. O'Connell

Member, Governing Committee, Lewes Center for Physics.

Member, Research Advisory Committee of NBS.

Division 532, Technical and Professional Committee Participation and Leadership (cont'd)

J. S. O'Connell (cont'd)

Member, Advisory Committee "Workshop Electron Rings for Nuclear Physics Research", Lund, Sweden, October 1982.

Member, Advisory Committee "Magnetic Spectrometer Workshop", Williamsburg, Virginia.

Robert B. Schwartz

Member, International Standards Organization (ISO) Technical Committee on Nuclear Energy (ISO/TC 85).

Member, ISO Subcommittee 2 on Radiation Protection.

Member, ISO Work Group 3 on Neutron Reference Radiations.

Michael P. Unterweger

Member, American Society for Testing and Materials (ASTM) Committee D-22 on Methods for Sampling and Analysis of Atmospheres.

Oren A. Wasson

Member, Department of Energy Nuclear Data Committee.

Member, General Program Advisory Committee to 1985 International Conference on Nuclear Data for Basic and Applied Science.

MAJOR CONSULTING AND ADVISORY SERVICES

Division 532, Nuclear Radiation

1. R. S. Caswell advised the N.C.I. in the development of their long range Radiation Therapy Research Plan.

2. M. Danos served as advisor and scientific consultant to the Chief of Nuclear Physics, Saclay, France.

3. D. M. Gilliam exchanged visits with the neutron diagnostics staff of the Princeton Plasma Physics Laboratory to make arrangements for NBS calibration of PPL's neutron yield instrumentation.

4. J. Grundl consulted with SEFOR Calibration Center on program directions in support of dosimetry calibration reactor pressure vessel dosimetry.

5. J. M. Robin Hutchinson and K. W. Inn assessed the quality of research work performed by Battelle Northwest Laboratory under the NRC/DoE Bioassay Program and made suitable recommendations.

6. R. G. Johnson consulted with the Experimental Physics Division of Lawrence Livermore National Laboratory during FY-83.

7. R. G. Johnson consulted with the Los Alamos National Laboratory October 1983 on experiments and computer systems at WNR facility.

8. G. Lamaze led effort to revise ASTM Standard on terminology relating to radiation measurements and dosimetry.

9. L. Maximon is consultant to two groups in the Department of Nuclear Physics at CEN, Saclay: The High Energy Nuclear Physics Group which does electron nuclear scattering and the Metrology and Fundamental Neutron Physics Group which does photo-nuclear physics.

10. E. D. McGarry and G. Lamaze completed calibrations for in-situ neutron source strength measurement at SEFOR facility in Arkansas.

11. S. Meshkov served as visiting professor at the California Institute of Technology, Pasadena, California; University of California, Irvine, California; and University of California, Los Angeles, California.

12. I. G. Schröder provided basic design study for Neutron Radiography Facility sponsored by the Smithsonian Institution.

Division 532, Major Consulting and Advisory Services (cont'd)

13. R. B. Schwartz consulted with the Pennsylvania State University on setting up a neutron personnel dosimetry quality assurance program.

14. R. B. Schwartz provided consulting and testing services for the Los Alamos Scientific Laboratory in connecting with the development of a new neutron remmeter.

15. R. B. Schwartz consulted with the Physikalisch-Technische Bundesanstalt in connection with neutron filtered beam intercomparisons.

JOURNAL EDITORSHIPS

Division 532, Nuclear Radiation

R. S. Caswell, Member of Editorial Board, Journal of Physical and Chemical Reference Data.

B. M. Coursey, Editor, International Journal of Applied Radiation and Isotopes.

W. B. Mann, Editor, Environment International.

W. B. Mann, Editor, International Journal of Nuclear Medicine and Biology.

W. B. Mann, Editor-in-Chief for North America, International Journal of Applied Radiation and Isotopes.

TRIPS SPONSORED BY OTHERS

Division 532, Nuclear Radiation

A. D. Carlson traveled to Smolenice, Czechoslovakia to attend and chair a session at the IAEA Consultants' Meeting on the Uranium-235 Fast Neutron Fission Cross Section and the Californium-252 Fission Neutron Spectrum. (March 28-April 1, 1983)

R. S. Caswell, sponsored by the National Cancer Institute, traveled to New York City, N.Y., for site visit to Radiological Research Laboratory of Columbia University. (October 20-22, 1982)

R. S. Caswell, sponsored by the National Cancer Institute, attended meeting of N.C.I. workshop on the long-range Radiation Therapy Research Plan in Philadelphia, Pennsylvania. (February 6-7, 1983)

R. S. Caswell, sponsored by the Italian government, presented two invited lectures at C. S. N. Casaccia, Rome, Italy. (May 22-24, 1983)

R. S. Caswell, sponsored by the International Commission on Radiation Units and Measurements, attended Annual Meeting of the ICRU, Paris, France. (June 25-July 2, 1983)

R. S. Caswell, sponsored by the Radiation Research Society, attended 7th International Congress of Radiation Research in Amsterdam, The Netherlands. (July 3-8, 1983)

R. S. Caswell, sponsored by Columbia University, participated in meeting of the Advisory Committee for the Radiological Research Accelerator facility in New York City, N.Y. (September 8-10, 1983)

R. S. Caswell, sponsored by Atomic Energy of Canada, Ltd., presented invited lecture in Chalk River, Ontario, Canada. (October 17-19, 1983)

M. Danos traveled to Center for Nuclear Studies (CEN), Paris (Saclay), France, to reformulate quantum chromodynamics for treatment by the relativistic bound state formulation; collaboration with Drs. Gillet and Gogny. (November 1-15, 1982)

M. Danos traveled to Institute Theoretical Physics, Frankfurt University, Frankfurt, West Germany, for collaboration on quark-gluon plasma and other nuclear physics problems. (November 16-December 16, 1982)

M. Danos participated in Working Group discussions on High Energy Ion Collisons and Quark Matter Phyisci, Brookhaven National Laboratory, New York, New York. (December 17, 1982)

Division 532, Trips Sponsored by Others (cont'd)

M. Danos traveled to the Center for Nuclear Studies (CEN), Paris (Saclay), France, to reformulate quantum chromodynamics for treatment by the relativistic bound state formulation and collaboration with Drs. Gillet and Gogny. (January 15-February 28, 1983)

M. Danos traveled to Duke University, Durham, N.C. to confer with Drs. Biedenharn, Delsanto and others on the question of structure of alpha particles, monopoles, etc. (February 24-26, 1983)

E. V. Hayward collaborated on experiment at the Max-Planck Institute, Mainz, Germany. (September 4-October 30, 1982)

E. V. Hayward attended the meeting of the Special Committee for the Medium Energy Electron Accelerator, Argonne, Illinois. (November 8-9, 1982)

E. V. Hayward attended meeting of the SURA Board of Trustees, University of South Carolina, Columbia, S.C. (November 11-12, 1982)
Division 532, Trips Sponsored by Others (cont'd.)

E. V. Hayward collaborated on experiment, Max-Planck Institute, Mainz, Germany. (May 15-June 20, 1983)

D. D. Hoppes spent a week working at OMH, Budapest, Hungary with support from the host institute under a U.S.-Hungarian agreement.

R. G. Johnson traveled to Los Alamos National Laboratory to participate and consult on experiments at WNR facility, consult on computer systems at WNR, and present invited talk. (October 24-30, 1983)

W. B. Mann traveled to Oxford, England to deliver seminar proceedings for publication to Pergamon Press. (May 26, 1983)

S. Meshkov, To participate in Lampf II Study Group, Los Alamos National Laboratory, Los Alamos, New Mexico, July 26-28, 1983.

J. S. O'Connell attended Workshop on Electron Rings for Nuclear Physics Research, Lund, Sweden. (October 5-7, 1982)

Robert B. Schwartz, sponsored by the IAEA, traveled to Vienna, Austria to consult with Dr. George Burger of the Gesillschaft fur Strahlen-und Umweltforschung, Neuherberg, Germany and with officials of the International Atomic Energy Agency (IAEA) concerning an IAEA manual on neutron dosimetry calibrations which Burger and Schwartz are writing. (Sept. 19-24, 1983)

STANDARD REFERENCE MATERIALS

Division 532, Nuclear Radiation

Standards Issued - 1 September 1982 through 31 August 1983

SRM	Radionuclide	Principal Use
4410H-I	Technetium-99m	Calibration of instruments for activity measurements of radiopharmaceuticals
4406L-F	Phosphorus-32	"
4417L-B	Indium-111	"
4407L-H	Iodine-125	"
4401L-I	Iodine-131	"
4412L-H	Molybdenum-99	"
4415L-G	Xenon-133	"
4416L-D	Gallium-67	"
4404L-F	Thallium-201	"
4400L-F	Chromium-51	"
4417L-C	Indium-111	"
4309-F	Xenon-127	Calibration of instruments for monitoring reactor off-gases
4310-B	Mixed-radionuclide gas	"
4275-B	Mixed radionuclide	Calibration of the efficiency of germanium gamma-ray or x-ray spectrometry systems as a function of energy
4276-B	Mixed radionuclide	"
4260-C	Iron-55	"
4264-B	Tin-121m	"

Division 532, Standard Reference Materials (cont'd)

4919-E	Strontium-90	Solution standard intended for calibration of detectors and for testing radiochemical methods for measurements of radiostrontium
4339	Radium-228	Standard solution for calibrating environmental-monitoring instruments
4990-C	Carbon-14 (oxalic acid)	Contemporary radiocarbon-dating standard
4222-B	Carbon-14 (hexadecane)	Liquid-scintillator calibration

CALIBRATION SERVICES PERFORMED

Division 532, Nuclear Radiation

I. Neutron Measurements and Research Group

Calibration Services Performed at 3 MV Van de Graaff

1. Calibration of neutron dosimeters at a neutron energy of 500 keV for the Naval Surface Weapons Laboratory, October 29, 1982.

2. Calibrated Super Heated Liquid Drop Detector in neutron beam for Yale University, October 28, 1982.

3. Calibration of γ ray survey instruments in 6-7 MeV photon beam for the Nuclear Regulatory Commission, August 1983.

Division 532, Calibration Services Performed (cont'd)

II. Neutron Field Standards Group

Type of Service	Customer	SP 250	No. of Tests	Income k$
Special Measurement Services	Baltimore GE	8.1A	2	0.50
	Gamma Metrics	8.1A	1	0.20
	GPU Nuclear	8.1A	1	0.20
	Phila Electric	8.1A	1	0.20
	Triangle Res	8.1A	1	0.20
	Univ San Fran	8.1A	1	0.45
	Total		7	$ 1.75
Neutron Source Calibrations	Univ. Calif.	8.1B+8.1C	3	2.67
	Univ. Ark.	8.1B+8.1C	3	1.30
	LLNL	8.1B+8.1C	1	0.70
	Total		7	$ 4.67
Neutron Personnel Protection Instruments @ Filtered Beams	Calvert Cliffs	8.1H	3	1.40
	Phila Electric	8.1H	1	0.40
	Rochester G E	8.1H	1	0.40
	Siemens Gamma	8.1H	1	0.96
	Washington PPSS	8.1H	1	0.40
	Total		7	$ 3.56
Neutron Personnel Protection Instruments @ Cf-252	Army Aberdeen	8.1J	1	1.60
	Calvert Cliffs	8.1J	1	0.50
	Carolina P L	8.1J	1	0.25
	Carolina P L	8.1J	1	0.50
	Duke Power	8.1J	1	0.25
	Duquesne Light	8.1J	1	0.25
	GPU Nulear	8.1J	1	0.60
	Knolls Atomic	8.1J	1	0.25
	Mississippi P L	8.1J	1	1.30
	Omaha Pub Power	8.1J	1	0.25
	Siemens Gamma	8.1J	1	0.90
	Washington PPSS	8.1J	1	0.60
	Total		13	$ 7.25
Thermal Neutron Density Standard	G44341 Army Lexington	8.1P	1	0.28
	G44346 Army Redstone	8.1P	1	0.28
	228194 Cornell Univ	8.1P	1	0.28
	Total		3	$ 0.84
		Grand Total:		$18.1

Division 532, Calibration Services Performed (cont'd)

Type of Service	Customer	SP 250	No. of Tests	Income k$
Remmeter Calibration	Carolina Power and Light Company	8.1J	4	1.0
Remmeter Calibration	Calvert Cliffs Nuclear Plant	8.1J	28	4.0
Remmeter Calibration	Mississippi Power and Light Company	8.1J	8	1.55
Remmeter Calibration	Duquesne Light Company	8.1J	1	.25
Remmeter Calibration	Omaha Public Power District	8.1J	2	.5
Remmeter Calibration	GPU Nuclear Corp.	8.1J	5	.9
Remmeter Calibration	Washington Public Power Supply Systems	8.1J	3	.5
Remmeter Calibration	RAD Services, Inc.	8.1J	1	.25
Remmeter Calibration	Philadelphia Electric Co.	8.1J	2	.4
Remmeter Calibration	Rochester Electric Co.	8.1J	1	.25
Dosimeter Irradiation	GPU Nuclear	8.1J	45	1.1
Remmeter Calibration	Eberline Instrument	8.1J	3	.55

Division 532, Calibration Services Performed (cont'd)

III. Radioactivity Group

August 1, 1982 to August 1, 1983

	Scheduled Tests[1]		Non-scheduled Tests	
	Number of Sources	Total Fee $K	Number of Sources	Total Fee $K
Category				
Alpha-Particle Sources 8.2 H, I, J	24	11.8	5	3.2
Beta-Particle Point Sources and Gases (^{85}Kr) 8.2 P, Q, R	0		2	1.7
Gamma-ray Solutions, Point Sources, and Gases (^{133}Xe) 8.2 B, C, D	10	6.0	44	20.9
Mixed Radionuclide Sources, Solutions, Point Sources, and Gases[2]	--	--	24	8.3
Other Services	--	--	--	3.2
	34	17.8	75	37.3

Footnotes

(1) Four sources under one Test Folder are counted as 4 calibrations.

(2) Replicate samples are not considered as separate sources. For example, Amersham submits 2 each of 3 different source forms. This is counted as 3 samples.

TECHNICAL ACTIVITIES

Division 533, Radiation Physics

Task No. 15231 - Radiation Measurement Standards and Technology for Health and Safety
Task No. 15232 - Radiation Measurement Standards and Technology for Industrial and National Programs
Task No. 15233 - Far UV Radiometry
Task No. 15234 - Far UV Measurements
Task No. 15235 - Electron Physics Research

The Radiation Physics Division provides the central national basis for measurements of electron and photon radiation in the energy range from about 5 eV (near ultraviolet) to 10 MeV.

In support of this mission radiation standards and advanced measurement techniques are developed. The Division provides national standards for UV radiation (NBS synchrotron radiation facility and standard photodiodes), and for high energy ionizing radiation (absorbed dose-in-water calorimeters and air ionization chambers). Calibration services are available for: (1) the calibration of X-Ray, γ-Ray, and β-particle dosimeters, of interest principally in radiation therapy and radiation protection applications; (2) high dose ionizing radiation dosimeters, of interest principally in radiation processing applications; and (3) UV detectors and spectrometers, of interest principally in space, atmospheric, and fusion research.

With the goals of improving the standards and measurement techniques and understanding the fundamental physical phenomena upon which they are based, the Division investigates fundamental energy deposition and transfer mechanisms. Theories are developed for stopping power and bremsstrahlung cross sections and applied to dosimetry measurement problems. Photoexcitation and photoionization processes are studied to investigate the interaction of photons with matter on an atomic scale. Polarized electrons are utilized to probe the magnetic microstructure of surfaces and to study low energy electron-atom and electron-surface collisions with unprecedented accuracy. Pulsed radiolysis studies are carried out to study the effects of radiation on condensed phases and biologically-interesting molecules, and to help understand the mechanisms for radiation damage, radiation protection, and chemical repair.

Some new directions for research that were identified during the past year include : (1) development of computer-compatible data files by the Photon and Charged Particle Data Center to supplement traditional printed compilations; (2) high energy electron dosimetry in the energy range 5-20 MeV using the new NBS CW accelerator; (3) real-time X-Ray radiography using digitized image processing techniques; (4) application of laser-enhanced resonance ionization techniques to high resolution and high sensitivity mass spectroscopy; and (5) the investigation of magnetic microstructure using the NBS UHV electron microscope and polarized electron measurement techniques.

As can be seen in the following sections the Division staff has been active in publishing research papers, providing calibration services, presenting invited talks, sponsoring conferences, providing consultation services, and participating in technical and professional committees. We have also been very active in technical collaborations within NBS and with universities, hospitals, industry, and other government agencies.

The principal accomplishments of the past year are described in the following technical reports.

RADIATION THEORY GROUP

Stopping Power

The electron and positron stopping power and ranges tables issued in July 1982 in NBSIR 82-2550 have been updated in December 1982 in a second edition, NBSIR 82-2550-A. The updated version contains results for a larger set of materials, and contains positron radiative stopping powers obtained by an improved treatment that takes into account previously neglected positron-electron differences.

A preliminary table has been prepared of proton stopping powers and ranges in 72 materials of dosimetric interest. At energies above 1 MeV this table is based on the Bethe stopping power theory, combined with semi-empirical shell corrections, density-effect corrections, and mean excitation energies already adopted in earlier work on electron stopping powers. At energies below 1 MeV the new tables are based primarily on experimental stopping powers for elemental materials and the application of the Bragg additivity rule.

The density effect corrections used for electron and positron stopping powers were obtained in numerical calculations based on the Sternheimer dispersion model. It is also very useful to have the density-effect results available in terms of analytical formulas. This was accomplished by using Sternheimer's five-parameter approximation formula. Using a newly developed computer algorithm, these parameters were

tabulated for 285 materials. These parameters are applicable not only to electrons, but also to protons and mesons.

Bremsstrahlung Cross Sections

Earlier pilot calculations of the cross section for the emission of bremsstrahlung by electrons in the field of the atomic nucleus have been extended to all elements. Cross sections have been systematically evaluated for electrons with energies from 1 KeV to 1 GeV in all elements with atomic numbers Z = 1 to 100. These calculations, for the cross section differential in the emitted photon energy, depend on the synthesis of: (a) results of exact phase-shift calculations by Pratt, Tseng, and collaborators; (b) analytical results derived by Davies, Bethe, Maximon, and Olsen in the high-energy approximation; (c) the Coulomb correction factor of Elwert; and (d) the results of the high-frequency limit of Jabbur and Pratt.

Computer-Readable Critically Evaluated Cross Sections

The Photon and Charged Particle Data Center has in the past disseminated its critically-evaluated data mainly in the form of printed tables. In order to satisfy the needs of the growing number of people who want to use the data in further machine computations, and in order to allow dissemination of data more extensively than can be done in printed form, a new policy has been initiated of disseminating such data in computer-readable form on magnetic tapes.

Two such data files have recently been prepared. Data file XGAM contains data pertaining to the interaction of x- and gamma rays with atoms and electrons (scattering, photo-electric absorption and pair production cross sections, attenuation coefficients) in the energy region 1 keV to 100 GeV, for all elements with atomic number Z = 1 to 100. Data file EPSTAR contains stopping powers for electrons in 285 materials, and for positrons in 29 materials of dosimetric interest. The information in EPSTAR includes collison, radiative, and total stopping powers, ranges, density-effect corrections and bremsstrahlung yields. Currently work is in progress on several other data files, including a file of photon cross sections for approximately 300 compounds, and a file of bremsstrahlung cross sections (differential in emitted photon energy) for all elements.

Single and Multiple Elastic Scattering of Charged Particles by Atoms

Calculations of the elastic scattering of charged particles by atoms have been carried out in which the screening of the atomic nucleus by the orbital electrons was taken into account through the use of Hartree-Fock potentials. These calculations were done: (a) quantum-mechanically in the WKB approximation of Moliére; and (b) by a classical-mechanics trajectory calculation. The cross sections from calculation (a) were used

for the evaluation of the angular multiple scattering distribution according to the theories of Moliére and of Goudsmit and Saunderson. Cross sections from calculation (b) were used for the evaluation of the nuclear stopping power for protons, and for calculating the mean differences between the path lengths and projected ranges of protons in various materials.

Penetration of Electrons Through Multi-Layer Media

Whereas the basic NBS Monte Carlo program ETRAN applies to the tration of electrons and associated bremsstrahlung photons through homogeneous media, an extension of the program (called ZTRAN) has been developed which can be used to treat one-dimensional transport problems in media consisting of several layers of different composition. The first application of ZTRAN is being made with reference to the design of composite (high-Z/low-Z) shields for the protection of personnel or equipment in space vehicles. This investigation is carried out as a collaboration with the Space Technology Division at the NASA Langley Research Center.

Response of Intrinsic Ge Detectors to High-Energy Gamma Rays

The new NBS Instrument Calibration Facility, now under development, will use 6.5 MeV gamma rays produced by the $^{19}F(p,\alpha)\ ^{16}O$ reaction. In order to allow conversion of the measured pulse-height distributions to true energy spectra, the detector response function was calculated, with emphasis on the detector efficiency, the photo-peak efficiency, and the first and second escape-peak efficiencies. In the multi-MeV region the calculations are complicated by the motion of the secondary Compton and pair electrons which has a strong influence on the response function. Systematic calculations have been carried out for the detector and irradiation geometries used in the NBS calibration facility, at energies from 100 keV to 10 MeV.

Radiation Protection: Orders-of-Reflection Duct Penetration Calculation

In order to minimize the penetration of radiation into protective structures, the shelter entrances are often designed in the form of multi-leg ducts which trap the incident radiation in the duct walls. The calculation of the penetration of radiation through such ducts or mazes can be done by a variety of methods that depend on the use of the Monte Carlo method. Direct analog Monte Carlo simulation is in principle possible, but is inefficient and prohibitively expensive. An alternative is the tracing of the passage of the radiation through the duct as a sequence of reflections from the duct walls, using precomputed wall albedo data obtained by the Monte Carlo method. Even this approach is still too complicated and expensive to allow consideration of the large number of duct configurations that are of practical interest.

A more economical method has recently been developed and implemented by L. V. Spencer. This method, called "orders-of-reflection method" involves the following steps: (1) The penetration of the radiation (neutrons or gamma rays) through single straight ducts of various dimensions is first calculated in a one-velocity treatment, assuming an albedo with an angular dependence given by Chadrasekhar's theory, assuming isotropic scattering. This penetration probability is calculated for the case of 0,1,2, ...,n reflections from the walls; (2) An estimate of the energy and angular characteristics of the radiation transmited after 0,1,2,,,n reflections is then made by using the results of another Monte Carlo calculation in which the energy and angular characteristics of the multiply-reflected radiation is computed in a space-independent treatment; (3) The results of calculations (1) and (2) are combined to obtain a transfer function which relates the intensities, direction, and energy characteristics of the radiations entering and leaving a single straight duct or duct segment.

Using the output of one such calculation as the input for the next, the transmission of the radiation through a sequence of ducts can readily be calculated, for any spatial configuration of successive duct legs. The approximations made in the orders-of-reflection method are particularly applicable to neutrons. However, the method, with some adaptation, has also been found to be applicable to gamma rays.

An extensive data base of neutron and gamma ray albedo data has been generated, and the orders-of-reflection method has been implemented in a computer code DCTDOS, which allows very rapid calculations of radiation penetration even through rather complex duct configurations. Trial calculations have indicated very good agreement with earlier calculations, mainly done at Oak Ridge, based on the more complicated alternative Monte Carlo method described above. The orders-of-reflection method may also be applied to shielding problems pertaining to medical radiation sources and to accelerators.

DOSIMETRY GROUP

Use of ionizing radiation is becoming ever more widespread in modern society. The exposure of humans can be purposive (medical) or incidental (occupational), but both require close control to ensure that the radiation is efficacious in the one case, and harmless in the other. Such control can only be achieved with reliable measurement. With the increased use and the improved knowledge of radiation effects, the need for more accurate measurement is constantly increasing. The measurement of ionizing radiation for the purpose of controlling a radiation effect falls in the field of radiation dosimetry. The Dosimetry Group has the responsibility for providing an up-to-date basis for reliable measurement of ionizing radiation, principally in medicine and radiation protection.

Division 533, Technical Activities (cont'd.)

This program involves: (1) establishment and maintenance of the national primary dosimetry standards; (2) dissemination of the units established by those standards by means of calibration services and measurement quality assurance programs; (3) research and development of measurement technology as necessary for any part of the program; and (4) participation in the relevant national and international activities of the community of radiation users.

X-ray and γ-ray Calibration and Measurement Assurance Services

Calibration services for x-ray and γ-ray measuring instruments were temporarily suspended during the year to permit installation of a new 300-kV x-ray generator. Consequently the calibration load was about half of last year's load. The reimbursable income for the 202 tests performed was $84,000. Principal users were medical institutions and nuclear power establishments.

The opportunity was taken during the x-ray generator down-time to reassess NBS x-ray beam calibration qualities. Of the 21 beam qualities previously offered, five were discontinued, and 16 new qualities were added. Thus 32 x-ray beam qualities are now offered. The present set of x-ray beam calibration qualities: (1) covers a wider range of generating potentials than before; (2) is in close agreement with recommendations of the relevant ISO and IEC standards; (3) is in good agreement with practice in other national standards laboratories; and (4) provides three self-consistent families of beam qualities that allow interpolation between instrument calibration factors. Establishing the new qualities required considerable effort in determining appropriate beam filtration and in measuring attenuation parameters to provide adequate beam characterization.

The 300-kV x-ray generator, reported one year ago as having just been delivered, has been installed, tested, and is now fully operational. Because the x-ray generator has a very stable and reproducible x-ray output, and computer control provides rapid and accurate setting of x-ray tube potential and current, the efficiency of the x-ray instrument calibration service has been appreciably improved.

The DEC computer used in conjunction with the x-ray calibration range data-acquisition system has been upgraded from 1103 to 1123, to provide increased speed and memory. The necessary programs have been written and calibration data acquisition and computation now operate using the new system.

A Hewlett Packard 9836 computer has been obtained and installed in a mobile calibration console. The console incorporates all measurement equipment required for radiation instrument calibrations. The HP 9836 works in conjunction with an HP 3497 data-acquisition system. The new

system releases the HP 9826 console, previously used only for gamma-ray instrument calibrations, for use also in the beta-particle source calibration program.

The measurement assurance program for secondary calibration laboratories was necessarily interrupted by the calibration shut-down due to installation of the new x-ray generator. The program continues, and at the time of writing instruments were being prepared for both therapy-level and protection-level measurement assurance tests.

The Navy TLD measurement assurance program continues. The program is sponsored by the Naval Electronics System Command, and involves preparation by NBS of sealed boxes of 15 TL dosimeters, 12 of which have been given known exposures to ^{137}Cs gamma rays. The boxes are dispatched to designated Naval units for readout, the results of which are returned to NBS for comparison with the NBS exposures. TL readers that indicate exposures differing from the NBS exposure by more than ±10 percent are repaired and recalibrated. About 230 such boxes, containing 2760 exposed dosimeters, were dispatched during FY83.

The ^{125}I NBS standards developed during the previous fiscal year have been put to use. Calibrations have been performed for all three types of ^{125}I brachytherapy sources, and these calibrated seeds are now being used as local standards by the manufacturer, the 3M Company.

High-Energy Electron and Photon Measurement Assurance Services

Because the times for the biannual Fricke chemical dosimetry service were changed, only one complete test fell within FY83. Currently 55 groups engaged primarily in radiation therapy are applicants for this service, some participating only once a year but most desiring biannual participation.

Two pilot tests were carried out to compare measurement assurance for radiation therapy beams by LiF TLDs with that by Fricke dosimeters. The TLDs require a dose of only 2 Gy (200 rad) compared with 50 Gy (5000 rad) for the Fricke dosimeters, give greater spatial resolution, and have lower shipping costs. The pilot studies, carried out with 25 participating groups, confirmed that a reliable measurement assurance service with LiF TLDs is feasible, for both high-energy electrons and photons. However, at present the TLD service is more labor-intensive than the Fricke dosimetry service.

Standard Beta Particle Fields

The beta-particle sources (^{147}Pm, ^{204}Tl, and $^{90}Sr+^{90}Y$) and the extrapolation chamber designed by the PTB and constructed in Germany, arrived during the early part of the fiscal year. The extrapolation chamber has

been used to study the variation of absorbed dose with distance from the source, the variation within the plane of measurement, and the dependence on air density between source and chamber. The ^{90}Sr and ^{204}Tl sources were found to be well behaved, with only minimal variations, but the behavior of the lower-energy ^{147}Pm source was found to be much more dependent on experimental conditions. The dose rates from the sources have been measured and compared with values supplied by PTB. The agreement with the PTB measurements is about 1 percent for ^{90}Sr and ^{204}Tl, and about 3 percent for ^{147}Pm. The sources have been used to calibrate several portable dosimeters and a series of film badges, in terms of water absorbed dose.

Standard Monoenergetic Electron Beams

Work continued on the development and characterization of monoenergetic electron beams for the calibration of instruments primarily used in radiation protection applications. Intensities in the scanned beams at suitable distances from the exit windows of the 500-keV and the 4-MeV electron accelerators were found to vary by less than 10 percent over areas between about 9 cm and 20 cm in diameter, an adequate degree of uniformity for most protection instruments. Preliminary air dose-rate measurements were made with the extrapolation chamber at electron energies between 100 and 400 keV. These measurements will be repeated in FY84 and extended to the energy range from about 1.5 to 3.5 MeV.

Extension of Instrument Calibration Capability to 6.5-MeV Photons

An approximately 6.5-MeV photon beam is obtained from the $^{19}F(p,\alpha\gamma)^{16}O$ reaction using 2-MeV protons produced in the positive-ion Van de Graaff generator using a thick CaF_2 target. Experiments to characterize the beam have been essentially completed. Pulse-height distributions were measured with an intrinsic Ge detector and a NaI(Tl) detector whose response functions are known. Both detectors were calibrated with a ^{60}Co gamma-ray source. The efficiency function of the Ge detector was computed and a method was devised for arriving at the beam spectrum utilizing the measured pulse-height distributions of the two detectors. Water absorbed dose rate was determined with LiF TLD samples in an acrylic phantom. The TLD system was calibrated with ^{60}Co gamma radiation, which has been shown to give essentially the same TL response as x rays produced at generating potentials up to about 18 MV. During FY84 the beam will be unfolded and an attempt will be made to arrive at water absorbed dose rate from the spectrum, to compare with the TLD measurements. This work was performed jointly by the Radiation Physics and the Nuclear Radiation Divisions. It is expected that the salient features of the results will be incorporated in an international standard being developed under the auspices of ISO/TC 85/SC 2/WG 2.

Calibration of Radiation Protection Instrumentation

The scheduled evaluation for the NRC of the Panasonic TLD system in accordance with the criteria of ANSI N545-1975 has been completed and extended to include, among other studies, a calibration of the TLDs in the newly established standard beta-particle beams. The system is now being used by the NRC for environmental dosimetry.

Six types of survey meters that had been calibrated earlier with x-ray beams of conventional energy and with ^{137}Cs and ^{60}Co gamma-ray beams were calibrated in the beta-particle beams and in the 6.5-MeV photon beam.

During FY84 one or more types of survey meters will be used to study the feasibility of obtaining instrument response to beta particles from the instrument response function measured with essentially monoenergetic electrons by folding the response function into the beta-particle spectrum.

Absorbed-dose Calorimetry

Successful investigations of two new ideas in absorbed-dose calorimetry were carried out in FY83. The first is the polystyrene-water calorimeter. Absorbed-dose measurements are made at a point in sandwiched discs of polystyrene submerged in water. Using cobalt-60 radiation, and calculating a conversion factor to give water absorbed dose, the results give further evidence of an exothermic radiation effect in water of about 3 to 4 percent. The dozen or so water calorimeters that have been constructed (based on the NBS design) can be readily converted to polystyrene-water calorimeters, by simply sandwiching the thermistors between two thin slabs of polystyrene. Plans are being made to extend this principle to other materials than polystyrene, in order to improve the NBS standard of water absorbed dose.

The second new idea is the temperature-drift balancer. Temperature drifts are one of the most troublesome features of calorimetry. While reducing drifts by making temperature adjustments within the calorimeter is always good practice, this new idea offers an additional approach. The electrical signals caused by small remaining internal temperature gradients are instantly reduced by merely adjusting a resistance-capacitance circuit that causes a drift in electrical signal opposite to that produced by temperature gradients. The temperature-drift balancer was first used with the polystyrene-water calorimeter, and has proven to be a simple and effective device that improves the accuracy of the measurement. It could become a standard feature of many calorimeter bridges.

Experiments have been carried out with a calorimeter designed to study the exothermic radiation effect in water. An enclosed beaker con-

taining distilled water and a sensing thermistor is submerged in a larger volume of water that is thermally isolated. Measurements in the cobalt-60 beam have shown an initial difference in water absorbed dose between water saturated with oxygen or with hydrogen, but the difference disappears after some irradiation of the water. Measurements are being continued varying the conditions, including the purity of the saturating gases, in order to test the theory that the exothermic effect will disappear in the absence of oxygen and the presence of very pure hydrogen.

Absorbed-dose Measurement Techniques

As part of an investigation into improved techniques for absorbed-dose measurement for high-energy radiations, comparisons have been made between several kinds of radiation detectors, using the NBS standard ^{60}Co beam. Liquid-filled ionization chambers, air-filled ionization chambers, and a graphite calorimeter have been compared, with the cooperation of visiting scientists from Sweden and Hungary. Preliminary results indicate that the liquid-filled chamber will have significant advantages over air-filled chambers, and may function as a superior transfer instrument for absorbed-dose calibration. The work will continue using higher energy beams and other detectors.

X-RAY PHYSICS GROUP

The X-ray Physics Group performs measurements and standards research that affect the utilization of ionizing radiation in technological applications, including medical and industrial radiology, radiation hardness testing, radiation processing, radiation sterilization, and radiation effects on materials and biologically active molecules.

High Dose Gamma-Ray Dosimetry

Previously established radiation calibration and test services have been in great demand by over 100 industrial and other agency users. The test services consist of irradiating customer-supplied dosimeters or samples with Co-60 gamma-rays to a specified absorbed dose in the range 10^3 to 10^8 rads. The standard service to radiation processing users has grown considerably especially in the area of radiation sterilization of medical supplies. Some companies have needed up to 20 calibrations during the five-year listing of this service and require regular calibration of dosimeters as a means of process quality control to ensure safe release of medical products to the consumer.

These high-dose services to the Nation were broadened still further during the past year, to include users engaged in electron-beam radiation processing applications and radiation effects on materials (e.g. reactor components, electronic components, duct gaskets, and sealants). These services have provided calibration of Co-60 irradiators and electron beam

accelerators used in the testing of electron devices and electronic systems employed in the missile systems of both DoD and NASA as well as other systems used by national laboratories such as Sandia, Los Alamos, Lawrence Livermore Labs., Brookhaven National Laboratory, and Battelle NW. In addition, efforts continue on the determination of complex photon spectra in various multilayer materials irradiated by Co-60 and flash x-ray machines, and the effects of these spectra on dose interpretations in multilayer semiconductor devices.

The usefulness of these services to the fast-growing US radiation processing industry is illustrated in the specifications for dosimetry measurements traceability to NBS for the release of sterilized medical products (see Proposed Standard for Radiation Sterilization of the Trade Association, Association for the Advancement of Medical Instrumentation dated April, 1983. New proposed rule making by the FDA with the Federal Register also calls for radiation dosimetry standardization through NBS for food preservation by ionizing radiation.

In support of the calibration program, new dosimeter systems are developed to serve as transfer standards. Some important new applications of some of the radiochromic dosimetry systems previously developed in this program have been announced during the past year.

(1) New fibre optics systems based upon the NBS optical waveguide dosimeter have become commercially available and are now used for food irradiation quality control.

(2) Radiochromic films are being used for dose distribution mapping in clinical radiology, in particular, for measuring dose distributions from β-ray and γ-ray sources used as eye applicators in cancer therapy.

(3) Radiochromic dosimeters are being used in the radiobiological studies of cellular survival studies, haematology, radiation genetics studies, irradiated animal mortality investigations, and insect disinfestations of fruits (medfly and oriental fly treatments).

(4) In the development of very large scale integrated (VSLI) circuits at IBM, masks for x-ray and UV lithography are provided by thin coated films of radiochromic dyes.

(5) Radiochromic dosimeters are being used for mapping isodose contours and determining absolute absorbed dose rates in large radionuclide sources and spent fuel rod sources.

Activity in the area of international standards for high-dose dosimetry was also strong, expecially with respect to committee involvement. For example, W. L. McLaughlin is chairing the Report Committee of the International Commission in Radiation Measurements and

Units on the topic "Dosimetry for Radiation Processing". We have also participated in an international intercomparison of the performance of high-dose calorimeters designed last year for standardizing industrial and medical electron beam doses from high flux density 10 MeV accelerators. Other participants in the collaboration are the UK National Physical Laboratory, the West German Physicalisch Technische Bundesanstalt, and the Danish Risø National Laboratory.

Three projects supported by other agencies focus on radiation dosimetry at high doses:

(1) the design of dosimetry and spectral sensitivity studies for radiation effects on electronic devices and components (DNA-DoD);

(2) the development of new dosimetry systems for use in radiation emergencies (FEMA). This work investigates the response characteristics, kinetics, and mechanisms of some radiochromic dyes in order to select a stable, sensitive, and reproducible chemical system, which can be developed into a suitable fiber optics dosimeter for use in civil defense and military operations;

(3) the study of the response characteristics of various high-dose chemical and solid-state dosimeters for weapons testing, especially absorbed dose rate effects and temperature effects (DoE).

Radiology and Radiographic Standards

Measurement methods are being developed to evaluate the low contrast sensitivity of screen-film imaging systems. These studies will help to provide a standard x-ray imaging system that can be used as a basis for comparing the performance of different types of x-ray imaging systems used, for example, in medical radiology applications. In addition, a real time radiography system based on a state-of-the-art processor is being developed to investigate the measurement problems associated with real-time imaging, an increasingly important technique in industrial evaluation of materials, components, and systems.

In cooperation with the National Institute of Dental Research and the U.S. Army Institute of Dental Research, we have initiated a program to develop non-film, photoelectronic imaging systems for dental applications. These systems will be able to utilize digital image processing techniques and can be expected to provide new diagnostic information for the dentist. In the development of this program the key elements required for real time dental x-ray systems are either a real time intra-oral x-ray image detector or an intra-oral, multiposition x-ray source. Each of these respective elements are presently under development in collaborative programs at American Optical, Inc. and Ridge, Inc., respectively. The

final design of a real time dental x-ray system will depend on the results obtained in the development of the above key elements.

Radiographic standards and standard procedures are developed especially for use in quality control of high quality industrial radiological systems. An important part of this program is to analyze existing standards that measure image quality, and to develop an image quality indicator that can be used as an international standard. Standards are also provided for assessing x-ray equivalent penetrameter sensitivity.

The ASTM standard for evaluating image quality response of industrial x-ray film for 200 keV x-ray sources has been published. An NBS SRM for use with this standard has been made available to industry. Studies are in progress to extend this standard to high energy x-ray sources such as 5 to 15 MeV linear accelerators. Round robin testing in cooperation with industrial laboratories is continuing on these high energy tests. In other ASTM activities, we have authored several sections of the tutorial document on real time radiography, which is now undergoing main ASTM society ballot.

In a related quality assurance program for the Department of Defense, we are the principal consultant for evaluating the procedures employed by industry to inspect the propulsion units of large diameter missiles with high energy, real-time radiological systems.

Measurements are underway to develop standard quasi-monoenergetic x-ray beams. In the energy region from 50 keV to 4 MeV the beams will be used to measure the energy dependent response of various types of medical and industrial x-ray imaging systems. In the 100-300 keV range the beams will be used for the purpose of evaluating the image information transfer properties of industrial radiographic systems. Initial efforts will focus on the evaluation of the transfer properties of the fluorescent, metallic, and fluoro-metallic screens currently in use.

Ionizing Radiation Effects

The ionizing radiation effects program has been concerned with both instrumentation and chemical studies. In the area of instrumentation we have the following results:

(1) The Febetron 705 pulse radiolysis system has been fully developed for computerized and synchronous use of a kinetic spectrophotometric system, with time resolution of 0.1 μs, and an optical multichannel analyzer, with time resolution of 1 μs. This arrangement allows instantaneous readout of the absorption spectrum of short-lived transients (free radicals) and the reaction rate constants of the associated kinetics in one pulse. Structured absorption spectra can be

measured now with high resolution and increased accuracy and in much less time than by the standard point by point approach.

(2) A newly developed mass selective detector by Hewlett Packard was coupled to the existing gas chromatography (GC) giving a full GC/MS facility which can be used simultaneously as a GC and GC/MS instruments.

In chemical studies, we have the following results:

(1) Investigations of radiation induced crosslinks between amino acids in homo-oligo peptides in aqueous solutions have been extended to tyrosine (Tyr). The Tyr-Tyr dimers were isolated and characterized. It was found that the crosslinks are formed via phenoxy radicals and are of two types: (a) C-C crosslinks and (b) C-O-C crosslinks.

(2) Radiation-induced crosslinks between thymine (T), a DNA base, and uracil (U), an RNA base, were found to take place with a high yield (~ 50% of all primary water radicals yield crosslinks). The T-T and U-U dimers have not been observed in irradiated DNA and RNA so far. The newly develped analytical methodology can now be used for search of these dimers in irradiated DNA.

(3) Preliminary results indicate radiation induced crosslinks between thymine and phenylalanine, T-Phe; and between thymine and tyrosine, T-Tyr. These results are relevant to radiation induced damage to DNA where crosslinks between DNA and proteins are observed but the nature and the mechanism of formation is not known.

(4) Pulse radiolysis of cumine (Cu) and derivatives provided information regarding the reactivity of the alkoxy radical, CuO$\cdot$ This information is relevant to autoxidation processes in fats (food chemistry) and membranes (biochemistry).

(5) Absolute absorbances (ε, $M^{-1}cm^{-1}$) of various aroxy radicals, ArO$\cdot$, have been measured by pulse radiolysis using $CO_3^{\cdot-}$ radicals. These radicals were found to exclusively oxidize dissociated hydroxy derivatives of aromatic compounds at high rates ($k \sim 10^9 M^{-1}s^{-1}$), in contrast to some other methods in the literature.

This work has been done in collaboration with the Chemical Thermodynamics Division of the NBS Center for Chemical Physics.

FAR UV PHYSICS GROUP

The Far UV Physics Group is characterized by research on the metrology of short wavelength, far ultraviolet radiation (radiometry) and by research on measurement methods utilizing far ultraviolet radiation. Use is made of the NBS synchrotron ultraviolet radiation facility (SURF), as well as other synchrotron radiation facilities (Orsay, Brookhaven), to

investigate the fundamental interactions of photons with atoms and molecules and to establish a basis for spectrometer sensitivity measurements in the far ultraviolet. Independent of SURF, laboratory research is carried out to further develop a detector standards calibration service in the vacuum ultraviolet, to study multi-photon effects in laser-excited and laser-ionized materials, and to investigate fundamental fragmentation processes in organic molecules in collaboration with the NBS Chemical Kinetics Division.

SURF Improvements

Efforts are in progress to increase the output brightness of the SURF storage ring. These efforts have already resulted in storing record currents in excess of 60 mA at full energy. This represents about a factor 5 improvement in beam brightness. Other mechanical and electrical modifications are expected to further increase the stored current and enhance the experimental programs dependent upon SURF.

Angle Resolved Photoelectron Molecular Spectroscopy

The highlights of the past year have been the the publication of results obtained with our existing variable wavelength, angle-resolved, photoelectron spectrometer and the inauguration of an entirely new apparatus for use at SURF to continue these studies.

Studies of SF_6, C_2H_2, C_2N_2 and CO_2 were completed and published. The study of SF_6 resolved discrepancies in the literature concerning the term designation scheme for the valence levels of SF_6. Additionally, the effects of a predicted shape resonance were measured and compared to theory. The results were in general agreement with theory but indicated that there is a great deal of interchannel coupling unaccounted for in the theory.

The other works published were studies of the effects of autoionization on molecular branching ratios and asymmetry parameters. We have found large departures from Franck-Condon predictions of relative vibrational intensity over an energy range of many electron volts in the case of shape resonances. Autoionization can also lead to transitions within a vibrational progression that violate Franck-Condon predictions. For example, in the case of acetylene, Franck-Condon considerations would predict that only a few vibrational modes would be excited. It was found that in the ground state of the ion, many vibrational modes were being excited. Furthermore, in the region of strong autoionization, bending modes of the ion were excited. Such modes are not usually excited in a linear molecule due to symmetry constraints.

An entirely new photoelectron spectrometer and vacuum chamber has been constructed and installed on SURF to study atomic and molecular

photoionization processes. The instrument features two 4-inch mean-radius hemispherical electron energy analyzers, one of which is rotatable. The analyzers are capable of achieving an energy resolution of 9 meV. The sample inlet system has both effusive jets and a supersonic nozzle system. The chamber is triply magnetically shielded so that a residual field of less than 500 microgauss can be maintained.

A newly constructed grazing-incidence monochromator will provide high flux dispersed radiation down to about 10 nm. This will permit the study of inner valence shell and core level excitations on the new ultrahigh vacuum photoelectron spectrometer using both triply differential photoelectron and threshold photoelectron-photoion techniques. Little is known about fragmentation kinetics, total and partial ionization cross sections, and angular distributions in this high energy region. Initial studies will be concerned with molecular systems such as CO_2, C_2H_2, and C_3H_4 isomers.

This work is a collaboration among SURF staff, SURF visiting scientists, the NBS Chemical Kinetics Division, and the Argonne National Laboratory.

Photoelectron-Photoion Coincidence

Detailed fragmentation studies of iodobenzene resulted in precision measurements for the heat of formation and the rate energy curve. The data in the literature were reviewed and comparisons and evaluations made. As a result, the rate energy dependence for iodobenzene was proposed as an absolute benchmark for ion fragmentation rate measurements.

A study of dimethyl ether from ionization onset to 20 eV has been completed and submitted for publication. The study among other things clarifies the reaction paths for the formation of HCO^+ and H_2COH^+.

Work has been completed in a study of 2-hexanol. This study, in collaboration with Brooklyn Polytechnic Institute, is one in which the breakdown curve (relative ion yield vs. internal energy) is used to address problems in sterochemistry. Work to be pursued in FY 84 includes finishing the study of diazines and further work on large ring compounds.

The work is done in collaboration with the NBS Chemical Kinetics Division.

Polarized Fluorescence

A series of studies has been carried out at SURF using the polarization of fluorescence as a probe of molecular autoionization. These studies showed that the polarization of fluorescence from excited-

state molecular photoions provides a direct probe of the photoionization dynamics and the symmetry signatures of autoionizing resonances.

This year we began to modify the experiment at SURF to more fully exploit the high flux capabilities at SURF and the experimental opportunities. The following capabilities will be available: (1) ability to study polarized fluorescence from molecular gases; (2) application of electric fields to study threshold shifts at photon energies above the ionization threshold; and (3) ability to study wavelength dispersed fluorescence from molecular systems. Initial measurements are planned for simple molecular systems like C_2H_2, CH_4, and H_2O during FY84.

This work is a collaboration between SURF staff, SURF visiting scientists, and Boston University.

Surface Science

We have supported at SURF the establishment by the NBS Surface Science Division of an experimental capability to study adsorbed molecules on surfaces. These studies use several SURF monochromators and an ultrahigh vacuum system. Photon stimulated desorption (PSD) of ions is being studied to understand the desorption mechanisms and energetics. Variable wavelength ultraviolet photoemission spectroscopy is also utilized to characterize the surface species formed upon adsorption of the molecules on a clean metal substrate. Ion desorption mechanisms for ionically and covalently bonded adsorbates are investigated.

During the last year, staff from the Surface Science Division studied the oxidation of the Ti(001) surface, and have made the first observation of interatomic resonant photoemission in an oxide. They have also found a direct relationship between resonant photoemission and the mechanism of photon stimulated desorption in oxidized chromium. In addition, evidence for a new ion desorption mechanism in PSD of H^+ ions from OH adsorbed on Ti, Cr, and Cu surfaces has been seen.

New High Energy Capability at SURF

The success of our programs utilizing the high-flux normal-incidence monochromator has led us to proceed with the extension of our capabilities to shorter wavelengths. We have designed and procured all of the components of a new high-throughput grazing-incidence monochromator for SURF-II. Only the delay in delivery of the gratings has delayed completion of the monochromator. This instrument will use SURF's orbiting electron beam as its entrance slit--thus taking advantage of SURF's small vertical beam size and high brightness. The grating will be placed as close as possible to the orbit and will intercept 51 mrad of horizontal orbit and (for wavelengths below 500Å) the full vertical radiation output. Using three independently optimized gratings, the monochromator will cover

the 30-600Å spectral range. Its resolution is expected to be about 0.6 eV at full intensity. The new monochromator will allow us to extend our programs in surface science, ultraviolet photoemission spectroscopy, and gas-phase angle-resolved photoelectron spectroscopy to higher photon energies. It should be operational in Fall 1983.

Very High Resolution Spectroscopy at SURF

The National Science Foundation is partially supporting the installation of a very high resolution 6.65 m normal-incidence spectrometer at SURF. The goal of this project is to do research on the dynamics of energy transfer in atoms and molecules with an energy resolution that is a factor of 10 better than at any other synchrotron radiation facility in the world. The instrument will cover the 300-2000Å spectral range with resolving powers of $1\text{-}2\times10^5$. In addition, it will provide highly polarized radiation (polarization >98% for λ>600Å). A new beam line will be constructed for this instrument. The concrete base for the spectrometer has already been poured. The instrument should be operational by summer 1984. This project is a collaboration between SURF staff, the University of Maryland, and the Naval Research Laboratory. Expected NBS users are from the Centers of Radiation Research, Basic Standards, and Chemical Physics. Outside users expressing interest in using this facility are from NRL, U. MD, ORNL, Yale, Argonne, SUNY Binghamton, Ohio State, U. Nebraska, Harvard College Observatory, and Imperial College.

Electric Field Effects

The absorption cross section of H_2 has been measured in the spectral region 775-824Å and the effects of electric fields up to 22 kV/cm on the cross sections have been investigated. The apparent cross section is found to be increased in the neighborhood of optically allowed transitions to $np\sigma\ ^1\Sigma_u^+$ and $np\pi\ ^1\Pi_u$ states with n=4-7. We attribute this increase in absorption to field mixing with nearby optically forbidden states. Additional experimental studies await the installation of the 6.65 m high-resolution spectrometer at SURF. In the meantime, an attempt is being made to determine the absolute cross section of atomic barium from threshold (2378Å) to 1150Å. A 0.2 m monochromator has been installed on a SURF beam line and a double heat pipe has been mounted in its exit beam. Preliminary relative cross section have been obtained for part of the spectral range. This work is a collaboration among SURF staff, a SURF visiting scientist, and the NBS Center for Basic Standards.

Laser Prepared States

Limited resources have delayed the implementation of a new class of experments at SURF which utilize both lasers and synchrotron radiation. In the interim it has been possible to continue a collaborative research

program at LURE in Orsay, France. This experiment consists of a toroidal grating monochromator hooked up to the French storage ring, ACO, in Orsay, and a ring dye laser of about one watt power stabilized to approximately 20 MHz bandwidth. The output of the monochromator and the laser intersect at right angles in the sensitive volume of a cylindrical mirror electron spectrometer (CMA). An effusive beam of metal vapor intersects these photon beams and the photoelectrons produced in the interaction zone are detected by the CMA. This year we have been able to accomplish several major goals in this program.

In the following two experiments, synchrotron radiation was used to determine the density of excited and ground state atoms, and the laser was used to produce the excited 3p states.

1) We observed for the first time low energy electrons produced directly by associative ionization, defined by the reaction $Na(3p) + Na(3p) \rightarrow Na_2^+ + e^-$, and by energy pooling collisions, defined by the reaction $Na(3p) + Na(3p) \rightarrow Na(3s) + Na(nl)$, where nl defines some nearly resonant Rydberg level, and where another collision of Na(3p) with Na(nl) produces ionization.

2) With improved spectrometer resolution we were able to discern structure in the associative ionization process. The photoelectron peaks are separated by 0.13 eV and are interpreted as a resonant collision producing zero energy electrons and vibrationally excited Na_2^+ and a collision between the excited atoms of low kinetic energy producing Na_2^+ in the lowest vibrational level.

In the next experiments, synchrotron radiation was employed to produce the photoionization from laser excited atoms.

3) We measured the oscillator strength of autoionizing resonances in core excitations of the type $2p^6 3p \rightarrow 2p^5(^2P_{3/2,1/2})\ 3s3p(^{1,3}P)$.

4) We are in the process of measuring the partial photoionization cross section from the 5d metastable state in barium vapor.

In addition to scientists from LURE, scientists from the Laboratory Aimé Cotton, the Service de Physique des Atoms et des Surfaces, CEN/Saclay, and SUNY-Stony Brook are involved.

Soft X-Ray Emission Spectroscopy at NSLS

A collaboration has been initiated among NBS, the University of Tennessee, and Oak Ridge National Laboratory to use the technique of soft x-ray emission spectroscopy to study compounds that are easily damaged by

electron beam irradiation. The hardware for the experiment will be installed at the NSLS at Brookhaven National Laboratory probably during the summer of 1984. Initial studies will be the emission spectra of systems of interest to materials scientists. It has been proposed to study boundaries and interfaces in silicon compounds and other systems of importance in the fabrication of semiconductor devices.

Photoabsorption Studies of Laser Ionized Species

Construction is nearly complete on a new VUV spectrometer featuring photoelectric recording of spectra with a state-of-the-art VUV optical multichannel analyzer. This system, will be used in our studies of VUV absorption from laser-excited and laser-ionized atoms. The improved time resolution and sensitivity provided by the new system will allow a greater number of such species to be studied with a resulting advancement in our understanding of how increased nuclear attraction and long-range coulomb forces affect atomic and molecular orbitals in regions near orbital collapse.

This work is being done in collaboration with the Atomic and Plasma Radiation Division which has developed a laser-produced plasma to be used in the absorption measurements as an intense background source of EUV radiation.

Ultrasensitive Trace Analysis

In a new effort, begun in collaboration with the Mass Spectrometry Group in the Center for Analytical Chemistry and the Atomic and Plasma Radiation Division, we have studied the use of resonant multiphoton ionization as a technique for ultrahigh selectivity and sensitivity in isotope trace analysis. Theoretical calculations show that by combining the isotopic selectivity available in laser multiphoton ionization with that provided by a conventional mass spectrometer, one may achieve isotopic abundance sensitivities in excess of $1:10^{14}$. Such sensitivities can presently be attained only in selected cases by high-energy accelerator mass spectrometry. Experimental work has been initiated to demonstrate this technique in such cases as $^{6}Li:^{7}Li$ and $^{88}Sr:^{90}Sr$.

SURF Radiometric Intercomparisons

Last fall an intercomparison was carried out between the silicon photodiode, the tungsten lamp, and the synchrotron radiation irradiance scales in collaboration with the Radiometric Physis Division. Agreement between the SURF-based irradiance scale and the lamp-based scale was to within the experimental error associated with the sources. The comparison with the silicon detector-based scale differed by about 2%. Part of the discrepancy was thought to be due to the filter-diode transfer device used in the comparison. The source of this discrepancy is presently under

investigation by using several techniques. One technique is use an integrating sphere to eliminate possible interference or inhomogeneity effects associated with the filter. Another is to recompare the silicon detector-based scale and the lamp-based scale using monochromator measurement methods. Another intercomparison with SURF will be scheduled after these tests, probably during the spring of 1984.

Spectrometer Calibrations

SURF II has been applied as a primary standard of spectral irradiance for the calibration of spectrometer and photometer systems in the spectral region 4-400 nm. These calibrations are primarily in support of the programs of NASA and the Department of Energy. We are providing periodic calibrations of the NRL Solar Ultraviolet Spectral Irradiance Monitor (SUSIM) at SURF both before and after its flights on the Space Shuttle. Recalibration is expected to occur many times in the next decade. Other calibrations this year have been made for NASA/Goddard, two groups from NRL, Princeton Plasma Physics Laboratory, North Carolina State Univ., U. Colorado-LASP, and two groups from Johns Hopkins University. The facility is solidly scheduled through most of next year.

Transfer Standard Detectors

The far UV radiometry effort at NBS includes the calibration and supply of transfer standard photodiode detectors in the vacuum ultraviolet. During FY 83, 22 outgoing calibrations were performed, serving such disciplines as aeronomy, astronomy, and plasma, solar, and solid state physics, and furnishing the radiometric basis in the far UV for other standards laboratories. We also collaborated with Los Alamos National Laboratory in the characterization of photocathode materials used for laser fusion diagnostics and with the Naval Research Laboratory to characterize spatially resolved, low level XUV detectors.

The construction of a new and improved detector calibration system at SURF is nearing completion. It includes a new custom monochromator of our design. This monochromator is expected to have a factor of five increase in throughput and higher resolution (0.2Å) than the one it replaces. It will permit the interchange of two optimized gratings without breaking vacuum. We expect this system to be operational in FY 84.

ELECTRON PHYSICS GROUP

The Electron Physics Group has ongoing research efforts in electron collision physics including electron-surface interactions, surface magnetism, electron interaction theory, electron polarization phenomena, electron-atom and electron-molecule collisions, and electron optics and

instrumentation. The wide applicability of electron based measurement technologies allows us to contribute to the solution of many diverse scientific and technological problems.

Surface Magnetism and Electron Diffraction

Our work on the scattering of spin polarized electrons from surfaces continues with a high level of activity. As a consequence of our advancement of polarized electron source and detector technology, almost every experiment we do is breaking new ground and being done for the first time. This is particularly true of our most recent work on surface magnetism. By using our polarized electron gun to observe the effects of the exchange interaction, we are able to sense the local net alignment of spins in the surface of a ferromagnet. The short mean free paths for elastically scattered electrons make this technique extreme surface-sensitive unlike neutron scattering.

During the past year we have concentrated our study of surface magnetism on the use of the very recently developed technique of inverse photoemission spectroscopy. The direct process, i.e., spin polarized, angle resolved, and energy resolved photoemission, is normally measured using a high intensity synchrotron radiation source, a UV monochromator, an electron energy analyzer, and a spin polarization detector. We have demonstrated that it is possible to do the inverse experiment, where spin polarized electrons at a specific energy and angle of incidence are scattered from a target and the UV photons at a selected wavelength are detected. With a nickel (110) single crystal target we demonstrated that only minority spin electrons are absorbed into unfilled d-bands and give rise to UV photons. This type of experiment allows one to observe the spin polarized unfilled states near the Fermi level. By varying the angle of incidence we also measured the dispersion of these bands.

We continued our work in inverse photoemission by attempting to see effects caused when atoms and molecules are absorbed onto a ferromagnetic surface. We are interested in observing how the bonding of the absorbate to a surface affects the unfilled d-band of the substrate and how the magnetic character of the substrate changes. It is also possibile that a molecular absorbate will have its own unfilled states which may be observable with this technique. Further, it would be interesting to know whether these unfilled molecular states would be polarized by the adjacent magnetic substrate. We have modified the experiment to improve the signal strength, the reliability of the UV photon detector, and our ability to absorb gases on clean ferromagnetic surfaces under highly controlled conditions. Our first measurement were of O_2 chemisorption on nickel(110). Several distinct structures in the O_2/Ni(110) bonding

have been observed. At low coverages a (2X1) LEED structure appears in low energy electron defraction measurements. At higher exposure a (3X1) LEED structure appears. At very high coverages a surface oxide forms. The differences between the clean, (2X1), and (3X1) structures are subtle but decreases in intensity and polarization of the d-band peak at near the Fermi energy are observable.

We expect to complete our study of absorbates during the next year. Also planned for the next year, is a study of the inverse photoemission from a GaAs substrate. This is the process symmetric to the GaAs photoemission which has proven very successful for the production of polarized electrons. The inverse process may lead to a way of optically measuring the polarization of a free electron beam.

We have completed for the present time our work on polarized electron scattering on ferromagnetic glasses. We studied surface hysteresis curves and the temperature dependence of the surface magnetization. One of the questions answered by this work was whether the Born approximation was a sufficiently valid description of the elastic scattering process. We found it not to be adequate. We also studied inelastic scattering, and in particular, secondary electron production. There is no theory developed adequately enough to make meaningful comparisons with our results. As a result we have begun some collaborative work in this area with the Surface Science Division.

As a result of our measurement last year of the spin polarization of secondary electrons emitted from ferromagnetic materials, we believe it would be possible to measure the magnetization of surfaces with the spatial resolution of a scanning electron microscope (SEM). This is in the range 100-1,000 Å. We are fortunate at NBS to have time available on a Vacuum Generators HB50A ultra-high vacuum SEM. Preliminary considerations indicate that a modification of the design of the secondary electron collector used in the Vacuum Generators instrument should allow us to collect the ejected polarized secondary electrons, pass them through an energy analyzer, and finally analyze their spin polarization. This would allow us to map the magnetization of the sample at high spatial resolution. Conventional SEM methods of observing magnetic domains are low in contrast and have a resolution limited to the domain size. We expect, by comparison, to be able to measure the change in magnetization across a domain or a sufficiently wide domain wall. During the past few months we have begun, in collaboration with the Optical- and Micro-Metrology Group of the National Engineering Laboratory, to design and construct the necessary additional equipment to attempt this measurement on the NBS ultra high vacuum electron microscope.

High Energy Resolution Electron Scattering.

We have begun to to revitalize our electron spectrometer system, through various mechanical and electrical changes, to permit an efficient study of well characterized surfaces under ultra high vacuum conditions. This involves the addition of a LEED and Auger system to characterize the surface and the requisite sample holders and manipulators to position the sample in the electron energy loss spectrometer.

We are also planning to extend our electron optics codes to include electron-electron repulsion in the design of electron monochromators and analyzers. This is made possible with the availability of very high speed vector computers. Generally such effects as space charge and anomalous energy broadening are neglected in ordinary computer codes but can limit the operation of electron energy monochromators. When complete, our new electron scattering apparatus will be capable of serving as a test bed for new designs developed through large scale computers simulations.

Electron-atom Collisions

We are investigating electron-atom scattering problem in an experiment where all the parameters are determined so that we can make the step from measuring cross sections to the more fundamental determination of quantum phases and amplitudes. We have constructed a crossed beam, polarized atom, polarized electron scattering apparatus where sodium atoms are polarized by optical pumping with a CW-dye laser. The electron beam comes from a GaAs polarized electron source. The use of a laser to optically orient the sodium beam also facilitates measurement of polarization of the beam via laser fluorescence or Faraday rotation measurements. It is also possible to use this laser to optically pump the sodium to an excited, optically oriented atomic state that could be studied by polarized electron scattering.

We have made extensive measurements over the last year of asymmetries associated with ionization by electron impact. The basic question is how the threshold law for ionization varies if the two exiting electrons are initially in a singlet or triplet state. This experiment should help decide between two contending theories for threshold ionization, Wannier theory and the coulomb-dipole theory. We are presently analyzing data and preparing several publications. Further data taken at very high energy resolution may be necessary to test for the existence of modulations in the asymmetry at very near threshold.

Scattering Theory

Dr. Penn spent most of the past year as the Program Director for Condensed Matter Theory at the National Science Foundation, but is still engaged in calculating the properties of small metal spheres.

Small metal spheres of radius 15-50 Å are of fundamental interest since they represent a state of matter that is intermediate between an atom and a solid. Because of their size and spherical geometry they exhibit an anomalously large optical absorption.

A theory was developed for the optical properties of small metal spheres that pays special attention to the role of the surface. Surface scattering can be important if the overall size of the sample becomes smaller than the ordinary mean free path characteristic of phonons and impurities. For many years it has been assumed that the optical properties of small spheres can be understood by means of a Drude dielectric function that incorporates a boundary scattering rate $1/\tau_s \approx v_F/R$ where v_F is the Fermi velocity and R is the sphere radius. We have calculated an effective scattering rate $1/\tau_s = fv_F$ where f is a function of the photon frequency. We find that the largest contribution to f is not boundary scattering but rather that f is determined by the electron density profile of the sphere. The boundary scattering is reduced an order of magnitude by screening effects. We find that f is strongly frequency dependent in contrast to the classical result for boundary scattering $1/\tau_s = v_F/R$. This finding ought to provide a crucial test of our theory.

We have applied a similar theory to the scattering of electrons from small metal spheres and find that the scattering is roughly an order of magnitude larger than that predicted by "classical" theories that do not incorporate the effects of non-local response of the surface electrons.

SPONSORED CONFERENCES

Division 533, Radiation Physics

W. R. Ott organized a Special Symposium on NBS Research held January 10 through 13, 1983, at NBS, Gaithersburg. This NBS-wide symposium provided a special opportunity for the NBS staff to learn more about the work of their NBS colleagues. Twenty-four invited talks were presented by staff from NML, NEL, and ICST.

INVITED TALKS

Division 533, Radiation Physics

Celotta, R. J., "Recent Advances in Electron Spin Polarization Measurements," US/JAPAN Seminar on Electron-Molecule Collisions and Photoionization Processes, Los Angeles, California, October 28, 1982.

Celotta, R. J., "Spin Polarization Phenomena in Surface Physics," Physics Department, Howard University, Washington, D.C., March 25, 1983.

Celotta, R. J., "Electron Polarization Detection," Symposium on Polarization and Correlation in Electron-Atom Collisions, Münster, Germany, July 25, 1983.

Cromer, C. L., "VUV Generation in Strontium," University of Virginia, Charlottesville, Virginia, April 13, 1983.

Dizdaroglu, M., "Isolation and Characterization of Radiolytic Products of Peptides," Department of Nutrition and Food, Massachusetts Institute of Technology, Cambridge, Massachusetts, October 8, 1982.

Ederer, D. L., "An Overview of Research at NBS Using Synchrotron Radiation at SURF-II", Conference on the Application of Accelerators in Research and Industry, North Texas State University, Denton, Texas, November 9, 1982.

Ederer, D. L., "Synchrotron Radiation and Applications," Department of Physics, North Carolina State University, Chapel Hill, North Carolina, February 7, 1983.

Ederer, D. L., "Photoionization from Laser-Excited States by Synchrotron Radiation, Joint Institute for Laboratory Astrophysics, University of Colorado, April 26, 1983.

Humphreys, J. C., "Principals of Calorimeter Design for Use in Electron Beams," Institute of Physics, Universidad Nacional Autonoma Mexico, Mexico, December 14, 1982.

Humphreys, J. C., "Factors Affecting the Accuracy of Calorimeter Measurements in Electron Beams," Institute of Physics, Universidad Nacional Autonoma Mexico, Mexico, December 15, 1982.

Humphreys, J. C., "Instrumentation for High-Dose Electron Beam Calorimeters," Institute of Physics, Universidad Nacional Autonoma Mexico, Mexico, December 17, 1983.

Division 533, Invited Talks (cont'd)

Kelley, M. H., "The Spin Asymmetry in Electron Impact Ionization," Symposium on Polarization and Correlation in Electron-Atom Collisions, Münster, Germany, July 26, 1983.

Loevinger, R., "The Principle of Parsimony: Applications in Radiation Dosimetry," Landauer Memorial Lecture, Joint Meeting of the California Local Sections of the Health Physics Society and the AAPM, Berkeley, California, November 1982.

Loevinger, R., Seltzer, S., and Heaton, T., "The Physics and Mathematics of Beta Particle Dosimetry for Radiation Protection, International Beta Dosimetry Symposium, Gaithersburg, Maryland, February 15, 1983.

Lucatorto, T. B., "Resonant Laser Excitation and Ionization of Dense Vapors: as Object of Study and as a New Tool for Atomic Physics", Milton S. Eisenhower Research Center, Johns Hopkins University, Laurel, Maryland, December 9, 1982.

Lucatorto, T. B., "Resonant Laser Excitation and Ionization of Dense Vapor: as Object of Study and a New Tool for Atomic Physics," Laser '82 Conference, New Orleans, Louisiana, December 14, 1982.

Lucatorto, T. B., "Vacuum Ultraviolet Absorption Studies on Excited Atoms and Ions", Physical Chemistry - Chemical Physics Seminar, University of Maryland, College Park, Maryland, March 30, 1983.

Madden, R. P., "An Overview of the OSA Annual Meeting," Optical Society of America, Tucson, Arizona, October 19, 1982.

Madden, R. P., "Harnessing Luminous Electrons for Science and Technology: The Story of Synchrotron Light," Presidential Lecturer to 9 local sections of the Optical Society of America: San Diego, California; Stanford, California; and Boulder, Colorado, February 10-17, 1983; Albuquerque, New Mexico; Tuscon, Arizona; Los Angeles, California; and Portland, Oregon, March 31-April 8, 1983; Melbourne, Florida and Huntsville, Alabama, May 8-12, 1983; and Los Alamos, New Mexico, June 28, 1983.

Madden, R. P., "Present Status and Background of NBS/NRL Brookhaven Project," Brookhaven Project Management Review, NBS, Gaithersburg, Maryland, June 13, 1983.

Madden, R. P., "SURF-II: An Absolute Source for VUV Radiometry", Third National Synchrotron Radiation Instrumentation Conference, Brookhaven National Laboratory, Upton, New York, September 13, 1983.

McLaughlin, W. L., "Dye Dosimetry," to Students and Technical Staff of Federal Emergency Management Agency Testing Facility at Old Navy Yard, Washington, D.C., December 21, 1982.

McLaughlin, W. L., "Radiochromic Measurement of Low-Energy X-Rays," IBM Research Center, Yorktown Heights, New York, April 12, 1983.

McLaughlin, W. L., "Dosimetry and Quality Control," Research & Development Associates for Military Food and Packaging Systems, Inc., 37th Annual Meeting, Norfolk, Virginia, April 13, 1983.

McLaughlin, W. L., "Fiber Optics Dosimetry," Federal Emergency Management Agency, L'Enfant Plaza, Washington, D.C., May 9, 1983.

McLaughlin, W. L., "Optichromic Dosimetry," Federal Emergency Management Agency, L'Enfant Plaza, Washington, D.C., May 25, 1983.

McLaughlin, W. L., "Dosimetry," Gordon Conference: The Direct Action of Ionizing Radiation on Macromolecules, Plymouth State College, Plymouth, New Hampshire, August 18, 1983.

McLaughlin, W. L., "Electron Beam Calorimeter," Becton - Dickinson Research, Research Triangle Park, North Carolina, August 25, 1983.

Neta, P., "Inter- and Intramolecular Electron Transfer Processes Studied by Pulse Radiolysis," 15th Latin American Chemical Congress, San Juan, Puerto Rico, October 28, 1982.

Parr, A. C., "Resonance Phenomena in Molecular Photoionization," Chemical Physics Institute, University of Oregon, Eugene, Oregon, January 5, 1983.

Parr, A. C., "Studies of Ion Fragmentation and Molecular Photoionization Using Photoelectron Spectroscopy," Joint Institute for Laboratory Astrophysics, University of Colorado, Boulder, Colorado, April 8, 1983.

Parr, A. C., "Photoelectron Spectroscopy in Recent Years at NBS," American Society for Mass Spectrometry, Boston, Massachusetts, May 10, 1983.

Parr, A. C., "The Determination of Gaseous Ion Thermochemistry Using Threshold Photoelectron Photoion Coincidence Spectroscopy", Workshop on Advanced Laser Technology for Chemical Measurements, Lawrence Livermore National Laboratory, Livermore, California, June 9, 1983.

Parr, A. C., "Angle Resolved Photoelectron Spectrometers," Third National Synchrotron Radiation Instrumentation Conference, Brookhaven National Laboratory, Upton, New York, September 13, 1983.

Pierce, D. T., "Electron Spin Polarization Probes for Surface Magnetism: Recent NBS Results," Physics Colloquium, Swiss Federal Institute of Technology, Zurich, Switzerland, October 4, 1982.

Division 533, Invited Talks (cont'd)

Pierce, D. T., "Electron Spin Polarization Studies of Surface Magnetism," Solid State Physics Seminar, Cambridge University, Cambridge, England, October 7, 1982.

Pierce, D. T., "Electron Spin Polarization Studies of Surface Magnetism," Solid State Physics Seminar, University of Maryland, College Park, Maryland, November 11, 1982.

Pierce, D. T., "New Insights from Electron Spin Polarization Studies of Surfaces," 29th National American Vacuum Society Symposium, Baltimore, Maryland, November 17, 1982.

Pierce, D. T., "Electron Spin Polarization Studies of Surface Magnetism," Solid State Seminar, Brookhaven National Laboratory, Islip, New York, December 9, 1982.

Pierce, D. T., "Spin Polarized Electron Studies of Surface Magnetism," Physics Department, Johns Hopkins University, Baltimore, Maryland, March 3, 1983.

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TECHNICAL AND PROFESSIONAL COMMITTEE PARTICIPATION AND LEADERSHIP

Division 533, Radiation Physics

Martin J. Berger

Chairman, International Commission on Radiation Units and Measurements (ICRU), Committee on Stopping Power.

Member, National Council on Radiation Protection and Measurements (NCRP), Committee #52 on Conceptual Basis of Dosimetry.

Member, National Council on Radiation Protection and Measurments (NCRP), Committee #55 on Experimental Verification of Internal Dosimetry.

Robert J. Celotta

Chairman, NBS Research Advisory Committee, 1982-1983.

Editorial Board, Review of Scientific Instruments.

Member, Program Committee, Division of Electron and Atomic Physics, American Physical Society, 1982-1983.

Charles E. Dick

Member, Technical Program Committee, Biannual Conferences on Applications of Small Accelerators in Industry and Medicine.

David L. Ederer

NSLS User Committee.

Member, Optics News Editorial Committee.

Chairman, Education Committee, Optical Society of America.

Margarete Ehrlich

Chairman, Health Physics Society Standards Committee, Work Group on Criteria for Testing Personnel Dosimetry Performance. (Disbanded June 1983).

Member, ISO/TC 85/SC 2/WG 2, Photographic Dosimeters and Reference Radiation.

Division 533, Technical and Professional Committee Participation and Leadership (cont'd)

Margarete Ehrlich (cont'd)

Member, Health Physics Society Standards Committee, Work Group on Criteria for Testing Environmental Dosimetry Performance.

Member, Work Group on Revision of ANSI/ANS 6.1.1, Neutron and Gamma-Ray Flux-to-Dose Rate Factors, American Nuclear Society.

John H. Hubbell

Secretary, Commission on Crystallographic Apparatus, International Union of Crystallograpy, Task Group on X-Ray Absorption Coefficients.

Chairman, American Nuclear Society (ANS) Radiation Protection and Shielding Division ANS-6 Ad Hoc Committee on SI Units.

Member, Cross Section Evaluation Working Group (CSEWG) Subcommittee on Shielding.

Secretary, Pro-tem Committee, now-forming International Radiation Physics Society.

Member, American Nuclear Society (ANS) Isotopes and Radiation Division Nuclear Data Committee.

Jimmy C. Humphreys

Member, ASTM F-1.11 Subcommittee on "Quality and Hardness Assurance" of the F-1 Electronic Committee.

Secretary, ASTM Committee E10.07 "Ionizing Radiation Dosimetry and Radiation Effects on Materials and Electronic Devices".

Robert Loevinger

Member, BIPM Consultative Committee for Standards for Measurement of Ionizing Radiation, Section I, X- and Gamma-Rays and Electrons.

Member, OIML, SP.16-SR.2, Secondary Standard Dosimetry Laboratories.

Member, IAEA-WHO Network of Secondary Standard Dosimetry Laboratories, Advisory Council.

Member, IEC TC 62/SC C/WG 3, Performance of Dosimeters. (Disbanded March 1983).

Division 533, Technical and Professional Committee Participation and Leadership (cont'd.)

Robert Loevinger (cont'd.)

Member, ANSI/N44, Equipment and Materials for Medical Radiation Applications.

Member, Medical Internal Radiation Dose Committee, Society of Nuclear Medicine.

Consultant, AAPM Radiation Therapy Committee.

Member, AAPM Radiation Therapy Committee Task Group 3, Regional Calibration Laboratories.

Member, AAPM Radiation Therapy Committee Task Group 21, High-Energy Photon and Electron Dosimetry. (Disbanded August 1983)

Member, AAPM Radiation Therapy Committee Task Group 22, Brachytherapy.

Consultant, AAPM Radiation Therapy Committee Task Group 24, Physical Aspects of Ouality Assurance in Radiation Therapy. (Disbanded August 1983)

Chairman, AAPM Science Council Committee on the Effect of SI Units.

Thomas P. Loftus

Member, ANSI/N13, Radiation Protection.

Member, ANSI/N42, Working Group on Inspection and Test Specifications for Direct and Indirect Reading Quartz Fiber Pocket Dosimeters.

Thomas B. Lucatorto

Co-Chairman, 1984 Conference on Laser Techniques in the Extreme Ultraviolet.

Robert P. Madden

Member, Advisory Committee for the Stoughton Storage Ring (Tantalus), University of Wisconsin.

Member, Editorial Advisory Board, Optics Communication.

Member, International Committee for the International Conference on VUV Radiation Physics.

Division 533, Technical and Professional Committee Participation and Leadership (cont'd.)

Robert P. Madden (cont'd)

Member, Executive Committee, Optical Society of America, 1982-83.

President, Optical Society of America (OSA), 1982.

OSA Board of Directors, 1982-83.

Member, AIP Board of Directors, 1982.

Member, Council of Scientific Society Presidents (CSSP), 1982-83.

Member, CSSP Executive Committee, 1983.

Member, International Working Group for Middle Atmosphere Program on Solar Spectral Irradiance Measurements, 1981-84.

Member, Council of U.S. Synchrotron Radiation Laboratory Directors.

Member, Program-Advisory Committee of the International Conference on X-Ray and VUV Synchrotron Radiation Instrumentation.

Presidential Lecturer, Local Sections of the Optical Society of America.

Member, OSA Committee on Finance and Investment, 1982.

Member, OSA Objectives and Policy Committee, 1983.

Member, AIP Nominating Committee, 1982.

Member, AIP Physics Today Advisory Committee, 1983.

Thomas J. McIlrath

Member, Technical Council; Chairman, Atomic Spectroscopy Technical Group, Optical Society of America.

Co-Chairman, OSA Conference on Spectroscopy in Support of Atmospheric Measurements.

Member, Program Committee, Optical Society of America Annual Meeting.

Division 533, Technical and Professional Committee Participation and Leadership (cont'd.)

Thomas J. McIlrath (cont'd)

Member, Program Committee, Division of Electron and Atomic Physics, American Physical Society.

Chairman, 1982 Conference on Use of Lasers for High Resolution Spectroscopy in the Vacuum Ultraviolet.

Participant and Panel Chairman, Workshop on Current Trends in Atomic Spectroscopy, Tucson, AZ, October, 1982.

General Chairman, 1983 Annual Meeting, Optical Society of America.

Vice Chairman, 1985 Gordon Conference on Atomic Physics.

Advisory Panel, 1984 Conference on Laser Techniques in the Extreme Ultraviolet.

Advisory Editor, Laser Focus Magazine.

William L. McLaughlin

Chairman, American Nuclear Society (ANS) 9, Nuclear Terminology and Units, Subcommittee 9.1, Health Physics and Dosimetry.

Member, ASTM E10.07, Radiation Effects on Electronic Materials and Devices.

Technical Advisor, Association for the Advancement of Medical Instrumentation Subcommittee on Radiation Sterilization of Medical Devices, Task on Radiation Dosimetry.

Member, ANS 9.2 Subcommittee on Shielding, of the Nuclear Terminology and Units Committee.

Technical Advisor, ISO WG-1, Nuclear Energy Terminology Task on the ISO TC/85 Committee on Nuclear Energy.

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

Division 533, Technical and Professional Committee Participation and Leadership (cont'd.)

William L. McLaughlin (cont'd)

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

William R. Ott

Member, Local Committee, 8th International Colloquium on UV and X-Ray Spectroscopy of Laboratory and Astrophysical Plasmas, Washington, DC, 1983-1984.

Member, International Working Group for Middle Atmosphere Program on Solar Spectral Irradiance Measurements, 1981-1984.

Robert C. Placious

Chairman, ASTM E7.01.03, Subcommittee on Industrial Radiographic Film Classification.

Member, ASTM E10.07, Nuclear Technology and Application Subcommittee on Radiation Effects on Electronic Materials and Devices and Pulsed Radiation Effects.

Member, ANSI PH 2.31, Committee on Photographic Sensitometry, Subcommittee on Medical X-Ray Film Standards.

Member, ASTM F12.60, Controlled Access Security Search and Screening Systems.

Member, ASTM E7.01, Nondestructive Testing Committee on Radiographic Practice and Penetrameters.

Member, ANSI PH 2.34, Committee on Photographic Sensitometry, Subcommittee on Industrial X-Ray Film Standards.

Member, New York Academy of Science.

Division 533, Technical and Professional Committee Participation and Leadership (cont'd.)

Daniel Polansky

Member, ASTM E07.01 Nondestructive Testing Committee on Radiographic Practice and Penetrameters.

Member, ASTM E07.02 NDT Committee on Radiographic Standards.

Member, ASTM E07.05 NDT Committee on Neutron Radiography.

Member, ASTM E07.91 ISO/TC135.

Member, ANSI PH 2.31, Committee on Photographic Sensitometry, Subcommittee on X-Ray Film Standards.

Stephen M. Seltzer

Member, International Commission on Radiation Units and Measurement (ICRU), Committee on Stopping Power.

Michael G. Simic

Member, Military R&D Associates.

Member, Task Force, Council on Agricultural Science and Technology.

Lewis V. Spencer

Member, National Council on Radiation Protection and Measurements Committee #40, Task Groups on A-Bomb Survivor Dosimetry and Biological Aspects of Radiation Protection Criteria.

Member, Panel on the Re-assessment of A-Bomb Dosimetry, Advisory Committee on the Radiation Effects Research Foundation, National Academy of Science-National Research Council.

Member, Shielding Glossary Committee, American Nuclear Society.

Member, Interagency Committee on Federal Guidance for Occupational Exposure to Ionizing Radiation.

MAJOR CONSULTING AND ADVISORY SERVICES

Division 533, Radiation Physics

1. M. J. Berger is a consultant to the ICRU committee on High Energy Electron Dosimetry.

2. M. J. Berger is a consultant to the AAPM Task Group on Photon and Electron Dosimetry.

3. M. J. Berger and S. M. Seltzer collaborated with the Department of Physics, Brookhaven National Laboratory, on the calculation of the density effect on the stopping power of charged particles.

4. M. J. Berger, J. H. Hubbell, and S. M. Seltzer advised the ICRU Committee on Material Equivalents and Tissue Substitutes on photon attenuation coefficients and electron stopping powers.

5. M. J. Berger and S. M. Seltzer advised the Department of Physics, Brookhaven National Laboratory, on electron transport problems pertaining to the storage of radioactive waste material in salt domes.

6. R. J. Celotta and D. T. Pierce consulted on the construction and operation of GaAs polarized electron sources with B. Dunning and G. K. Walters, Rice University, Houston, Texas; J. Williams, University of Eastern Australia, Perth, Australia; M. Lubell, City College of N.Y.; G. Prinz, Naval Research Lab; and D. Golden, University of Oklahoma.

7. C. E. Dick consulted on proton radiography for NDT and medical applications for J. Saudinos, Saclay, France.

8. C. E. Dick provided S/N ratios and attenuation coefficients for radiographic applications for E. Szymanski and R. Ledley, Georgetown University Hospital, Washington, DC.

9. C. E. Dick provided data on phosphor characterization by single photon counting for E. Mickish, DuPont.

10. C. E. Dick provided the X-Ray response of Si detectors for E. Rosato, Inst. for Experimental Physics, Naples, Italy.

11. C. E. Dick provided beta ray dosimeter and detector calibrations for B. Erkkila, LANL.

12. C. E. Dick developed Apple plotting programs for R. Moore, Hillborow Hospital, Univ. of Johannesburg, South Africa.

13. C. E. Dick provided electron detector calibrations for B. Erkkila and R. Brake, LANL.

14. C. E. Dick provided electron detector response for F. Hajnal, DOE Environmental Lab., NY.

15. C. E. Dick provided zero frequency normalization of screen-film DQE for R. Wagner, BRH.

16. C. E. Dick provided data on X-Ray attenuation properties of Gd_2OS for P. Rocket, KMS Fusion, Ann Arbor, MI.

17. C. E. Dick provided filtered x-ray spectra for Y. Wang, Thomas Jefferson Hospital, PA.

18. C. E. Dick provided bremsstrahlung and K ionization cross section data for Mark Twigg, NBS.

19. C. E. Dick provided attenuation coefficients and scintillator efficiencies for Les Slaback, NBS.

20. C. E. Dick performed X-Ray radiographic inspection of a "Blaylock" painting for Martin Gnossi, NBS, and Jackie Brandt, Smithsonian Inst.

21. C. E. Dick provided stereo x-ray pairs for D. Craig, NBS, OERI.

22. S. R. Domen advised S. Wang of the National Institute of Metrology in Beijing, China, concerning construction and operation of the NBS absorbed-dose graphite calorimeter and NBS absorbed-dose water calorimeter.

23. S. R. Domen advised C. Ross of the National Research Council of Canada concerning modification of his calorimeter circuit for incorporation of the NBS temperature-drift balancer.

Division 533, Major Consulting and Advisory Services (cont'd)

24. S. R. Domen continues to consult with about a dozen individuals in many countries who have constructed absorbed-dose calorimeters based on the NBS design.

25. J. H. Hubbell responded to inquires to the X-Ray and Ionizing Data Center on matters pertaining to photon cross sections from over 300 scientists in the U.S. and abroad.

26. J. H. Hubbell is a consultant to the ICRU Task Group II-B-1 Radiation Dosimetry: X-rays from 5-150 keV.

27. J. H. Hubbell is a consultant to the LBL/CERN Particle Data Group.

28. J. H. Hubbell advised H. Diltingsrud and G. Gels, FDA, Nucl. Med. Lab., Cincinnati, on methodology for computing dose rates from radioactive clouds.

29. J. H. Hubbell advised P. Kliauga and S. M. Khanna, Radiological Research Lab., Columbia University, on methodology for computing dose-rates to the inner ear in Mössbauer experiments using small plaque sources.

30. J. C. Humphreys advised Radiation Dynamics, Inc., on setting up passive dosimetry and active calorimetry measurement system for electron beams. Similar service performed for Becton Dickinson.

31. R. Loevinger was a member of an Ad Hoc Technical Review Group that evaluated research proposals for the National Cancer Institute.

32. R. Loevinger was invited to a meeting of NRC officials as a consultant on measurement assurance methods for calibration laboratories.

33. W. L. McLaughlin provided consultation to W. Todd, Harshaw Chemical Co., Solen, OH, regarding the methods of charged particle dosimetry and depth-dose measurement.

34. W. L. McLaughlin provided holographic measurements of electron beam depth dose to H. Borella, EG&G, Inc., Santa Barbara, CA.

35. W. L. McLaughlin assisted R. Brake, Los Alamos Scientific Lab., Los Alamos, NM, in radiochromic dosimetry.

36. W. L. McLaughlin provided consultation with R. Baker and C. Graham, Lawrence Livermore Labs., Livermore, CA on very high dose measurements of neutrons and photon doses, using color center formation in LiF, and high-dose radiochromic calibrations.

37. W. L. McLaughlin prepared a technical exhibit for "Science in Medicine" Exhibition in Washington, DC.

38. W. L. McLaughlin planned with W. Plimpton, K. Glibbert, and P. Apodaca, Sandia Labs, Albuquerque, NM, high dose dosimetry for neutrons and photons for weapons test diagnostics.

39. W. L. McLaughlin designed new radiochromic and fibre optics dosimeters for medical and food irradiation applications for K.C. Humphreys and A. Kantz, Far West Technology, Inc., Goleta, CA.

40. W. L. McLaughlin planned a high dose dosimetry workshop for US DOE National Labs. with R. Brake, Los Alamos, NM.

41. W. L. McLaughlin performed calculations and measurements of depth dose of charged particles in various liquid systems with I. G. Draganic, Univ. Mexico, Mexico City.

42. W. L. McLaughlin hosted a seminar on Radiation Chemicals of Comets with I. G. Draganic, Univ. Mexico, Mexico City.

43. W. L. McLaughlin consulted with R. Andrewski, Gamma Technology, NY, on dosimetry for the irradiation of food.

44. W. L. McLaughlin assisted M. Donofrio, Rockbestos Corp., New Canaan, CT, with electron beam dosimetry at very high dose rates in radiation processing.

45. W. L. McLaughlin consulted with R. Roedinger, ISO-STER, South Africa, regarding food-irradiation dosimetry quality control.

46. W. L. McLaughlin collaborated with W. Owens, Isomedix, Inc., Parsippany, NJ, on international intercomparisons and calibrations of plastic dosimeters.

47. W. L. McLaughlin provided R. Nakata, Rockwell International, CA, information on high-dose dosimetry methods for quality assurance in radiation processing.

48. W. L. McLaughlin provided high-dose dosimetry data on thin plastic films in pulsed electron beams for Chen Xion, Peking Normal Univ., Peking, China.

49. W. L. McLaughlin consulted with B. Donn, NASA, regarding long term (>1 year) dosimetry of charged particles using radiochromic thin films.

50. W. L. McLaughlin planned with A. F. Dawond, Director, NIS, Cairo, Egypt, a dosimetry program collaboration between NBS and the National Institute of Standards, Cairo, Egypt.

51. W. L. McLaughlin planned a program of high-dose gamma-ray testing and dosimetry of sealants and gasket materials for power reactors with S. Wohl, Tremco, Inc, Pittsburgh, PA.

52. W. L. McLaughlin consulted with N. Getoff, Univ. Vienna, Austria, on pulse radiolysis of dyes and dye films for kinetics studies of dye formation.

53. W. L. McLaughlin provided dosimetry services and consultation on the use of ^{60}Co sources for J. Benedetto, NBS, Washington, DC.

54. W. L. McLaughlin advised F. Boschers, 3M Co., TX, on high dose dosimetry for sterilization of medical devices and their materials.

55. W. L. McLaughlin consulted with K. Vitale, Syntex Corp., Palo Alto, CA, to solve problems of standardization of plastic dosimeters used at dry ice temperatures.

56. W. L. McLaughlin assisted M. Childs, UOP Research Center, Des Plaines, IL, in quality control dosimetry for electron beam curving of plastics.

57. W. L. McLaughlin assisted G. Sykes, NASA-Langley, Langley, VA, in the standardization and dose mapping of the area around a large ^{60}Co gamma-ray source.

58. W. L. McLaughlin provided assistance in area monitoring around large ^{60}Co gamma-ray sources to L. Shapiro and H. Boeing, Univ. Cincinnati, OH.

59. W. L. McLaughlin provided consultation on electron beam diagnostics for plasma physics requirements for W.C. Hsieh, Shaw Industries, Toronto, Canada.

60. W. L. McLaughlin performed neutron and photon dosimetry at high doses and dose rates for Drs. Broyles and Plimpton, Sandia Labs.
61. W. L. McLaughlin performed traceable high-dose dosimetry as a means of product release in radiation sterilization for C. Keeley, American Hospital Supply Co., El Paso, TX.

62. W. L. McLaughlin designed an experiment for depth-dose measurements with electron beams of various energies for J. Griesel, Honeywell, Inc., Clearwater, FL.

63. W. L. McLaughlin provided an international calibration and intercomparison for dosimeters irradiated with low-energy electrons for Drs. Nable and Rangwalla, Energy Sciences, Inc, Woburn, MA.

64. W. L. McLaughlin provided area monitoring in nuclear fuel storage area for J. Silverman, Three-Mile Island Power Station, PA.

65. W. L. McLaughlin consulted with W. A. Quam, EG&G, Inc. Santa Barbara, CA, regarding neutron-gamma ray ratios of responses of high-dose dosimeters and depth-dose profiles.

66. W. L. McLaughlin provided quality control dosimetry in x-ray lithography and electron beam lithography for W. Grobman, IBM, Yorktown Heights, NY.

67. W. L. McLaughlin designed dosimetry program for quality control of irradiation of organ and prosthetic implants for sterilization purposes for B. Davis, ISCI - Bard, Billerica, MA.

68. W. L. McLaughlin designed calorimetry calibration technique for 4 MeV electron beams used in radiation processing of polymers and elastometers for P. Farrell, Radiation Dynamics, Inc., Melville, NY.

69. W. L. McLaughlin provided the standardizing high-dose measurements and dose distributions for low-energy electron beam curving of plastics for W. Bacich, ITER Systems, St. Louis, MO.

70. W. L. McLaughlin developed new chemical dosimeters for high-LET radiation for R. Culp, Center for Applied Isotope Studies, Univ. of Georgia.

71. W. L. McLaughlin designed test and dosimetry methods for plastics irradiated to very high doses for G. Strand, Pacific Testing Lab., Seattle, WA.

72. W. L. McLaughlin designed for P. Van Etten, Lockheed Corp., Sunnyvale, CA, dosimetry methods for both electron (high-dose rate) and photon (low-dose rate) irradiations.

73. W. L. McLaughlin designed a depth-dose experiment for verifying electron transport calculations in various materials and across interfaces for B. Warner, Univ. Minnesota.

74. W. L. McLaughlin initiated discussions and consultations on quality control and traceability for multi-lab sterilizing standardization for T. Fisher, Becton Dickinson, Sumter, SC.

75. W. L. McLaughlin performed for V. Rosemond, Davis & Geck, American Cyanamide, Danbury, CT, statistical analysis of dosimetry release of radiation sterilized materials used in hospitals.

76. W. L. McLaughlin provided dosimetry information on quality control for irradiation of space shuttle foods for S. Thompson, Radiation Technology, Inc., Rockaway, NJ.

77. W. L. McLaughlin chose a selection of polymer compatibilities of carbozole dioxazine dyes (for dosimetry) for S. Doshi, Eton Plastics, Aurora, OH.

78. W. L. McLaughlin designed quality control dosimetry for 10-MeV electron dosimetry processing for J. Ross, Martin Marietta, OH.

79. W. L. McLaughlin performed dosimetry consultation on dye systems for testing particle-track theory for C. Trumbore, Univ. Delaware.

80. W. L. McLaughlin designed infra-red spectrophotometry as a new means of dosimetry (analysis of crystalline organics) for J. Williams, Neutron Products, Inc., Dickerson, MD.

81. W. L. McLaughlin performed high dose dosimetry in neutron-gamma-ray fields with the use of ^{6}LiF-^{7}LiF for G. Zeman, AFRRI, Bethesda, MD.

82. W. L. McLaughlin performed low-energy x-ray and gamma-ray dosimetry at high doses for H. Ito, IBS, San Jose, CA.

83. W. L. McLaughlin designed a method for purifying dyes for R. Burke and M. Marenthal, Center for Analytical Chemistry, NBS.

84. W. L. McLaughlin performed measurement and standardization of thin-films for G. Barrett, Neutron Products, Inc., Dickerson, MD.

85. W. L. McLaughlin consulted D. Dingee, Battelle NW, Richland, WA, regarding the US industry prospects for growth in radiation sterilization.

86. W. L. McLaughlin performed for S. Apostalon, Becton Dickinson Research, Rutherford, NJ, electron beam calibration consultation for on-line industrial quality control sterilization of medical syringes.

87. W. L. McLaughlin consulted with M. Kahn, Bossard, Inc., New York, on the use of dosimetry for quality control in the preservation of various foodstuff by ionizing radiation.

88. W. L. McLaughlin performed a consultation on x-ray stimulation of luminescence of phosphors incorporated in polymers for F. Wang, Polymer Division, NBS.

89. W. L. McLaughlin consulted with E. Figge, Baxter-Travenol, Round Lake, IL, on dosimetry of sterilized medical products (statistical analyses).

90. W. L. McLaughlin consulted on dosimetry project for bracheotherapy and opthalmic applicators for tumor treatment for G. Glasgow, Univ. of Wash., St. Louis, MO.

91. W. L. McLaughlin designed procedures for 4 MeV - 10 MeV electron processing of foodstuff for D. Wocek, Vitametrics, Inc., San Diego, CA.

92. W. L. McLaughlin developed food irradiation quality control through the use of fibre optics dosimetry for T. Klein, Owens-Illinois, Champlain, IL.

93. W. L. McLaughlin developed cellulose triacetate systems for high-dose dosimeters for K. Tanaka, Japan Atomic Energy Research Institute, Takasaki, Japan.

94. W. L. McLaughlin developed dosimetry systems for traceability of radiation measurements for food irradiation for C. Takaguchi, Food & Drug Administration, Washington, DC.

95. W. L. McLaughlin designed a new program for radiation sterilization of medical supplies for C. Parra, Abbott Laboratories, Austin, TX.

Division 533, Major Consulting and Advisory Services (cont'd)

96. W. L. McLaughlin designed a new program for processing chemical systems (sterility) for M. Pines, MSD Merck, West Point, PA.

97. W. L. McLaughlin consulted with D.M. Strelczyk, Radiation Dynamics, Inc., Melville, NY, on the use of radiochromic dosimetry in 2-4 MeV electron beams (calibrations, beam mapping, standardization).

98. W. L. McLaughlin consulted on dosimetry of electron beams (quality control) with D. Hillman, McDonald-Douglas, St. Louis, MO.

99. W. L. McLaughlin designed a project for standardizing response curves of fiber optics dosimeters for food irradiation for T. Rensel, International Nutronics, Inc., Palo Alto, CA.

100. W. L. McLaughlin consulted on absorbed dose rate effects on polychlorostyrene dosimeters with S. Jeng, Kendall, Barrington, IL.

101. W. L. McLaughlin planned an international dosimetry intercomparision for high dose dosimeters used in electron accelerator facilities with U. Deffner and D. Regulla, Gesellschaft fur Strahlenforschung und Umweltforschung, Neuherberg, West Germany.

102. W. L. McLaughlin designed an electron-beam calorimeter for radiation processing application; and introduced new plastics dosimeters for sterilization of medical supplies and polymeric devices for Marion Strelcyck, Radiation Cynamics, Inc., Melville, NY.

103. W. L. McLaughlin provided information on radiation processing of foodstuff for Chen Fugen, Zhang Shaoqui, Cao Xuexin, Zhu Jinxin, and Xu Kecheng, Inst. Nuclear Research, Academica Sinica, Shanghai, China.

104. J. W. Motz consulted with Ridge, Inc., on design and construction of an intra-oral x-ray source for real-time dental radiography and tomography.

105. J. W. Motz consulted with R. Webber at NIH on the design of real-time radiographic systems for dentistry.

106. J. W. Motz consulted with E. Larr at the Fort Detrick Army Dental Research Group on portable systems for dental radiography.

107. R. C. Placious advised the Federal Aviation Administration on x-ray screening systems.

108. R. C. Placious, D. Polansky, and J. Sparrow provide radiographic services and consultation to NBS investigators. There also exists a continuing service to the Department of Defense in maintaining and improving the radiological programs for the inspection of large diameter rocket motors by defense contractors.

109. S. M. Seltzer collaborated with staff members at the Naval Research Laboratories and the Naval Surface Weapons Center on the development of a beam current monitor for intense electron beams.

110. S. M. Seltzer is a consultant to the Space Systems Division, Langley Research Center, NASA, on radiation transport and space shielding.

111. S. M. Seltzer consulted on problems in radiation transport and shielding, and collaborated on the development of x-ray imaging systems with members of Goddard Space Flight Center, NASA.

112. S. M. Seltzer collaborated with staff members at the University of Maryland and Radiation Dynamics, Inc., on calculations pertaining to the feasibility of electron-beam bremsstrahlung for commerical radiation processing.

113. S. M. Seltzer consulted on NaI and Ge detector response to photons with staff at Brooklyn College and with Goddard Space Flight Center.

114. M. G. Simic is a consultant of the Norris Cotton Cancer Center, Dartmouth Medical School, Hanover, NH.

115. M. G. Simic is a consultant to IAEA, Vienna, Austria, regarding radiation chemistry.

116. C. G. Soares advised J. C. McDonald of the Battelle-Northwest Laboratory on spectrometric methods of determining the peak kilovoltage of x-ray generators.

117. L. V. Spencer provided advice to FEMA, NCRP and NAS-NRC on radiation problems pertaining to civil defense.

JOURNAL EDITORSHIPS

Division 533, Radiation Physics

M. J. Berger, Editorial Board, Journal of Radiation Research, Japan Radiation Research Society.

R. J. Celotta, Co-editor, Methods of Experimental Physics, Academic Press.

R. J. Celotta, Member, Editorial Board, Review of Scientific Instruments, American Physical Society, 1982-1984.

W. L. McLaughlin, Editor, International Journal of Applied Radiation and Isotopes.

W. L. McLaughlin, Editor, Radiation Physics and Chemistry.

J. W. Motz, Editor, Computerized Radiology.

TRIPS SPONSORED BY OTHERS

Division 533, Radiation Physics

R. J. Celotta, attended and presented invited talk at US/Japan Seminar on Electron-Molecule Collisions and Photoionization Processes, Los Angeles, CA, Oct. 26-29, 1982.

R. J. Celotta, attended and presented invited lecture at the Symposium on Polarization and Correlation in Electron-Atom Collisions, Münster, West Germany, July 23-27, 1983.

C. L. Cromer presented a lecture to the Physics Department of the University of Virginia, Charlottesville, VA, April 13, 1983.

D. L. Ederer presented a lecture to the Department of Physics at North Carolina State University, Raleigh, NC, February 7, 1983.

D. L. Ederer presented a lecture at the Joint Institute for Laboratory Astrophysics, University of Colorado, Boulder, CO, April 26, 1983.

D. L. Ederer attended the Gordon Conference of Atomic Physics at Colby-Sawyer College, New London, NH, funded by Gordon Research Conferences, July 4-8, 1983.

J. C. Humphreys presented a series of three lectures on radiation dosimetry and electron beam calorimetry for the Institute of Physics, Universidad Nacional Autonoma Mexico, D.F., Dec. 13-20, 1982.

M. H. Kelley, presented seminar at the General Motors Research Laboratories, Warren, MI, March 9, 1983.

R. Loevinger was a member of a site visit team at the University of Wisconsin in January 1983 and at Allegheny General Hospital in Pittsburgh in May 1983, as part of a calibration laboratory accreditation program. The trips were paid for by the host institutions.

R. Loevinger participated in a Symposium on Electron Beam Therapy at the University of Pennsylvania in April 1983, and gave an invited lecture. The trip was sponsored by the local chapter of the AAPM.

R. Loevinger participated in meetings of the MIRD Committee of the Society of Nuclear Medicine, in Atlanta, GA, in March 1983, and at Stonybrook, NY, in July 1983. The trips were paid for by the Society of Nuclear Medicine.

Division 533, Trips Sponsored by Others (cont'd)

R. Loevinger participated in a week-long training course for calibration-laboratory personnel, put on by the IAEA in Vienna, Austria, in June 1983. The trip was paid for by the IAEA.

R. Loevinger gave the 1982 Landauer Memorial Lecture in Berkeley, CA, in November 1982. The trip was sponsored by the local chapters of the Health Physics Society and the AAPM.

T. B. Lucatorto attended the Gordon Conference of Atomic Physics at Colby-Sawyer College, New London, NH, funded by Gordon Research Conferences, July 4-8, 1983.

R. P. Madden attended Physics Today Advisory Committee for the American Institute of Physics, New York, NY, September 29-October 1, 1983.

R. P. Madden presented presidential lecture to local sections of the Optical Society of America in San Diego, CA, Stanford, CA and Boulder, CO, February 10-17, 1983; Alburquerque, NM, Tucson, AZ, Los Angeles, CA and Portland, OR, March 31-April 8, 1983; Melbourne, FL and Huntsville, AL, May 8-12, 1983, and Los Alamos, NM, June 28, 1983.

R. P. Madden attended the Board of Directors Executive Committee meeting of the Optical Society of America, Boston, MA, May 23-25, 1983.

W. L. McLaughlin visited Risø National Lab in Denmark to present training course and lectures on radiation dosimetry processing, September 8-October 3, 1982.

W. L. McLaughlin visited Radiation Technology, Inc., Rockaway, NJ, to perform dosimetry for the radiation preservation of food for the space shuttle, December 2-3, 1982.

W. L. McLaughlin gave a talk and consultation on x-ray beam dosimetry for microelectronics applications for IBM Research Center, Yorktown Heights, NY, April 12-13, 1983.

W. L. McLaughlin visited the National Physical Laboratory, UK, to discuss 10 MeV electron beam calorimetry, June 6-18, 1983.
W. L. McLaughlin visited Oxford, England, UK to attend an editors meeting for Pergamon Press, June 6-18, 1983.

W. L. McLaughlin visited Harwell, England, UK to attend an ICRU committee meeting, June 6-18, 1983.

Division 533, Trips Sponsored by Others (cont'd)

W. L. McLaughlin attended the Gordon Research Conference on "Direct Action of Ionizing Radiation on Macromolecules" at Plymouth, NJ. August 14-19, 1983.

W. L. McLaughlin visited the Becton Dickinson Research Lab., Research Triangle Park, NC, August 24-26, 1983.

A. C. Parr presented lecture to the Chemical Physics Institute of the University of Oregon, January 5, 1983.

D. R. Penn discussed theoretical physics at the University of California, Berkeley, CA, August 12, 1982; and presented a talk at the Xerox Corporation, Palo Alto, CA, August 13, 1983.

D. T. Pierce, presented Solid State Seminar at Brookhaven National Laboratory, Upton, NY, December 9, 1982.

D. T. Pierce, presented an invited talk at IBM Research Center, Yorktown Heights, NY, May 3, 1983.

M. G. Simic visited the Boris Kidric Institute for Nuclear Sciences, Belgrade, Yugoslavia in connnection with IAEA, October, 1982.

M. G. Simic attended the 4th International Meeting on Radiation Processing in Dubrovnik, Yugoslavia, October, 1982.

M. G. Simic attended the Miller Conference (European Radiation Chemistry Conference) in Hünefeld, W. Germany, June, 1983.

M. G. Simic attended the III International Conference on Oxygen Radicals in München, W. Germany, July, 1983.

J. H. Sparrow visited Coulport, Scotland, to determine the competence of Royal Naval Ammunition Depot's radiographic inspection procedures for large diameter motors to established standards. July 24-29, 1983.

CALIBRATION SERVICES PERFORMED

Division 533, Radiation Physics Division

Type of Service	Customer Type*	SP 250 Item No.	Number of Calib'ns or Tests	Income
Calibration of x-ray and γ-ray measuring instruments	1-7	8.3B,C, D,H,I	202	$ 84k
Irradiation of TL dosimeters	2-6	8.3M,N	32	
Calibration of penetrameters	1	8.3K	0	
Calibration of γ-ray sources	2-4	8.4E,F	11	$ 7k
Calibration of β-particle sources	2,4-6	8.4K	7	
Chemical dosimetry measurement assurance service for electron beams	2	8.5B,C	40	$ 19k
High-dose irradiation	3-7	8.6B	290	
Dose interpretation	4-7	8.6C	40	$ 29k
Spectrophot. reading of dosimeters	4-6	8.6D	289	
Irradiat. of TLD dosims, & prep. of units for shipboard measurement	Navy	N.A.	232	$ 70k
Instrument calibration & evaluation	Nucl. Reg. Commission	N.A.	1	$ 3k
Far UV radiometric transfer standard detectors (photodiode calibrations)	1,3-8	N.A	22	$ 32k
Totals			1244	$244k

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

TECHNICAL ACTIVITIES

Division 534, Radiometric Physics

Task No. 15241 - Advanced Optical Radiation Measurements

Task No. 15242 - Maintenance and Dissemination of Optical Radiation Measurements

Task No. 26101 - Quantum Radiometry

INTRODUCTION

The Radiometric Physics Division is the primary focal point within NBS for carrying out the traditional Bureau mission of promoting accurate meaningful, and compatible optical radiation measurements in the wave-length region between 200 nm and 14 μm. The Division fulfills this mission by

- o conducting fundamental research aimed at new approaches to optical radiometry,
- o conducting applied research to extend existing radiometric standards and calibration procedures,
- o maintaining and disseminating the U.S. radiometric scales,
- o developing resources of expertise for the solution of radiometric problems wihtin NBS, government, industry, and the public sector.

The Division's efforts are closely coupled to the radiometric programs of other CRR Divisions in the ultraviolet below 200 nm. The Division interacts with other units of NBS; such as the Offices of Measurement Services, Non-Destructive Evaluation, and Standard Reference Materials. A project to develop measurement methods and standards for luminescence spectrometry, started last year in cooperation with the Center for Analytical Chemistry, was continued in FY 1984. A new collaborate effort with the Center for Absolute Physical Quantities, in optical fiber thermometry, was started in the second half of the fiscal year with specially allocated Director's Reserve funds.

The continuing progress in the Division's research, development, and dissemination work is detailed in the following reports of the four Group Leaders. Division-wide, there has been a concerted effort to intercompare source and detector based radiometric scales, to develop radiometric methods based on self-calibrated photodiodes, and to transfer these new methods to user groups.

Our staff is engaged in numerous interactions with professional societies and standards committees at the national and international levels. These interactions, as well as the feedback received from our calibration customers, are essential elements of our program planning. For example, the Division gave high priority to the needs identified in the Fourth CORM Report and has formulated its response to the report, containing suggestions to make the CORM/NBS interaction even more productive.

Because of a world-wide interest in the Division's work in detector-based radiometry, we have devoted substantial efforts to international cooperations in this field. For example:

- We are participating in international intercomparisons organized by the Consultative Committee on Photometry and Radiometry (CCPR) to evaluate the practical consequences of the recent redefinition of the candela. Our Division was chosen to be the convening laboratory for one of these, an intercomparison of $V(\lambda)$ silicon photodetectors by 12 national standardizing laboratories.

- We have initiated a collaborative project with the National Institute for Standards of Egypt to realize photometric base units by means of interference-filtered, self-calibrated silicon photodiodes.

- A joint effort is under way with the Institute for Technical Physics in Budapest, Hungary, to develop new methods and instrumentation for photometry and low-level radiometry.

- Several Division employees serve on international committees, such as the International Commission on Illumination (CIE), which are concerned with the development of new measurement methods and standards in radiometry and spectrophotometry.

These international activities have enabled the Division to further our research programs by attracting a number of talented foreign guest workers:

Mr. Sheng-Tsong Chang from the National Science Council of Taiwan, participating in the development of spectrophotometric standards.

Dr. Mohamed Khodair and Mr. Shafik Khalil from the National Institute of Standards, Cairo, Egypt, collaborating in the above-mentioned Egyptian project.

Mr. Eike Krochmann from the Technical University of West Berlin, Germany, working on the design of a slit-less prism spectrometer for absolute spectroradiometric measurements.

Mr. Jean Verdebout from the Free University in Brussels, Belgium, investigating interface recombinations in silicon photodiodes.

Mr. Jeffrey Tapping from the National Measurement Laboratory, Sidney, Australia, consulting on the development of a new photoelectric pyrometer, and performing research on optical fiber thermometry.

These additions to our staff, albeit temporary, have helped significantly in the Division Work. Mr. John Ward has been converted from part-time temporary to full-time permanent assignment to the Calibrations Group. Mr. A. T. Hattenburg from the Center for Building Technology has been transferred into the Division to a full-time position in the Spectroradiometry and Optical Pyrometry Group. We have also had temporary assistance from three talented student employees: Mr. Philip Calhoun from the University of Tennessee, Mr. Eli Liang from the University of Maryland, and Mr. Shelly Rosier from the Georgia Institute of Technology.

Furthermore, we have effected a reorganization that will speed the practical realization of source and detector based radiometry. A transfer of personnel took place between the Spectroradiometry and Optical Pyrometry Group and the Electro-Optics and Quantum Radiometry Group. Dr. Zalewski now heads the Spectroradiometry and Optical Pyrometry Group, and it now constitutes the largest Group in the Division.

As the reorganization of the Division became effective only towards the end of the fiscal year, the Group reports that follow pertain to the previous structure of the Division.

SPECTRORADIOMETRY AND OPTICAL PYROMETRY (J. B. Shumaker/E. F. Zalewski)

The primary objectives of this Group are to develop new calibrations, instrumentation, and techniques for pyrometry, radiometry, and photometry. Members of the group work closely with other members of the Division to achieve these objectives. In particular, they work closely with the Calibration and Dissemination Group to generate and maintain pyrometric, radiometric, and photometric calibrations. They also assist other government agencies in solving problems encountered in the pursuit of high accuracy radiometry.

Optical Pyrometry

During the most recent scale realization by Walker of the Calibration Group, a change was uncovered in the spectral radiance and irradiance scales much larger than would be predicted from prior experience with lamp output drift. This was traced to errors in the temperature calibrations above the gold point. That is, a systematic error suddenly appeared in the calibrations performed with the photoelectric optical pyrometer. Waters working with Lewis of the Calibration Group located two possible causes: an increase in scattered light and an abrupt change in the transmittance of the interference filter. Scattered light from elements preceding the filter was ruled out. A new filter has been ordered but not yet received so the problem is not resolved.

The appearance of a problem with high temperature calibrations emphasizes the need for back-up systems for measurements which are a fundamental part of the calibration program. Such a back-up system once existed for the photoelectric optical pyrometer but is no longer available. To solve the problem in the short term, the instrumentation that was developed for the more efficient spectral irradiance scale realization by Saunders and Shumaker is being employed by them as an optical pyrometer. Temperature calibrations obtained with this instrument will enable the spectral irradiance scale realization to be completed and several calibration orders to be filled, as well as the resolution of several intercomparisons (see below).

The design for a new photoelectric optical pyrometer by Waters has undergone extensive modifications, influenced in large part by the work of Tapping and Jones of the Australian National Measurement Laboratory and to a lesser extent by the recent advances in both radiometry using silicon photodiodes and radiation thermometry using sapphire optical fibers. Thus it is a great advantage that Tapping has just joined the Division as a guest worker. Although his primary interest is in the optical fiber thermometer project he has consulted at length with Waters on the design of the new optical pyrometer. The components for the new optical pyrometer have been ordered, and laboratory space previously devoted to blackbody development and heat-flux sensor work has been re-arranged to accommodate the new pyrometer.

Spectroradiometry

The work on the new method of realizing spectral irradiance by Saunders and Shumaker has been completed, except for the last step. This was to be a comparison between the results obtained with both the old and new methods. As noted above, this was impeded by the setback in optical pyrometry.

The final results of other intercomparisons involving spectral irradiance have also been held up for the same reason: the intercomparison with SURF by Saunders and Schaefer and the detector based spectral irradiance measurements on FASCAL by Zalewski and Gladden.

Preliminary results of the SURF intercomparison indicated that there may be a problem with the linearity of the silicon photodiode and/or amplifier. This was studied using the automated beam conjoiner developed by Shumaker. Previous linearity measurements using the AC/DC technique (Schaefer and Zalewski) were verified. One advantage of the new beam conjoiner was demonstrated by this application: its ease of use. Because of its applicability throughout the Division, it is the intention to build at least one more automated beam conjoiner.

As part of the work on the design and construction of the new beam conjoiner, Shumaker has completed a chapter on linearity for the Self-Study Manual. This manuscript is in the final review state of publication.

This past year saw the final phase of the work on solar ultraviolet radiometry by Saunders, Kostkowski, Ward, Popenoe, and Green (University of Florida): publication of a Self-Study Manual chapter on the method of high-accuracy spectral irradiance measurements in the ultraviolet, and the pending publication in the Journal of Geophysical Research of the analysis of the solar observations made in Florida. Although this work made considerable headway in advancing the state of the art in solar ultraviolet radiometry, the original problems in monitoring the ultraviolet transmission of the atmospheric ozone layer still exist as well as the problems in ultraviolet radiometry encountered in the studies of the myriad effects of ultraviolet radiation on living organisms. This work was originally funded by the EPA and because of limited finances it does not appear that EPA will be in a position to fund it in the foreseeable future.

In addition to the already mentioned Self-Study Manual chapters on Linearity and Solar Spectral UV Irradiance, chapters on Blackbody Radiation and Temperature Scales by Richmond (Center for Chemical Engineering) and on Spectrophotometry by Venable (Hunter Associates Laboratory, Inc.) are well along. Substantial progress has also been made on the chapters on Thermal Radiation Properties of Matter by Richmond and

on Time Parameters in Radiometry by Nicodemus (Catholic University). There now remain chapters on Physical Photometry and on Spectroradiometry of Spectral Lines, to be completed along with the others during FY 1984.

Array Radiometry

The commercially available array radiometers (optical multichannel analyzers) were examined and one was purchased. As a first application of this instrument, Hattenburg is using it to perform a special calibration. This is more completely described in the section on the work of the Calibration and Dissemination Group.

Long-Wave Infrared

This area of radiometry is highly relevant to DoD and consequently all the work is in response to their needs. During the past fiscal year Yokley, Ward and Calhoun (University of Tennessee) built and characterized two highly precise room temperature blackbodies: one for the Air Force and one for the Navy. These were based on a blackbody that Yokley had designed about ten years ago. Because the NBS machine shop could not undertake the construction, all of the machining had to be performed using our own facilities. It has therefore taken much longer than expected to complete the project, but it is a credit to the ingenuity and skill of all involved, and Yokley in particular, that the project got completed at all.

In the cryogenic LWIR calibration chamber, because of the restricted space and the many connections that have to be dismantled and remade for each new test that is undertaken, the time required for each calibration is exhorbitant. This is because the chamber was originally designed for basic research in the long-wave infrared and not routine calibration work. Also each calibration performed in this chamber over the last few years was on a different device requiring unique support structures and changes in the alignment of various components. To eliminate the first problem Yokley has designed an extension to the chamber that has several access ports, thereby eliminating the need to completely dismantle the chamber for each new calibration. A suitable machine shop was found on the West Coast, and was awarded the contract to perform the work. Enlarging the volume will alleviate the second problem somewhat because each new test will not have to be crammed into a tight workspace.

Also, in connection with the cryogenic LWIR calibration chamber, steps have been taken to improve the detectivity of the system. A very sensitive capacitance thermometer has been developed by Van Degrift of the Cryogenic Thermometry Group in Division 522 (CAPQ). In consultation with Van Degrift, Yokley has begun ordering the components for this system. A very high-frequency (and also very expensive, >30K$) signal generator

was ordered for this fiscal year using the CCG funds. The CCG has expressed considerable interest in this work and has promised the additional funding needed to complete upgrading the cryogenic LWIR calibration chamber next fiscal year.

SPECTROPHOTOMETRY (J. J. Hsia)

The Spectrophotometry group is responsible for (1) establishing and improving high-accuracy spectrophotometric and densitometric scales in the National Measurement System by developing new instrumentation, establishing new measurement capabilities, and improving basic standards; (2) disseminating these scales by developing transfer standards and standard materials, establishing measurement assurance program services, performing calibration services, and providing consultation to the measurement community; and (3) studying and developing new methods for radiometric characterization of optical media and components for scientific research and for emerging technologies.

Major achievements were made during FY 83 in the areas of reflection transmission, fluorescence and densitometry.

Reflection

A long wavelength infrared spectrophotometry project has been started by Weidner this fiscal year. The purpose of this project is to establish IR measurement capabilities from 2.5 to 25 μm on transmittance, diffuse reflectance and specular reflectance and to provide standard wavelength standards. The sample holder for the Strong specular reflectometer has been designed and fabricated. The gold-plated ellipsoidal mirror for the diffuse reflectometer also has been designed and fabricated.

Two sets of diffuse-reflectance Measurement Assurance Program transport packages have been sent by Hsia to two instrument manufacturers and returned after measurements. These MAP packages consist of one set of 45°/0° and one set of 6°/hemispherical diffuse reflectors. Suggestions have been received for the clarification and improvement of measurement procedures.

A feasibility research study has been performed by Weidner and Hsia on using a sphere-chain as a tool to measure the linearity of a detection system over a large dynamic range and to provide known attenuation factors. More theoretical calculations are needed to estimate the effects of inter reflection and geometrical arrangement of spheres as well as the wavelength dependence of the device.

Hsia, as the International Chairman of the CIE Subcommittee on Standards and Techniques for the Characterizatrion of Materials, initiated and participated in the project on "Survey of International Reference Standards for Spectrophotometers and Colorimeters." The first draft has been completed and was discussed at the CIE September meeting in Amsterdam.

New Standard Reference Materials Nos. 2015 and 2016 have been calibrated by Weidner. These standards are Vitrolite white opal glass to be used on Hardy type spectrophotometers to calibrate diffuse spectral reflectance in the visible spectrum. The associated research studies on the translucency of these standards have been published.

Work is in progress to measure UV diffuse reflectances and bidirectional reflectance distribution functions of barium sulfate samples for the calibration of a Solar Backscatter Ultraviolet Radiometer for use in the NASA solar monitoring program. The work is being performed by Weidner.

Characterization studies and a pilot run on the MAP transport standards for retroreflection have been completed by Eckerle. Data from the two participant laboratories and the NBS have been analyzed for measurement uncertainty. Processes have been started to establish a MAP service on retroreflectance to serve the public.

Eckerle has advised ASTM Committee E-12 and performed the statistical analysis of an ASTM retroreflectance intercomparison.

Transmission

The near infrared extension of the high-accuracy reference spectrophotometer has been completed by Eckerle and Chao (National Science Council of Taiwan).. A new measurement capability in transmittance from 200 to 2500 nm has been established.

Two sets of transmittance MAP transport standards (measured by Eckerle and Widner) have been sent and returned after measurements from two instrument manufacturers. Each set consists of seven neutral density filters. Suggestions were received for clarification and improvement of the measurement procedures.

The international comparison of transmittance sponsored by the CIE Subcommittee on Standards and Techniques has been completed. Fourteen laboratories participated, including NBS. The Subcommittee has completed a draft of the two-part report. The first part consists of filter descriptions, measurement instruments and measurements, and transmittance data. The second part contains a statistical analysis of transmittance data and the results of some investigations on the temperature effect on transmittance of these filters.

Measurements of diffuse transmittance and reflectance of translucent materials often yield 15 to 20% errors. A sphere with one sample port and one monitor port was built by Weidner to study measurement methods for

diffuse transmittance. Sample apertures with different diameters were used. Computer simulations were performed to calculate a transmittance value for a sample aperture of infinite diameter. This method is applicable for certain translucent materials. NBS has participated in the intercomparison on diffuse transmittance and reflectance measurements of plastic samples with known absorptance. This intercomparison is managed by the CIE Subcommittee on turbid media.

Krochmann (Technical University of West Berlin) is calculating the transmittance and passband of a prism system as a possible alternative to interference filters used for filter radiometry. The calculation must take into account the extended source, finite aperture, index of refraction, prism geometry, detector size and distance from the prism and wavelength.

Eckerle and Weidner consulted with the Egyptian National Institute for Standards on the spectral transmittance of interference filters used for filter radiometry. Weidner also consulted with EPA on the calibration of neutral density filters for use in calibrating smoke emission monitoring equipment.

Fluorescence

A new program on fluorescence was initiated this fiscal year. The Reference Spectrofluorimeter will be used for this program. All optical and mechanical components have been installed by Weidner. The cooling water system for the arc source and the nitrogen gas system for the shutters have been designed and put in operation. The control of the instrument and data acquisition have been automated by Fowler. Automation hardware includes a microcomputer, CRT, disk drive, printer, plotter, interface control boards for shutters, encoders, and a digital voltmeter. Several control and data taking computer programs have been developed. The source, source optics, excitation monochromator, sample optics, emission monochromator, and detector have been aligned by Eckerle The process of charcterizing the instrument is progressing. Characterization parameters will include wavelength accuracy, stray radiation, bandpass, linearity, irradiance of the source, and the detector response.

Densitometry

Fink continued to produce x-ray film and photographic step tablets used in the calibration of optical densitometers (OD from 0 to 4) and microcopy resolution charts for determining the resolving power of microscopy systems.

The development of high optical density standards is progressing. The objectives of this program are to develop high optical density

standards (up to OD of 5.8) and to base the calibration of master standards on the Inverse Fourth Apparatus. The work involves development of hardware and software for the Inverse Fourth Apparatus, characterization of the Apparatus, and the issuance of high optical density standards. The instrument now is fully automated by Popenoe.

A computer simulation has been performed to determine the optimum positions which would give small uncertainty in determining 'zero distance'. These optimum positions were used to perform the measurements and the 'zero distance' has been determined to be 112 mm ±0.5 mm. In determining optical density of a film, the 'zero distance' was purposely varied from 112 mm to 110 mm and to 114 mm. The resulted differences in optical densities were within the theoretical predictions.

The uniformity of the power law dependence at different carriage positions was confirmed using the following method. The optical density of a film was measured at several positions of the carriage. The differences in optical densities were within the random noise of the measurements.

The lamp voltage was varied from 15 to 105 volts. The optical density determinations were insensitive to voltages from 85 to 105 volts.

Optical densities of a photographic step tablet measured with the Inverse Fourth Apparatus were compared indirectly with measurements from Inverse Square Instrument through a transfer densitometer by Fink and Popenoe. The results were within one percent of the values.

Preliminary direct intercomparisons on an x-ray step tablet betwen the Inverse Fourth Apparatus and the Inverse Square Instrument were performed. The agreements were also within one percent of the values.

Preliminary evaluation of low optical density samples indicated that the receiver using an integrating-sphere diffuser yielded higher optical densities than the one using an opal diffuser.

Several high optical density step tablets have been measured by Popenoe. These step tablets, produced by an x-ray company, have seventeen steps. The sixteenth step has an optical density of 5.45 and the last step has an optical density higher than 5.8 and thus is beyond the measurement capability of the Inverse Fourth Instrument.

ELECTRO-OPTICS AND QUANTUM RADIOMETRY (J. Geist)

The Electro-Optics Group is responsible for (1) providing the basis for photophysical process characterization in the National Measurement System, (2) developing a new detector based radiometry that is different both in conception and execution than the classical approach based on standard sources of optical radiation, and (3) developing new electro-optical technology for radiometric application. As was the case last year, the major part of the Group effort was devoted to studies of silicon junction diode physics as a basis for accurate radiometry.

During the last year, we cleared up part of the six percent discrepancy between the assignment of the level of spectral irradiance at SURF II according to synchrotron theory and according to silicon radiometry.

The filtered photodiode representing silicon radiometry had been calibrated by comparison to an EG&G UV 444B photodiode that was self-calibrated using a corona discharge to apply oxide bias. Recalibration showed that the UV 444B had been irreversibly damaged by the corona discharge. (This had never been observed in the original work in Australia). The UV 444B was replaced by one of the new 100% quantum efficiency detectors (UDT QED 100) that Zalewski tested last year, and a 2% to 3% discrepancy was observed with respect to the spectral irradiance standard lamps that had agreed with SURF II to within a few tenths of one percent last year.

A number of cross checks on various phases of the calibration and comparison confirmed this difference, and no obvious explanations were apparent. Because the spectral irradiance lamps vs. silicon radiometry comparison on FASCAL (that was described last year) showed only a 1% discrepancy, some thought that the problem could be with the interference filters. However, there was no concensus as to the exact property of the interference filter that was at fault. As a result, a number of different avenues of research were identified as pertinent to this problem.

The research plan consisted of six projects:

1) The transmittance of a clear glass sample and of an interference filter would be measured with the Division's high accuracy spectrophotometer and with the laser based system that was used to calibrate the filtered photodiode against the QED 100 quantum efficiency standard. The disagreement between the measurements obtained with the different instruments would be a measure of the spectrophotometric accuracy of the laser based system.

2) A number of different types of interference filter and filter components would be tested in collaboration with two manufacturers in an attempt to obtain filters with more spatially uniform transmittance.

3) An integrating sphere - interference filter - photodiode combination would be constructed for spectral irradiance measurements.

4) The filtered photodiode-sphere combination and a filtered photodiode without a sphere would both be calibrated against a QED 100 using the laser based characterization facility.

5) A silicon based spectral response calibration would be applied to Shumaker's abreviated version of FASCAL (jokingly called SLOCAL), including a test of the reciprocity between tuning the monochrometer through a fixed laser line and tuning a wavelength tunable laser line through the fixed monochrometer bandpass as techniques for measuring a monochrometer's spectral response.

6) A four way intercomparison would be carried out involving a) the existing spectral irradiance scale as maintained on a bank of lamps, b) the silicon calibrated SLOCAL, c) the silicon based filtered photodiode similar to that used at SURF II last year, and d) the silicon based filtered photodiode-sphere combination.

Projects 1 and 3 were completed during this year by Schaefer in collaboration with Eckerle and Saunders, respectively. Project 2 was not completed to our satisfaction, however, we decided to carry out Project 4 using only the integrating sphere and the best filters that we had obtained by September of 1983. This part of Project 4 and the intercomparison between the filtered photodiode-sphere combination and the existing spectral irradiance scale has been completed. We hope to have completed the remaining Projects 4, 5 and 6 by the end of the calendar year.

The results that we can report now are the following. When the spectral transmittance of a clear glass filter as measured by the laser based system is averaged over a number of interference fringes, the result agrees with the transmittance measured by the high accuracy spectrophtometer to within about 0.05%. However, when the spectral transmittance of an interference filter as measured by the laser based system is convolved with the bandpass of the high accuracy spectrophotometer, the result agrees with the transmittance measured by the spectrophotometer to within a few tenths of one percent near the peak of the filter transmission and to within a few percent in the near wings of the filter bandpass. The disagreement seemed to correlate better with spatial variations of transmittance than with laser power level at the detector. At any rate, it is clear that the characteristics of the laser based system that were tested in this comparison are not the source of the discrepancy.

More importantly, according to the filtered photodiode-sphere combination, the spectral irradiance at 600 nm of four lamps that maintain the NBS scale of this quantity is 0.76% ± 0.23% ± 0.15% lower than the current assignment. The first uncertainty is associated with the calibration of the filtered photodiode and the second is associated with the lamp to lamp variability. Recall that the uncertainty associated with the current assignment of lamp irradiance is 1.2% at this wavelength.

Some progress was also made last year in understanding the passivation and activation of recombination traps. Verdebout, a Ph.D student at the Free University in Belgium, and Booker of our group examined the behavior of an EG&G UV 444A photodiode under various conditions of oxide bias and passivation. The UV 444A was a good choice for this study because the 3nm thick oxide allows very large electric fields to be developed with small oxide biases. Many periods of oxide bias eventually resulted in an increase by a factor of 10,000 in the recombination trap density at the silicon-silicon dioxide interface. Without going into details, it now appears that thermal oxidation can passivate the interface by tying up the majority of dangling bonds at the oxide surface and strained oxygen silicon bonds that can be broken by the stress associated with large electric fields. Presumably these bonds cannot be reformed at room temperature. However, a complex involving an electron, a dangling bond, and an as yet unidentified neutral species is apparently stable at room temperature, resulting in an alternate passivation process. Verdebout has returned for two months this year to continue his study of recombination at the oxide-silicon interface. We hope to be able to devise some experiments to definitively confirm or contradict this model.

A number of the Multiple Amplifier Ratio Boxes Labeled Esoterically (MARBLE) (whose prototypes were discussed last year) were built under Fowler's supervision this year and delivered to various laboratories inside and outside NBS. In fact, with the acquisition of two MARBLE's and two QED 100's that had been tested at NBS, the Army Calibration Laboratory at Redstone Arsenal in Huntsville, Alabama was able to switch from an electrical power base to a silicon base for its primary radiometric standard below about 10 mW. Also, considerable progress was made in implementing complete microprocessor control of an electrically calibrated pyroelectric radiometer.

Based on the success of last year's feasibility study, Zalewski and Matheson of the Department of Biochemistry at the University of Georgia have measured the quantum yield of the chemiluminescence of luminol. At present there is widespread disagreement among various quantum yield measurements made by photochemists and photobiologists. Of the several compounds suggested as quantum yield standards, luminol has shown the most

promise and has been extensively studied. However, it has not been widely accepted as a standard because its quantum yield has not been accurately verified nor has the reaction protocol been precisely defined. Use of improved radiometric techniques based on silicon photodiodes has enabled a precise study of the reaction protocol and has resulted in a greatly improved repeatability and a reduction in the overall uncertainty of the quantum yield.

As part of the effort to extend the wavelength range of the calibration of the absolute spectral response of silicon photodiodes Booker and Gladden have measured the DRTIP radiometers at several mercury and xexon lines. These measurements along with the laser based response and reflectance measurements obtained last year are now being used by Gladden and Zalewski to calculate the absolute response at 10 nm intervals from 250 to 960nm. This is an extension of the interpolation calculations first reported by Geist, Zalewski and Schaefer, and requires a significant refinement of the model of the internal quantum efficiency.

PHOTOMETRIC-RADIOMETRIC CALIBRATIONS AND MAP (D. A. McSparron)

This group provides a firm measurement base for the Nation's optical radiation community (defense and aerospace, instrument manufacturers and commercial calibration laboratories, lighting and photographic industries, research institutions, etc.) To accomplish this objective, the group:

(1) maintains the U.S. photometric and radiometric scales and provides, improves and extends the NBS calibration services for the basic photometric and radiometric quantities--radiance temperature, spectral radiance, spectral irradiance, detector spectral responsivity, luminous intensity, luminous flux and color temperature.

(2) engages in activities such as intercomparisons, measurement assurance programs, consultations and ad hoc experiments that will insure that measurements made in laboratories outside NBS are being made at acceptable levels of accuracy.

The routine calibration program continues to occupy about 50% of the Group's activity. During FY 1983, calibration volume increased modestly (6%). As detailed in the section on Spectroradiometry and Optical Pyrometry, discrepancies were encountered in the realization of the radiometric scales and traced to a systematic error in temperature measurements. Walker and Lewis spent considerable time investigating this problem in collaboration with other members of the Division.

The effort to improve the documentation of the routine calibration services has continued to benefit from Hattenburg's efforts. Documentation of the services provided on FASCAL (spectral radiance and spectral irradiance) has continued to be the focus of this effort.

At the September, 1982 meeting of the Consultative Committee on Photometry and Radiometry (CCPR) plans were formulated for an international intercomparison of the photometric units of luminous intensity and luminous flux. These intercomparisons are of particular interest, since they will be the first attempt to quantitatively evaluate the effects of the recent redefinition of the photometric units. Lamps for these intercomparisons have been ordered and experimental planning is well underway. Much of the scale realization work described elsewhere in this report was undertaken in preparation for this intercomparison. NBS measurements for the first round of this intercomparison are scheduled for early FY-1984 with delivery of the lamps to the International Bureau of Weights and Measures scheduled for January, 1984.

The project to realize photometric scales through the route of self-calibrated silicon photodiodes and filter radiometry is well underway.

Two Egyptian guest workers, Khodair and Khalil, have collaborated with Bruening on this project. Appropriate interference filters have been procured and calibrated to an accuracy of 0.2%. Detector packages which are the main element of the experiment have been procured and are in the process of being characterized for linearity and quantum efficiency. When this characterization work is finished, the NBS scale of spectral irradiance and the NBS scale of luminous intensity will be compared with the detector scale. A noteworthy feature of this project is that all of the equipment and measurements have been duplicated so that the measurement capability can be taken to the Egyptian standards laboratory and thus form the basis of their photometric work.

The array radiometer specified and procured by the Spectroradiometry and Optical Pyrometry group has been used by Hattenburg on a project to calibrate a film sensitometer for the National Center for Devices and Radiological Health (NCDRH). The work included preliminary testing and debugging of the instrument, installation of a printer, fore-optics, and a delay trigger, and finally measurement of the spectral radiance (350 to 800 nm) of a low-radiance pulsed sensitometer. The measurement was performed in two stages to avoid S/N problems with the weak source; first, the time profile was determined with the sensitometer filters removed, and next the spectral radiance distribution, with filters replaced, was determined at equivalent levels in the continuous mode. NCDRH will use this work to standardize the processing of x-ray film in medical facilities nationwide.

Industry standardization of luminance and color properties of color TV sets is a prime concern to the Electronic Industries Association JT-31 Committee on Optical Characteristics of Display Devices. During the year, NBS participated with eight industrial labs in an intercomparison organized by this committee. The intercomparison consisted of measurements of chromaticity and luminance on a color TV monitor that had been modified to allow the color guns to be turned on individually and to accurately control the beam currents. Jackson measured the spectral irradiance produced by the monitor, on FASCAL, and computed the appropriate colorimetric and photometric parameters from the spectral data. This spectral procedure is in contrast to the industry practice of using filtered detectors for such measurements. The intercomparison showed a range in chromaticity values of 5 to 20 in the third place with NBS about in the middle. Assessment of these results is continuing.

The expansion of the program in the 2 to 25 micrometer, long wave infrared (LWIR) region is continuing as described in the Spectroradiometry and Optical Pyrometry Group report. Two calibrations were performed by Yokley (Spectroradiometry and Optical Pyrometry Group) and Ward during the year. One involved a cryogenic blackbody in support of the DARPA Teal

Ruby project and the other involved a room temperature blackbody in support of NAVY FLIR calibrations. The future importance of the LWIR area is becoming more widely recognized (see the National Conference of Standardizing Laboratories' National Measurement Requirements Committee report). Efforts to obtain major DOD funding will continue in the coming year.

The Fourth CORM Report identified as a high priority item, development of a sustained source of photometric standards with rapid accessibility. During the year several discussions were held with members of CORM and with members of the Lamp Testing Engineers Conference (LTEC). It was concluded that an appropriate mechanism for achieving this goal was to establish a program in which one or more commercial laboratories would maintain close ties with NBS through measurement intercomparisons. The commercial laboratories would undertake to issue standards rapidly and to generate standards of types not normally available from NBS. The intercomparisons would be designed to validate the measurement capabilities of the commercial laboratories to perform such work. Measurements of geometrically total luminous flux were considered in detail. Validation of a measurement capability for spectrally rich sources would require that at least one non incandescent source be available from NBS. Planning and equipment procurement for a program to calibrate some high pressure sodium lamps at NBS have begun. It is envisioned that when this intercomparison program is completed, CORM will disseminate the results to the measurement community.

SPONSORED CONFERENCES

Division 534, Radiometric Physics

U.S. Technical Committee 2.3 (Materials) of the CIE (International Commission on Illumination), U.S. Department of Commerce, April 21, 1983.

Infrared Information Symposium, NBS Gaithersburg, May 3-5, 1983.

Council for Optical Radiation Measurements, NBS Gaithersburg, May 23-24, 1983.

Lamp Testing Engineer's Conference, NBS Gaithersburg, May 25, 1983.

U. S. Technical Committees 1.2 (Photometry and Radiometry) and 2.2 (Detectors) of the CIE (International Commission on Illumination, Joint Meeting, NBS Gaithersburg, May 25, 1983.

INVITED TALKS

Division 534, Radiometric Physics

Cohen, J., "Introduction to Thermography for NDT," ASTM Committee E-7 on Nondestructive Testing, Fort Lauderdale, Florida, January 24, 1983.

Geist, J. C., "Quantum Yield of Silicon in the Ultra Violet," March Meeting of the American Physical Society, Los Angeles, California, March 21-25, 1983.

Mielenz, K. D., "Standardization in Spectrophotometry and Spectrofluorimetry," Ultraviolet Spectrom Group, Glaxo Operation UK Ltd., The Royal Institute of England, London, England, June 2, 1983.

Yokley, C. R., "Long Wave Infrared Calibrations at the National Bureau of Standards," SPIE Technical Symposium East '83, Arlington, Virginia, April 7, 1983.

PUBLICATIONS

Division 534, Radiometric Physics

Cohen, J., Introduction to Noise in Solid State Devices, NBS Tech. Note 1169 (December 1982).

Cohen, J., Elements of Thermography for Nondestructive Testing, NBS Tech. Note 1177 (May 1983).

Cohen, J., Three Guises of Generation-Recombination Noise, NBS Tech Note 1173 (April 1983).

Cohen J., Thermal-imaging system performance measures for nondestructive testing, Thermal Image Sensing Diagnostics (Thermosense VI), Proc. SPIE (in press).

Eckerle, K. L., Weidner, V. R., Hsia, J. J., and Kafadar, K., Measurement Assurance Program Transmittance Standards for Spectrophotometric Linearity Testing: Preparation and Calibration, J. Res. Nat. Bur. Stand. 88(1), 25-36 (January-February 1983).

Eckerle, K. L., Chao, Z. W., Weidner, V. R., and Hsia, J. J., Extension of a Reference Spectrophotometer into the Near Infrared, NBS Tech. Note 1175 (April 1983).

Eckerle, K. L., Hsia, J. J., and Liggett, W. S., Jr., Geometrical Alignment Errors in the Measurement of Prismatic Retroreflectors, Color Research and Application (in press).

Geist, J., The Physical Basis for the Self-Calibration of Silicon Photodiodes, Proceedings of Electro-Optics/Laser 80 Conference & Exposition, Boston, MA, (November 19-21, 1980), 203-205.

Geist, J., The Quantum Yield of Silicon in the Ultraviolet, Proceedings of the 10th International Symposium of the Technical Committee on Photon-Detectors, Berlin, (September 1982), 49-53.

Geist, J., and Gladden, W. K., Transition Rate for Impact Ionization in the Approximation of a Parabolic Band Structure, Physical Review B 27, No. 8, 4833-4830 (1983).

Geist, J., and Wang, C. S., New Calculations of the Quantum Yield of Silicon in the Near UV, Physical Review B 27, No. 8, 4841-4847 (1983).

Geist, J., Nyquist Noise in Current Carrying, Non-Linear Circuit Elements, J. Applied Phys. or Proceedings of IEEE (in press).

Kostkowski, H. J., Saunders, R. D., Ward, J. F., Popenoe, C. H., and Green, A. E. S., Self-Study Manual on Optical Radiation Measurements, Part III - Applications Chapter 1. Measurement of Solar Terrestrial Spectral Irradiance in the Ozone Cut-Off Region, Technical Note 910-5, (1982).

Kostkowski, H. J., Saunders, R. D., Green, A. E. S., Ward, J. F., and Popenoe, C. H., High Precision Atmospheric Ozone Measurements using Wavelengths Between 290 and 305 nm, Journal of Geophysical Research (in press).

Richmond, J. C., Hsia, J. J., Weidner, V. R., and Wilmering, D. B., Second-Surface Mirror Standards of Spectral Specular Reflectance (SRM's 2023, 2024, 2025), Nat. Bur. Stand. Spec. Publ. 260-79 (1983).

Schaefer, A. R., and Eckerle, K. L., Spectrophotometric Test Using a Dye Laser Based Radiometric Characterization Facility, Applied Optics (in press).

Schaefer, A. R., Hughey, L. R., and Fowler, J. B., Direct Determination of the Stored Electron Beam Current at the NBS Electron Storage Ring, SURF-II, Metrologia (in press).

Schaefer, A. R., Zalewski, E. F., and Geist, J., Silicon Detector Nonlinearity and Related Effects, Applied Optics 22, 1232-1236 (1983).

Shumaker, J. B., Self-Study Manual on Optical Radiation Measurements, Part I--Concepts, Chapter 10, Introduction to Coherence in Radiometry, NBS Tech. Note 910-6 (1983).

Verdebout, J., and Booker, R. L., Degradation of Native Oxide Passivated Silicon Photodiodes by Repeated Oxide Bias, J. Appl. Phy. 55, No. 2, 406-412 (January 1984).

Weidner, V. R., White Opal Glass Diffuse Spectral Reflectance Standards for the Visible Spectrum (SRM's 2015 & 2016), Nat. Bur. Stand. Spec. Publ. 260-82, (1983).

Wilkinson, F. J., Farmer. A. J. D., and Geist, J., The Near Ultraviolet Quantum Yield of Silicon, J. Appl. Physics (in press).

Yokley, C. R., Long Wave Infrared Testing at NBS, Proc. of SPIE Technical Symposium East '83, Proceedings - Applications of Optical Metrology--Techniques and Measurements II, Vol. 416, 2-8, (April 1983).

Zalewski, E., Description and Verification of the Silicon Photodiode Self-Calibrating Procedure, Proceedings of Electro-Optics/Laser 80 Conference and Exposition, Boston, MA, (November 19-21, 1980), 208-211.

Zalewski, E., and Tufino, M., Silicon Photodiode Self-Calibration as a Basic for Radiometry in the Infrared, SPIE, Contemporary Infrared Standards and Calibration 308, 2-6 (1981).

Zalewski, E., Recent Developments in the Techniques for the Self-Calibration of Silicon Photodiodes, Proceedings of the 10th International Symposium of the Technical Committee on Photo-Detectors, Berlin, (September 1982), 127-136.

Zalewski, Edward and Duda, C. R., A Silicon Photodiode Device With 100% External Quantum Efficiency, Applied Optics 22, No. 18, 2867-2873 (September 1983).

Zalewski, E. F., and Lind, M. A., Interlaboratory Comparison of Detector Spectral Response Transfer Capabilities, NBS Technical Note (in press).

TECHNICAL AND PROFESSIONAL COMMITTEE PARTICIPATION AND LEADERSHIP

Division 534, Radiometric Physics

Robert L. Booker

Member and Secretary, U.S. Panel of CIE TC-1.6 on Fundamentals of Visual Signalling.

Member, U.S. Panel of CIE TC-1.4 on Vision: Photopic Mesopic and Scotopic.

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

Robert J. Bruening

Vice-President, National Capital Section of the Optical Society of America.

Member, Lamp Testing Engineers Conference.

Julius Cohen

Member, ASTM E-7.10 Other NDT, Methods (Infrared).

Jon Geist

U.S. Representative of TC-2 - Photon Detectors Committee of the International Measurement Confederation (IMEKO).

Jack J. Hsia

Chairman, International Subcommittee on Standards and Techniques of CIE TC-2.3 on Properties of Materials.

Member, U.S. Panel of CIE TC-2.3 on Properties of Materials.

Member, ASTM D-1.26 Subcommittee on Optical Properties of Paint, Varnish, Lacquer and Related Products.

Member, ASTM E-12 Committee on Appearance of Materials.

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

Member, ASTM E-37 Committee on Thermal Measurements.

Delegate from ASTM to ISCC.

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

Jack J. Hsia (continued)

U.S. Delegate to 20th CIE Congress, Amsterdam, The Netherlands.

Consultant, CIE Technical Division II

Donald S. McSparron

Member, ANSI Z311 on Photobiological Safety of Lamps.

Member, Lamp Testing Engineers Conference.

Member, Illuminating Engineering Society (IES) - Testing Procedures Committee

Member, U.S. Panel of CIE TC-1.2 on Photometry and Radiometry.

U.S. Delegate to 20th CIE Congress, Amsterdam, The Netherlands.

Klaus D. Mielenz

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

Chairman, CIE International Technical Committee TC-2.3 on Properties of Materials.

U.S. Delegate to 20th CIE Congress, Amsterdam, The Netherlands.

Secretary, CIE Technical Division II

Member, ASTM E-13 on Molecular Spectroscopy.

Member, ASTM E-13.06 on Luminescence.

Member, Comite Consultatif de Photometrie et Radiometrie.

Board of Directors (ex officio), Council on Optical Radiation Measurements.

Fred E. Nicodemus

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

Member, U.S. Panel of CIE TC-1.1 on Terminology.

Robert D. Saunders

Member, IES Committee on Photobiology.

Member, Illuminating Engineering Research Institute (IERI) Committee on Extra Visual Effects.

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

A. Russell Schaefer

Member, U.S. Panel of CIE TC-2.2 on Detectors and Photometric Instruments.

Member, Teller's Committee of Optical Society of America.

John B. Shumaker

Member and U.S. Coordinator of U.S. Panel of CIE TC-2.3 on Polarization.

William D. Waters

Member, ASTM E-20.02 on Radiation Thermometry.

Edward F. Zalewski

Chairman, U.S. Panel of CIE TC-2.2 on Detectors.

Member, U.S. Panel of CIE TC-1.2 on Photometry and Radiometry.

U. S. Delegate to 20th CIE Congress, Amsterdam, The Netherlands,

MAJOR CONSULTING AND ADVISORY SERVICES

Division 534, Radiometric Physics

1. R. J. Bruening consulted extensively with Tom Luminello of Polaroid on the calibration and testing of photographic sensitometers.

2. K. L. Eckerle provided consultation to ASTM Committee E-12 on statistical analysis of intercomparison and precision statement for ASTM method on retroreflectance measurements.

3. K. L. Eckerle provided consultation to Drs. Shafik Khalil and Mohamed from the National Standards Institute of Egypt on spectral transmittance measurements of interference filters.

4. J. J. Hsia provided consultation to George Reed, Jr. of Kalwall Corporation on diffuse transmittance measurements using integrating sphere.

5. J. J. Hsia and D. A. McSparron consulted with Geng Zhiyuan and Liu Jianguo of Laser Testing Centre, Opto-Electronic Technology Institute, Beijing, China, on spectroradiometric and spectrophotometric measurements.

6. J. K. Jackson and A. T. Hattenburg provided consultation and on site measurements to John Sager of the Smithsonian Institute to resolve discrepancies in spectral irradiance measurements in plant growth chambers.

7. D. A. McSparron consulted with Dr. Gerald Burnett of General Dynamics and H. S. Peiser of the Office of International Relations on photometric equipment and appropriate tests of photometric measurement capability for the University of Petroleum and Minerals, Dhahran, Saudi Arabia (Dr. A. I. Al Mana, contact).

8. D. A. McSparron and K. D. Mielenz advised Mr. Donnelly and Mr. Steeb of General Electric on the NBS photometric calibration program and its role in the National Measurement System.

9. D. A. McSparron provided consultation to NASA and Bill Fowler of Ball Aerospace Division on calibration of the SBUV/II ultraviolet solar monitoring satellite.

10. F. E. Nicodemus is a technical advisor to the Joint Infrared Standards (JIRS) Working Group of the Countermeasures Sub-Group of the R&D Joint Technical Coordination Group on Aircraft Survivability (JTCG/AS).

Major Consulting and Advisory Services (cont'd)

11. F. E. Nicodemus is a Subject Specialist Representative for the Division to the NBS Library.

12. C. H. Popenoe is a member of the microprocessor subcommittee of the NBS Electronics Storeroom Committee.

13. C. H. Popenoe provides ongoing consultation and advice in areas of computer interfacing, laboratory automation, data acquisition and computer control to personnel in other divisions within NBS.

14. R. D. Saunders consulted with members of the staff of the Bureau of Radiological Health on spectral irradiance measurements for monitoring uv radiation hazards.

15. R. D. Saunders consulted with members of the staff of NOAA (Boulder, Colorado) on solar uv spectral irradiance measurements.

16. V. R. Weidner and J. J. Hsia provided consultation to Liu Jianguo and Geng Zhiyuan of Beijing Opto-electronic Technology Institute of China on prepration of tetrafluoroethylene powder and measurements of reflectance.

17. V. R. Weidner provided consultation to Tom Logan and William T. Winberry, Jr. of EPA in North Carolina on calibration of neutral density filters for use in calibrating smoke emission monitoring equipment.

18. C. R. Yokley consulted with Felix Schweizer of the Navy Metrology Engineering Center and Herb Little of Calspan Field Services on the design, construction, and calibration of blackbodies for DOD infrared work.

19. E. F. Zalewski visited the National Office of Measures in Budapest, Hungary, from Aug. 23 to 26, 1983 to assist the Optics Section in establishing radiometric and photometric scales based on the self-calibration of silicon photodiodes.

STANDARD REFERENCE MATERIALS

Division 534, Radiometric Physics

1. SRM 1001, X-Ray Film Step Tablet

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

2. SRM 1008, Photographic Step Tablets

   Used in the calibration of optical densitometers and similar equipment used in the photographic and graphic arts fields. Certified for Optical Densities from 0 to 4.

3. SRM 1010a, Microcopy Resolution Tests Charts

   Used for determining the resolving power of microcopy systems.

4. SRM 2061, Reflection Step Tablets

   Used in the calibration of reflection densitometers and similar equipment used in the photographic and graphic arts fields. Certified for optical density from 0 to 2.

5. SRM 2019 and 2020, White Ceramic Tile for Directional-Hemispherical Reflectance from 250 to 2500 nm,
   SRM 2021 and 2022, Black Porcelain Enamel for Directional-Hemispherical Reflectance from 250 to 2500 nm,
   SRM 2015 and 2016, White Opal Glass for Directional-Hemispherical Reflectance from 400 to 750 nm.

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

6. SRM 2003a, First Surface Aluminum Mirror for Specular Reflectance from 250 to 2500 nm.

   SRM 2023, 2024, and 2025 Second Surface Aluminum Mirror for Specular Reflectance from 250 to 2500 nm.

   For use in calibrating the photometric scale of specular reflectometers.

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

CALIBRATION SERVICES PERFORMED

Division 534, Radiometric Physics

Type of Service	Customer	SP 250	Number of tests	Income
Pyrometry		7.4 A thru G	15	$20K
	Defense & Aerospace		9	$13K
	Instrument & Cal labs		1	1K
	Lighting & Photography		2	2K
	Electrical & Materials		3	4K
Spectroradiometry		7.5 A thru J	31	$82K
	Defense & Aerospace		10	$48K
	Instrument & Cal labs		8	9K
	Lighting & Photography		3	5K
	Foreign		5	11K
	Electrical & Materials		5	9K
Photometry		7.7 A thru R	30	$48K
	Defense & Aerospace		10	$14K
	Instrument & Cal labs		5	15K
	Lighting & Photography		5	5K
	Foreign		8	11K
	Electrical & Materials		2	3K
Spectrophotometry		7.8 A thru I	35	$20K
	Defense & Aerospace		4	$ 5K
	Instrument & Cal labs		20	10K
	Lighting & Photography		3	1K
	Foreign		4	1K
	Electrical & Materials		4	3K
			111	$170

Calibration Services Performed (cont'd)

A. T. Hattenburg, special calibration of the spectral radiance of a low-radiance pulsed sensitometer for the National Center for Devices and Radiological Health.

TRIPS SPONSORED BY OTHERS

Division 534, Radiometric Physics

J. Geist, airfare and per diem supplied by University of Arizona to review design of solar spectral radiometer developed for solar monitoring program by University of Arizona for NOAA. (12/12-15/82).

K. D. Mielenz, airfare and per diem supplied by Perkin-Elmer Limited, London, England, for lecture at the Royal Institution at the invitation of the Ultraviolet Spectrophotometry Group. (6/1-2/83).

E. F. Zalewski, per diem supplied by the Hungarian National Office of Measures within the framework of the USA-Hungarian Exchange Program (8/23-26/83).

TECHNICAL ACTIVITIES

Division 535, Radiation Source and Instrumentation

Task No. 15252 - Provide linac beam
Task No. 15253 - FASTBUS instrumentation specification
Task No. 15254 - Design, install and test microtron components

CW Microtron Project

This project, sponsored by the Division of Nuclear Physics of the Department of Energy is a joint effort of the Radiation Source and Instrumentation Division of CRR and the Accelerator Technology Division of the Los Alamos National Laboratory. We have just completed the fourth year of this project. It has been a productive and successful year. The 100 keV beam line has been completed and tested (except for the rf chopping and bunching), and found to meet or exceed all design goals. The 2.7m preaccelerator section employing side-coupled rf structure has been built and tested (without beam), and found to meet or exceed all design goals.

In March 1983 we presented to DoE a revised budget and schedule for the project. At that time we predicted a September 1985 completion of the project including a full set of accelerator performance measurements. We have had to make some internal rearrangements of the schedule, primarily due to delivery delays of contracted construction work, and we have had to accept a slight delay in project completion due to a slightly reduced level of funding. We now forcast a March 1986 completion date. Spending since March 1983 has been within budget estimates presented at that time.

We have published a number of our technical innovations, and several of these are already having a significant impact on other accelerator projects. For example, the University of Illinois is reproducing our end magnets and copying our injection system (with only minor changes) in the upgrade of their superconducting microtron MUSL-2 to a ~ 200 MeV room-temperature machine. The side-coupled rf structure developed in our project appears ideal for several other applications.

Planning for New Facility

In January 1983 we submitted to DoE and NSF a proposal to fund the construction of a second stage, 1 GeV RTM, and experimental facilities for both the 200 MeV and 1 GeV machines. The proposal was reviewed by NSAC (Nuclear Sciences Advisory Committee). The proposal was not recommended for DoE/NSF funding by NSAC (along with three others) in favor of the SURA proposal for a 4 GeV CW machine. However the NSAC Panel "Strongly encourages the Department of Commerce to continue to operate the 200 MeV facili-

ty as it has NBS facilities in the past, welcoming collaborators from the external scientific community involved in experimental programs with NBS staff."

Based on this endorsement, plus strong interest from many potential university-based collaborators, and encouragement from high levels within DoE, NSF, and OSTP, we (Divisions 535 and 532) have submitted an initiative for the FY 1985 budget to support a vigorous research program using the RTM. The initiative includes several new staff positions plus new experimental apparatus to utilize the RTM, plus a provision to continue operation of the Linac, for neutron measurements only.

Consulting and Advisory Services

The application of accelerators and accelerator technology is growing at a tremendous rate, as evidenced by the fact that there is at present a severe nationwide shortage of trained accelerator physicists and engineers. Older applications of accelerators in fields such as cancer therapy, medical diagnostics, curing of paints and plastics, nuclear and high energy physics research, and many others are well known. Newer applications in such areas as fusion energy sources (both magnetic and inertial confinement fusion schemes do or might employ particle accelerators), weapons, weapon effects simulation, and materials far beyond what was thought possible a few years ago. NBS has an excellent reputation in the accelerator community, based largely on important contributions made in the past, and therefore we are constantly being called on to provide consulting and advisory services, as well as specific research work. Requests for our services in this area have come from many agencies including DoD, DoE, NSF, NASA, as well as a number of universities and industrial organizations. Although our in-house research programs on DoD accelerator needs have been phased out, both M. Wilson and S. Penner will continue to provide consulting services as requested.

LINAC OPERATIONS

Division 535, Radiation Source and Instrumentation Division

The NBS Electron Linac was designed in 1960 with maximum flexibility in order to support a wide variety of program activities of interest to NBS. Major users of the linac in FY 1983 included programs in neutron cross section standards and radiography, high energy electron scattering, electron activation, photonuclear research, and activation analysis. The last is an activity of the Center for Analytical Chemistry. In addition, a number of outside collaborators and guest workers participated in the above mentioned programs.

The Linac Operations staff normally consists of three engineers and seven technicians. At present the staff consists of only one engineer and four technicians. In spite of its relatively small size this group has achieved a highly commendable operating efficiency as described below. The staff operates and maintains the facility as well as designs, constructs, and installs new equipment to improve operations and extend the capability of the Linac and the beam handling system. The mechanical instrumentation group within the Division provides help by maintaining the integrity of the vacuum and cooling systems of both the Linac and beam handling system as well as designing, construction, and installing mechanical components. Table I shows the distribution of the total Linac Operations staffing time in operation of the facility for FY 1983 (through July 1983). The facility is staffed from 7:30am Monday morning and runs for experiments until 6:30 am Saturday. Scheduled maintenance hours have varied throughout the year.

Experiment time on the facility was requested by and allocated to users at scheduling meetings, which were held every four weeks. Time requested by experimenters did not come up to 100%. Table I shows a new item, unscheduled time, 324 hours. This was a result of several of our users not being able to schedule time due to equipment failure and then taking part in long range planning activities. Most of this time was used for the staff to use annual leave, etc. Table II shows the distribution of time by experiment for the fiscal year.

The unscheduled maintenance of 687.0 hours, through August 1, is broken down and summarized by system in Table III. The large amount of unscheduled maintenance is due, in the main, to three factors: (1) the facility is old, having begun operation for experiments in 1965, (2) the lack of resources, especially in FY 1982 and 1983, both financial and personnel wise, and (3) due to #2 we were unable to have a scheduled shut down for annual preventive maintenance.

Division 535, Linac Operations (cont'd.)

TABLE I

LINAC OPERATIONS

Month/Year FY 83	Scheduled Hours	Actual Hours
Maintenance	436.0	436.0
Unscheduled Maintenance	---	737.0[1]
Beam Time	3055.5	2303.5
Set-Up*	125.0	121.5
Experimental Down-Time**	---	18.5
Installation	---	---
Inventory	---	---
Unscheduled Time	380.0	380.0
TOTAL HOURS***	3996.5	3996.5

*Includes lock-up after scheduled maintenance.

**Linac available for operation, but experiment either not ready or breaks down during scheduled run.

***Total staffing hours.

[1]Includes 119.5 hours of Plant down time.

TABLE II

LINAC OPERATIONS

FY 1983
Distribution of Time by Experiment

	[1]Scheduled Beam Hours	Actual Beam Hours	[2]Setup Hours	[3]Unscheduled Maintenance Hours	[4]Experiment Downtime Hours	Total Scheduled Beam%	Total Actual Beam%
ELECTRON SCATTERING	239.0	186.0	11.0	27.0	15.0	7.5	8.1
NEUTRONS	1443.0	1132.0	36.5	273.5	1.0	45.4	49.1
PHOTONUCLEAR SPECTROMETER	1071.5	766.0	40.5	265.0	---	33.7	33.3
ACTIVATION ANALYSIS	300.0	145.5	27.5	126.0	2.5	9.4	6.3
LINAC ELECTRON ACTIVATION	127.0	74.0	6.0	45.5	---	4.0	3.2
	3180.5	2303.5	121.5	737.0	18.5	100	100

[1]Machine time assigned to experiment, includes scheduled setup time of 121.5 hours.
[2]Includes lock-up after scheduled maintenance.
[3]Includes 165.5 hours plant related unscheduled maintenance.
[4]Linac available for operation, but experiment not ready or breaks down during scheduled run.

$$\text{EFFICIENCY} = \frac{2303.5 + 165.5 + 18.5}{3180.5 - 121.5} \times 100 = 81.3\%$$

*THROUGH SEPTEMBER 1983

Division 535, Linac Operations (cont'd.)

TABLE III

LINAC OPERATIONS

FY 83

LINAC: Total unscheduled maintenance 571.5 hours

System:

Injector	197.0 hours	34.5%
Modulators	184.0 hours	32.2%
R.F. Drive	65.0 hours	11.4%
R.F. Window (Buncher)	34.5 hours	6.0%
Vacuum	27.0 hours	4.7%

No other system or item over 2%.

BHS: Total unscheduled maintenance 26.0 hours.

Balance of total unscheduled maintenance, 165.5 hours, due to air conditioning and power outage.

SURF OPERATIONS

Division 535, Radiation Source and Instrumentation Division

SURF-II is a dedicated synchrotron radiation facility. consisting of the recently upgraded 280 MeV electron synchrotron storage ring, a 10 MeV microtron injector and associated synchrotron radiation beamlines. It produces light in a narrow, intense, highly polarized beam with a continuous and accurately known spectrum from the infrared through the visible and into the extreme ultraviolet. SURF-II is unique among synchrotron light sources by virtue of its uniform and precisely known electron orbit.

SURF-II serves users from the Radiation Physics Division (533) as well as from other NBS divisions and outside users, in radiometric standards and calibration work, optical physics research, surface science, biochemistry, spectroscopy and other areas involving ultraviolet radiation. It fills a growing demand for radiation in the ultraviolet and soft x-ray region of the electromagnetic spectrum. The multiple ports at SURF now serve six active experimental stations, all of which can run simultaneously. The Optical Calibration Facility on beamline 2 is operating on a full schedule for outside user groups. Three additional stations are under construction.

During FY 83 several significant improvements in machine performance were achieved, principally in terms of beam current and beam stability. These improvements complement the increase in operating energy implemented in FY 82 and combine to make SURF-II a brighter as well as a more accurate source of ultraviolet radiation. A new record beam of 60 mA at 282 MeV was attained recently (the old record was 47 mA @ 243 MeV). Routine beam currents are now in the 20 to 40 mA range; formerly typical beams were 10 to 20 mA. Beam stability has been improved in two ways: (1) the short-term stability of the storage ring magnet power supply was improved by an order of magnitude and (2) the stability of the beam size in the "fuzzed" mode was improved dramatically by replacing the discrete frequency source used to drive the vertical beam resonance with a narrow-band white noise source. In addition to providing a cleaner, more stable light source, these last two improvements are also paying dividends from the point of view of machine performance and operating ease. Better magnet stability allows the operator to fine-tune the machine more easily and more quickly and to obtain consistently bigger beams. Similarly the use of white noise has greatly simplified the "fuzzed" mode of operation. No tuning is required. The operator merely sets the drive level with a single knob.

Considerable effort was expended this year to improve the vacuum quality in the machine. Chronic leaks in the microtron, transport line and storage ring were located and eliminated. The pumping capacity of the

microtron vacuum system was also improved. The effect on machine performance has been dramatic. At 10^{-8} torr, beam lifetime in the ring at 10 MeV injection energy was only a few seconds. Consequently, 50% of the beam or more may have been lost during the low-energy phase of the acceleration process. Now, at 10^{-9} torr, beam lifetime at 10 MeV is tens of seconds, long enough to accelerate nearly all the captured beam to high energy where vacuum effects are much less pronounced.

The improved pumping capacity of the microtron vacuum system has made it feasible to pursue detailed studies of mictoron performance. Orbit-by-orbit measurements of beam current have been performed. These indicate that beam losses occur primarily during the first three orbits in the microtron, as well as in the last two. The RF cavity is probably responsible for losses in the first few turns. Experiments with different cavity flight apertures are now in progress. The losses in the final orbits may be due to magnetic field inhomogeneity. Detailed field mapping will be required to verify that hypothesis. It may be possible to draw on the expertise of the RTM group after they have completed their measurements of the RTM end magnets.

While extraction from the microtron, transport to the ring and passage through the inflector channel are all quite efficient, capture in the storage ring is very inefficient. The capture process is controlled by the tune of the magnet and by the pulse bump field Investigation of capture vs. pulse bump coil voltage showed that the 10 kV provided by the present power supply is far below optimum. Boosting this voltage to 12 kV gave an immediate 50% increase in captured beam current and was in large part responsible for the 60 mA record beam. 15 kV may yield a 100% increase. Further increase beyond 15 kV, if warranted, would necessitate complete redesign of the pulser, the vacuum feedthroughs and the coil itself. For the present, the system circuitry, cabling and connectors have been upgraded to withstand 15 kV and a suitable power supply is on order.

It should be mentioned that the second harmonic RF system was tested and its effect on the beam was investigated. Its effectiveness in the present form was judged to be less than satisfactory for a number of reasons. The harmonic RF output showed excessive phase jitter relative to the fundamental. (This can be remedied with a phase-locked loop). The compromises made in combining the pulse bump coil with an accelerating cavity resulted in lower Q and less effective pulse bump operation. than if separate structures had been used. For the time being, the structure has been removed from the ring for further bench testing. The original bump coil has been reinstalled. However, the concept of harmonic RF excitation for bunch stretching is still a promising one. Since the half-life of an unfuzzed 60 mA beam is only about 20 minutes, the need for such a system is greater than ever and will continue to be pursued.

Reviewing the experience and accomplishments of the past year, it is interesting to compare the present performance of SURF with its original specifications on the one hand, and with the latest projection for the future on the other. The projections take into account the following:

(1) The record 60 mA stored beam was achieved with a microtron output of only 27 mA. The microtron has in the past produced 45 mA. With an optimized RF cavity, it may yield 60 mA or more, (limited by the available RF output of the magnetron.) This should provide at least a factor of two improvement.

(2) Increasing the pulse bump voltage to 15 kV should increase capture by another 30-40%, unless capture begins to plateau above 12 kV.

(3) The magnet, coils and power supplies are capable of supporting 300 MeV. The present 2 kW RF supply would have to be replaced with a 5 kW unit to maintain reasonable beam lifetime at that energy. The main RF cavity may have to be redesigned to avoid voltage breakdown. In addition, the water cooling system will require additional capacity to handle the increased thermal load.

In the projection for beam current it is tacitly assumed that no current-dependent instabilities will be encountered, or, if they are, that they can be overcome.

It is appropriate to acknowledge at this point that many of the improvements and accomplishments reported here and in past reports have been achieved through the continuing close cooperation between the SURF Operations staff and the Far UV Physics group of the Radiation Physics Division (533).

Table I. SURF II Performance History and Projections

	Original Specification	Present Performance	Projected Limits
ENERGY	240 MeV	282 MeV	300 MeV
CURRENT	10 mA	60 mA	160 mA

Operational statistics are not as impressive this year, due in large part to the shutdowns which were necessary to accomplish the various improvements described above. Whenever possible, these shutdowns were scheduled during lulls in user demand. Unscheduled downtime was up too, mainly because of vacuum problems with the microtron RF waveguide feedthrough. At present the machine is in very good health and is performing well at the newly-attained levels of beam intensity.

Division 535, SURF Operations (cont'd.)

Table 2. SURF Operational Statistics

	FY 81	FY 82	FY 83
Beam to users	1872 hours	855 hours	989 hours
Standby (beam available)	267	81	259
Studies & Maintenance	216	136	280
Unscheduled Downtime	126	159	304
Total hours	2481	1262 (6 month shutdown)	1832 (1 1/2 month shutdown)

SURF Users During FY 83

NBS Users:

R. Madden, D. Ederer, L. Hughey, A. Parr E. Saloman. S. Southworth, N. Swanson; Far UV Physics Group, Radiation Physics Division, 533

J. Geist, R. Schaeffer; Radiometric Physics Division, 534

J. Cooper, Center for Absolute Physical Quantities, 520

T. Madey, R. Stockbauer, D. Doering, R. Kurtz; Surface Science Division, 541

Outside Users:

G. Carruthers, NRL

M. Van Hoosier, NRL

R. Williams, D. Ma, S. Mak, NRL

J. Rife, NRL

D. Williams, J. Mentall, NASA Goddard

R. Linton, NASA Marshall

J. Chmielewski, Los Alamos

R. Catchings, Howard University

Division 535, SURF Operations (cont'd.)

G. Mount, R. Jakoubek, LASP University of Colorado

J. Risley, A. McPherson, N. Rouze, North Carolina State University

D. Hwang, Princeton University

C. Mehlman, CNRS France

E. Bertel, University of Innsbruck, Austria

D. Holland, Daresbury, U.K.

INSTRUMENTATION STANDARDS

Division 535, Radiation Source and Instrumentation

Electronic Instrumentation Maintenance and Construction

Provision of electronics instrumentation maintenance and construction services for the experimental programs of the Center for Radiation Research is a continuing responsibility of the Radiation Instrumentation Group in the Division. Instruments designed and constructed during 1983 number about 90 and maintenance has involved about 230 instruments.

Control Instrumentation Design and Construction

Design and construction of experiment and system control instrumentation continues to be an important element of Radiation Instrumentation Group activities. Recent examples of this instrumentation are: a target system controller for the electron scattering spectrometer used on the linear accelerator; an automatic, computer-controlled standards measurement system for the new 320 KV X-ray set; a vacuum control and interlock system for a low energy electron spectrometer.

Instrumentation Support for Physics and Chemistry Projects

Consulting and systems instrumentation has been provided to scientists in programs relating to neutron physics, electron physics, surface electron physics, X-ray dosimetry, radiation chemistry, vacuum ultraviolet physics (SURF), analytical chemistry, physical chemistry and photometry. In addition, very considerable support has been provided for RTM projects including wire-scanner amplifier development, high voltage terminal testing, and continuous and continuing support for instrumentation construction, wiring and installation. Gain-switchable, low-noise, D.C. current amplifiers for the RTM wire scanners were successfully completed. An exhaustive measurement of the noise levels of available charge-sensitive amplifiers, also for the scanners, was made.

During the year, the Group specified, procured and installed the Hewlett-Packard 9845 based computer aided design system which the Group maintains as an NBS facility. This equipment was funded by the Director's Office. Access on a time-shared basis is available to all NBS staff.

During the year we have been able to install two excellent spectrum analyzers, which with some ancillary generators, will enable us to make swept frequency measurements.

Consultation continues to be provided to other NBS Centers notably the Center for Analytical Chemistry and the Center for Chemical Physics. Two Egyptian scientists received training in repair and maintenance tech-

niques in our laboratory under an AID sponsored program. There is continuing consultative assistance being provided to the University of Petroleum and Minerals, Dharan, Saudia Arabia, on the subjects of instrumentation repair and maintenance.

Mechanical Instrumentation Services

Mechanical instrumentation services were provided for the Center for Radiation Research in connection with the particle accelerators of the CRR and the experimental programs of the Center. The services provided consist of design and construction of new equipment and facilities as well as maintenance, and modification of existing equipment. This past year for the first time an electron gun for the linac was rebuilt in-house and is currently in use with better beam characteristics than have been achieved with commercially rebuilt guns. The building program for the NBS LANL Racetrack Microtron is continuing. The viewscreens, wire scanners and chopper apertures have been installed in the 100 keV beam line and have successfully received beam. The turn around magnet supports have been built and installed in the RTM room. The water cooling lines have been installed in the RTM room and the water cooling distribution system has been designed.

RADIATION INSTRUMENTATION STANDARDS

Division 535, Radiation Source and Instrumentation

Standards work falls into three categories as follows:

(a) NIM Committee Standards - This involves development and maintenance of instrument standards, in cooperation with the National Laboratories, primarily for use in nuclear applications. NBS has the management responsibility for this work, with L. Costrell serving as Chairman of the NIM Committee. The Nuclear Instrumentation Module (NIM) system has been adopted nearly universally in the US and is the predominant system in nuclear laboratories throughout the world. There is a continous coordination requirement involving contact with numerous laboratories and manufacturers. Similar management, direction and maintenance are provided in the U.S. with regard to the international CAMAC (Computer Automated Measurement and Control) system that is utilized in the National Laboratories and in a large number of other laboratories and installations throughout the world. A third system now being developed and for which the Division has similar responsibility is the FASTBUS high speed modular data acquisition system for high energy physics and other applications. The FASTBUS development has been a major effort and is well underway, with commercial equipment available and prototype systems in operation or in preparation in several laboratories in the U.S., Europe and Japan.

The preparation of reports for the above systems involves a number of individuals and laboratories. Coordination and processing, as well as writing of some sections, is handled by the National Bureau of Standards. The documents are usually issued as Reports of the Department of Energy and then processed as Standards of the Institute of Electrical and Electronics Engineers (IEEE), the American National Standards Institute (ANSI), and the International Electrotechnical Commission (IEC). There are currently several CAMAC standards. These have been updated and the updated documents issued in FY 82. Some additions to the basic NIM standard, such as specifying the "IEEE Standard Interface for Programmable Instrumentation" (IEEE Std 488) as a digital data bus for NIM instruments, have been undertaken. The NIM digital bus specification has been submitted to the Department of Energy for publication. It has elicited considerable interest from industry and the user community.

The NIM and CAMAC standard instrumentation projects have resulted in a savings of at least 1.9 billion 1982 dollars according to a study recently conducted for the Department of Energy by a firm of economics consultants.[1] The study report states that the 1.9 billion dollars is considered to be a minimum figure conservatively arrived at on the basis of available data. 1.7 billion dollars is attributed to the NIM system initiated by the Center for Radiation Research[2] and the balance of 200 million dollars to the CAMAC instrumentation system developed by the ESONE

Committee of Euorpean Laboratories with the active collaboration of the U.S. NIM Committee and the CRR. The reports adds: "The benefits were estimated only if they could be documented from the literature or telephone contacts. There are a number of other direct and indirect benefits associated with the use of CAMAC and NIM interfaces which were not considered in this analysis because no measureable data were available." The total world-wide saving can be reasonably projected to be double the U.S. savings.

(b) National Voluntary Standards - The Division plays an active role in IEEE and ANSI Standards activities with L. Costrell serving 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. J. Whittaker serves on ASTM Commttee D-22 on Methods of Sampling and Analysis of Atmospheres.

(c) International Electrotechnical Commission - L. Costrell serves as Technical Advisor to the US National Committee of the IEC for IEC Committee TC45 on Nuclear Instruments. He serves as Chief US Delegate to TC45, as Chairman of the Working Group on Detectors and as a member of the working groups on Interchangeability and on Terminology. Numerous IEC draft documents were prepared and reviewed resulting in a number that were published and others that are to be published.

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1 "Benefit Analysis of Selected Accomplishemnts of DOE's Office of Health and Environmental Research", Final Report RR-166, November 29, 1982, Ecosometrics, Inc. (M. Lago, M. J. Ramsdell, S. F. Knapp, S. I. Siddique, Bethesda, MD.

2 "Standard Modules for Nuclear Insturmentation," NBS Report 8137, December 5, 1963, L. Costrell.

INVITED TALKS

Division 535, Radiation Source and Instrumentation

Costrell, L., "FASTBUS for Data Acquisition and Control," 1983 Particle Accelerator Conference, Santa Fe, New Mexico, March 21, 1983.

Debenham, P. H., "NBS-Los Alamos National Laboratory Racetrack Microtron," University of Illinois, Urbana-Champaign, Illinois, September 15, 1983.

Debenham, P. H., "Progress on the NBS-LANL CW Microtron," 7th Conference on the Application of Accelerators in Research and Industry, Physics Department, North Texas State University, Denton, Texas, November 8, 1982.

Penner, S., "The NBS Proposal for a One GeV CW Racetrack Microtron Facility," 1983 Particle Accelerator Conference, Santa Fe, New Mexico, March 23, 1983.

Penner, S., "Proposal for a 1 GeV CW Electron Accelerator Facility at NBS," University of Maryland Seminar Series - Accelerator Theory and Dynamical Systems, University of Maryland, College Park, Maryland, May 11, 1983.

Penner, S., "Status of NBS Microtron," University of Mainz, Mainz, West Germany, September 9, 1983.

Whittaker, J. K., "Selection, Procurement and Use of Microprocessors at NBS," National Bureau of Standards, Washington, D.C., October 26, 1982.

PUBLICATIONS

Division 535, Radiation Source and Instrumentation

Chen, P. T., and Rose, J. E., The Building Process and Budget Estimates for the Proposed Race Track Microtron Facility Addition, NBSIR 82-2616(R) (1982).

Costrell, L., and Dawson, W. K., FASTBUS Modular High Speed Data Acquisition System, Proceedings of IEEE International Conference on Communication, 5C.4.1-5C.4.5 (1982).

Costrell, L., and Dawson, W. K., FASTBUS for Data Acquisition, IEEE Particle Accelerator Conference, March 21-23, 1983, IEEE Transactions on Nuclear Science NS-30, No. 4, 2147-1151, (1983).

Cutler, R. I., Mohr, D. L., Whittaker, J. K., and Yoder, N. R., A High Resolution Wire Scanner Beam Profile Monitor with a Microprocessor Data Acquisition System, IEEE Transactions on Nuclear Science NS-30, No. 4, 2213-2215, (1983).

Cutler, R. I., Performance of the NBS-LANL RTM Injection Line Vacuum System, IEEE Transactions on Nuclear Science NS-30, No. 4, 2904-2905 (1983).

Debenham, P. H., Penner, S., Ayres, R. L., Cutler, R. I., Lindstrom, E. R., Mohr, D. L., Rose, J. E., Wilson, M. A. D., Yoder, N. R., Young, L. M., Mitra, A., Potter, J. M., Stokes, R. H., Tallerico, P. J., and Wilkerson, L., Progress on the NBS-LANL CW Microtron, Institute of Electronics and Electrical Engineers, Transactions on Nuclear Science NS-30, No. 2, 1391-1395 (1983).

Lindstrom, E. R., Debenham, P. H., Mohr, D. L., and Yoder, N. R., The NBS-LANL RTM End-Magnet Field Mapper, IEEE Transactions on Nuclear Science NS-30, No. 4, 3605-3607 (1983).

Parrington, J. R., Whittaker, J. K., and Zoller, W. H., Instrumentation for and Results of Particulate Sampling of Diurnal Winds at Mauna Loa Observatory (in press).

Penner, S., The NBS Proposal for a One GeV CW Racetrack Microtron Facility, IEEE Transactions on Nuclear Science NS-30, No.4, 3279-3285 (1983).

Rakowsky, G., SURF II Upgrade Features Magnet and RF System Enhancements, IEEE Transactions on Nuclear Science NS-30, No. 4, 3444-3446 (1983).

Wilson, M. A., Cutler, R. I., Lindstrom, E. R., Penner, S., Yoder, N. R., Ayres, R. L., Mohr, D. L., Young, L. M., and Martin, E. R., NBS-LANL RTM Injector Installation, IEEE Transactions on Nuclear Science NS-30, No. 4, 3021-3023 (1983).

TECHNICAL AND PROFESSIONAL COMMITTEE PARTICIPATION AND LEADERSHIP

Division 535, Radiation Source and Instrumentation

Robert L. Ayres

Member, NBS Microprocessor Storeroom Subcommittee

Chairman, NBS Microprocessor Users Group

U.S. Representative, Life Sciences Working Group of the International Committee for Radionuclide Metrology

Louis Costrell

Chairman, ANSI Technical Committee N42, Nuclear Instruments

Member, ANSI Technical Committee N41, Controls, Instrumentation, and Electrical Systems for Nuclear Power Generating Stations

Chief U.S. Delegate, International Electrotechnical Commission (IEC), Technical Committee on Nuclear Instruments (IEC/TC45)

Chairman, IEC/TC45 Working Group-9 on Radiation Detectors

Member, IEC/TC45 Working Group-3 on Interchangeability

Member, IEC/TC45 Working Group-1 on Classification and Terminology

Technical Advisor, U.S. National Committee of IEC

Secretary, Institute of Electrical and Electronics Engineers Nuclear Instruments and Detectors Committee of IEEE Nuclear and Plasma Sciences Society (IEEE)/NPSS)

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

Chairman, U.S. Department of Energy National Instrumentation Methods (NIM) Committee

Chairman, NBS Microprocessor Standards Actions Group

Philip H. Debenham

Member, Advisory Panel for DoE-sponsored University of Washington Superconducting Booster Project

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

Member, 1983 and 1985 Particle Accelerator Conference Program Committee

Samuel Penner

Member, International Advisory Committee for 1984 Linear Accelerator Conference (Germany)

Member, 1983 and 1985 Particle Accelerator Conference Program and Organizing Committees

Member, Review Committees for Saskatoon and Montreal at request of the Canadian Government

Julian K. Whittaker

Member, ASTM Committee D-22 on Methods of Sampling and Analysis of Atmospheres

Member, U.S. Department of Commerce, Industry and Trade Administration, Electronic Instrumentation Technical Advisory Committee

Chairman, Electronics Storeroom Committee, NBS

Chairman, Electronics Storeroom Committee Microprocessor Subcommittee, NBS

Chairman, NBS Property Review Advisory Board Panel

Member, ASTM Planning Committee for Medical Databases

MAJOR CONSULTING AND ADVISORY SERVICES

Division 535, Radiation Source and Instrumentation

1. R. Ayres serves as a member of the U.S. Pharmacopoeia Convention Advisory Panel to the Subcommittee on Radiopharmaceuticals.

2. S. Penner and M. Wilson continue to provide Accelerator Technology and Assessment and Oversight for DARPA.

3. J. Whittaker serves as a consultant on instrumentation and instrumentation maintenance and repair to AID for the Egyptian Government Standards Laboratories.

4. J. Whittaker serves as an advisor to two Egyptian visiting scientists in the field of repair and maintenance services.

5. J. Whittaker serves as an advisor to a graduate student in the Department of Chemistry, University of Maryland.

6. J. Whittaker serves as a consultant on electronics instrumentation and instrumentation repair and maintenance to the University of Petroleum and Minerals, Dhahran, Saudi Arabia.

SPONSORED SEMINARS & COLLOQUIA

CENTER FOR RADIATION RESEARCH

Jorrit de Boer, Sektion Physik, Universität München, West Germany, "Fairly Large Quantum Numbers: Multiple Coulomb Excitation of Rotational Nuclei," October 7, 1982.

Patricia Ann Snyder, Department of Chemistry, Florida Atlantic University, Florida, "Vacuum UV Natural and Magnetic Circular Dichroism Measurements Using Synchrotron Radiation," October 12, 1982.

A. B. Johnson, Nuclear Radiation Division, Center for Radiation Research, NBS, "The Interacting Boson Model for a System of Identical Nucleons," October 21, 1982.

Michael Kühne, Physikalisch-Technische Bundesanstalt, Berlin, Germany, "VUV Radiometry with Pulsed Sources," October 25, 1982.

Hans Svensson, University of UMEÅ - Radiation Physics Department, Sweden, "Some Physics Problems in High-Energy Radiation Dosimetry," November 1, 1982.

Larry K. Patterson, Radiation Laboratory, University of Notre Dame, Notre Dame, Indiana, "Photophysical Processes in Spread Monolayers at the Air-Water Interface," November 1, 1982.

Ulf Litzen, Universitet of Lund, Lund, Sweden, "Atomic Spectroscopy at Lund University: Term Analysis and Ion Lifetimes," November 2, 1982.

Sveneric Johansson, Universitet of Lund, Lund, Sweden, "Studies of Iron Group Spectra with Astrophysical Applications," November 2, 1982.

John Mosely, Department of Physics, University of Oregon, Eugene, Oregon, "Half-Collision Aspects in Photofragment Spectroscopy," November 3, 1982.

I. Slaus, Institut Ruder Boskovic, Zabred, Yugoslavia, "Study of the Reaction $^{12}C(n,3\alpha)n$ and its Energy Transfer from Threshold to 35 MeV," November 3, 1982.

J. W. Behrens, Nuclear Radiation Division, Center for Radiation Research, NBS, "A Review of Neutron-Induced Fission Cross Sections in the MeV Range -- Measurement and Prediction," November 5, 1982.

Jinx Cooper, JILA, National Bureau of Standards, Boulder, Colorado, "Redistribution: Why Half a Collision is Better Than One," November 9, 1982.

Fritz Riehle, Physikalisch-Technische Bundesanstalt, Berlin, West Germany, "The Radiometric Laboratory of PTB at the Electron Storage Ring BESSY," November 10, 1982.

V. Dose, Physikalisches Institut der Universität, Wurzburg, West Germany, "Ultraviolet Bremsstrahlung Spectroscopy," November 15, 1982.

J. Halbritter, Institut fur Kernphysik, Federal Republic of Germany, "On Enhanced Electron - RF - Emission Between Broad Area Electrodes and its Conditioning," November 15, 1982.

I. G. Draganic, Z. Draganic, Institute of Nuclear Studies, University Nacional Autonoma Mexico, Mexico D.F., "The Radiation Chemistry of Comets", November 17, 1982.

Gabriel Lombardi, Atomic and Plasma Radiation Division, Center for Radiation Research, NBS, "Redistribution of Radiation in Hydrogen and Helium: A Broadening Experience," November 23, 1982.

G. S. Hurst, Oak Ridge National Laboratory, Oak Ridge, Tennessee, "Applications of Resonant Ionization Spectroscopy," November 24, 1982.

John Weiner, University of Maryland, College Park, Maryland, "New Developments in Laser Assisted Collisions," November 29, 1982.

E. Hayward, Nuclear Radiation Division, Center for Radiation Research, NBS, "Photon Scattering from the Delta Resonance," December 2, 1982.

Nat Bhaskar, Physics Department, Princeton University, Princeton, New Jeresy, "Laser-Generated Nuclear Polarization in Noble Gases - Possible Applications to Fusion," December 3, 1982.

David Onley, Department of Physics, Ohio University, Athens, Ohio, "Developments in Virtual Photon Theory," December 9, 1982.

Joseph Swenson, Department of Physics and Astronomy, University of North Carolina and TUNL, Chapel Hill, North Carolina, "Measurement of Metastable Auger Electrons with a Position-Sensitive Electron Spectrometer," December 10, 1982.

E. G. Fuller, Nuclear Radiation Division, Center for Radiation Research, NBS, "The Deuteron and Other Problems (?) in Photonuclear Reactions," December 16, 1982.

Jeffrey Berkowitz, University of Michigan, "Electron Capture by Protons," December 21, 1982.

Alan G. Michette, Physics Department, Queen Elizabeth College, University of London, England, "Soft X-Ray Optical Components (Zone Plates), Manufacture (Electron Lithography) and Test for Soft X-Ray Microscope," December 22, 1982.

Maxime Tawil, New York University, New York, New York, "Heating and Cooling Sodium Vapor Using Collisionally Assisted Light Absorption," December 28, 1982.

John S. Risley, Department of Physics, School of Physical and Mathematical Sciences, North Carolina State University, Raleigh, North Carolina, "Experimental Determination of the Density Matrix for H^+ on He," January 5, 1983.

Michael Danos, Nuclear Radiation Division, Center for Radiation Research, NBS, "Present Thinking on the Quark-Gluon Plasma," January 6, 1983.

Daniel McLaughlin, University of Connecticut, "Dielectronic Recombination Rates for Lithium-like Ions," January 10, 1983.

David C. Eder, Princeton University, Princeton, New Jersey, "Ionization Equilibrium in Isolated H II Regions," January 11, 1983.

R. Jameson, Accelerator Technology Division, Los Alamos National Laboratory, Los Alamos, New Mexico, "RF Structure Development Work at Los Alamos," January 24, 1983.

Wolfgang L. Wiese, Atomic and Plasma Radiation Division, Center for Radiation Research, NBS, "The Transition Probabilities of Argon--Some Continuing Puzzles," January 25, 1983.

D. Harmin, Center for Absolute Physical Quantities, NBS, "The Stark Effect in Hydrogen Both Below and Above the Ionization Limit," February 8, 1983.

D. Harmin, Center for Absolute Physical Quantities, NBS, "Non-Hydrogen Systems-Extension of the Theory to Real Atomic Systems," February 9, 1983.

W. D. Grobman, IBM Research, Yorktown Heights, New York, "X-ray Lithography Involving Vacuum Ultraviolet Radiation Sources," February 9, 1983.

Yong-Ki Kim, Argonne National Laboratory, Argonne, Illinois, "Relativistic Effects in Atoms," February 10, 1983.

Claus-Juergen Lorenzen, Institut fur Experimentalphysik der Universitat Kiel, West Germany, "High-Resolution Laser Spectroscopy of Atomic Rydberg States," February 22, 1983.

Norberto Majlis, Universidade Federal Fluminense, Niteroi, Brazil, "Theory of Surface Magnetism," February 23, 1983.

C. Teague, Mechanical Production Technology Division, Center for Manufacturing Engineering, NBS, "Propagation and Scattering of Transient Electromagnetic Fields," February 24, 1983.

W. Greiner, Institute for Theoretical Physics, University of Frankfurt, Frankfurt, Germany, "Giant Nuclear Systems: Latest Data and Speculation on Novel Nuclear Structure," March 3, 1983.

Hartmuth Arenhövel, Johannes Gutenberg Universität, Mainz, West Germany, "Exchange Currents in Nuclei," a series of 6 lectures, March 4 - April 11, 1983.

Robert C. Richmond, Darmouth Medical School, Hanover, New Hampshire, "Radiation Mutagenesis and Protection," March 4, 1983.

Paul Kobrin, Department of Chemistry, University of California, Berkeley, California, "Atomic Photoelectron Spectroscopy Studies Using Synchrotron Radiation," March 4, 1983.

M. S. Dias, Instituto der Pesquisas Energeticas e Nucleares, Sao Paulo, Brazil, "Development of a New Absolute Detector for MeV Neutrons," March 10, 1983.

Larry Roszman, Atomic and Plasma Radiation Division, Center for Radiation Research, NBS, "The Dielectronic Recombination of Multicharged Ions: Destroy the Trees to See the Forest," March 10, 1983.

M. Landolt, Laboratorium fur Festkorperphysik, ETH Zurich, Switzerland, "Spin Polarization of Secondary Electrons from Magnetic Solids," March 17, 1983.

V. A. J. van Lint, Defense Nuclear Agency, Washington, D.C., "Correlation of Nuclear Displacement Effects in Materials with Particle Type and Energy," March 17, 1983.

B. H. Silverman, Department of Physics, University of California, Los Angeles, California, "Time Invariant Experiments in Light Nuclei," March 23, 1983.

J. J. Leventhal, Department of Physics, University of Missouri-St. Louis, St. Louis, Missouri, "Reactive Collisions of Rydberg Atoms," March 24, 1983.

J. B. McGrory, Department of Energy, Germantown, Maryland, "Nuclear Structure Information from Isotope Shift Measurements," March 24, 1983.

K. Shoda, Tohoku University, Mikamine, Japan, "Study of Photoion Production at Sendai," March 25, 1983.

H. Friedrich, Kellogg Radiation Laboratory, California Institute of Technology, "Autoionizing States of the Hydrogen Atom in Strong Magnetic Fields," March 29, 1983.

M. Danos, Nuclear Radiation Division, Center for Radiation Research, NBS, "Toward Solving QCD: The Structure of the Vacuum," March 31, 1983.

W. E. Spicer, Stanford University, Stanford, California, "Use of Synchrotron Radiation to Study Electronic Structure of Cu-Pt Alloys and CO Chemisorption," April 6, 1983.

Carlos Iglesias, Department of Mathematics and Physics, Rutgers University, "Electric Microfield Distributions in Strongly Coupled Plasmas," April 7, 1983.

Punit Gohil, Department of Physics, Imperial College of Science Technology, London, England, "Laser-Induced Fluorescence in Laboratory and Fusion Plasmas," April 12, 1983.

M. Sanzone, Instituto Nazionale di Fisica Nucleare Sezione di Genova, Genova, Italy, "Photon Scattering by Lead and Tantalum up to 80 MeV," April 12, 1983.

S. Williamson, Department of Physics, University of Illionis, Urbana, Illinois, "An (e,e'γ) Coincidence Study of ^{12}C," April 14, 1983.

Eckart Matthias, Freie Universität of Berlin, Berlin, West Germany, "State Mixing of Rydberg States," April 20, 1983.

C. Walker, Johns Hopkins University, Baltimore, Maryland, "Temperature Dependence of Magnetism at Iron Surfaces and Interfaces Using Mossbauer Spectroscopy," April 25, 1983.

Jean-Patrick Connerde, Imperial College of Science and Technology, The Blacklett Laboratory, London, England, "Atomic Double Wells," April 28, 1983.

J. Kirschner, KFA-IGV, JÜlich, West Germany, "Electron Spin Polarization in Photoemission and Appearance Potential Spectroscopy," April 28, 1983.

P. D. Higgins, Division of Radiation Oncology, University of Wisconsin, Madison, Wisconsin, "Microdosimetry and Radiobiology in Mixed Neutron and Photon Fields," May 10, 1983.

Chava Lifshitz, Department of Physical Chemistry, The Hebrew University of Jerusalem, "Time-Resolved Photoionization Mass Spectrometry," May 19, 1983.

R. P. Mason, National Inst. of Environmental Health Sciences, Research Triangle, North Carolina, "Peroxidaze Oxidation of Sulfite (Hydrated SO_2) to the Sulfur Trioxide Radical Anion," May 20, 1983.

Georges Lampel, Laboratoire de Physique de la Matiere Condensee, Ecole Polytechnique, Palaiseau, France, "Recent Developments in Understanding the Physics of the NEA GaAs Source of Spin Polarized Electrons," May 24, 1983.

Neville Connell, Xerox Palo Alto Research Center, Palo Alto, California, "Magneto-Optical Recording," June 6, 1983.

Keith Burnett, Department of Physics, JILA, University of Colorado, Boulder, Colorado, "Collisions in Strong Fields," June 7, 1983.

R. Raue, Institute for Solid State Physics, KFA, Jülich, West Germany, "Temperature Dependence of Energy, Angle, and Spin Resolved Photoemission from Ni," June 17, 1983.

J. Hunt, National Physical Laboratory, Teddington, England, "Establishment of Neutron Standards at the National Physical Laboratory," June 23, 1983.

H. M. Kramer, Physikalisch-Technische Bundesanstalt, Braunschweig, West Germany, "Dosimetry of X-rays: On The Determination of Water Absorbed Dose and Dose Equivalent in Phantoms," June 27, 1983.

Dennis Lindle, Lawrence Berkeley Laboratory, Department of Chemistry, University of California-Berkeley, Berkeley, California, "Resonant Photoemission: Autoionization in Helium and Shape Resonances in Molecules," July 11, 1983.

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NBS-114A (REV. 2-8C)

U.S. DEPT. OF COMM. BIBLIOGRAPHIC DATA SHEET (See Instructions)	1. PUBLICATION OR REPORT NO. NBSIR 84-2848	2. Performing Organ. Report No.	3. Publication Date April 1984

4. TITLE AND SUBTITLE

Center for Radiation Research Technical Activities for 1983

5. AUTHOR(S)

6. PERFORMING ORGANIZATION (If joint or other than NBS, see instructions)

NATIONAL BUREAU OF STANDARDS
DEPARTMENT OF COMMERCE
WASHINGTON, D.C. 20234

7. Contract/Grant No.

8. Type of Report & Period Covered

9. SPONSORING ORGANIZATION NAME AND COMPLETE ADDRESS (Street, City, State, ZIP)

10. SUPPLEMENTARY NOTES

☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

11. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)

This report summarizes research projects, measurement method development, testing and data evaluation activities, carried out during Fiscal Year 1983 in the NBS Center for Radiation Research. These activities fall in the areas of radiation measurements, atomic and plasma radiation, nuclear radiation, radiation physics, radiometric physics, and radiation sources and instrumentation.

12. KEY WORDS (Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)

Atomic radiation; nuclear radiation; plasma radiation; radiation instrumentation; radiation measurements; radiation physics; radiation sources; radiometric physics.

13. AVAILABILITY

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☐ Order From Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

☒ Order From National Technical Information Service (NTIS), Springfield, VA. 22161

14. NO. OF PRINTED PAGES

214

15. Price

USCOMM-DC 6043-P80