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Technical Activities 1987

Center for Radiation Research

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Chris E. Kuyatt, Director

U.S. DEPARTMENT OF COMMERCE
National Bureau of Standards
National Measurement Laboratory
Center for Radiation Research
Gaithersburg, MD 20899

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U.S. DEPARTMENT OF COMMERCE, C. William Verity, Jr., Secretary
National Bureau of Standards, Ernest Ambler, Director

ABSTRACT

This report summarizes research projects, measurement method development, calibration and testing, and data evaluation activities that were carried out during Fiscal Year 1987 in the NBS Center for Radiation Research. These activities fall in the areas of atomic and plasma radiation, radiation physics, radiometric physics, radiation sources and instrumentation, ionizing radiation, and nuclear physics.

Key Words: Atomic radiation, ionizing radiation; measurement support; 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, 1986 to September 30, 1987. The Center is one of four Centers in the National Measurement Laboratory.

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

The summary of activities is organized into six parts, one for each of the five Divisions in the Center: Atomic and Plasma Radiation, Radiation Physics, Radiometric Physics, Radiation Sources and Instrumentation, and Ionizing Radiation, and one for the Nuclear Physics Group. A major subgroup of the Ionizing Radiation Division is the Office of Radiation Measurement. Each organizational unit tells its own story in its own way. In general there is an introduction followed by a series of short reports on current activities, publications during the year, talks given, committee participation, and professional interactions.

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

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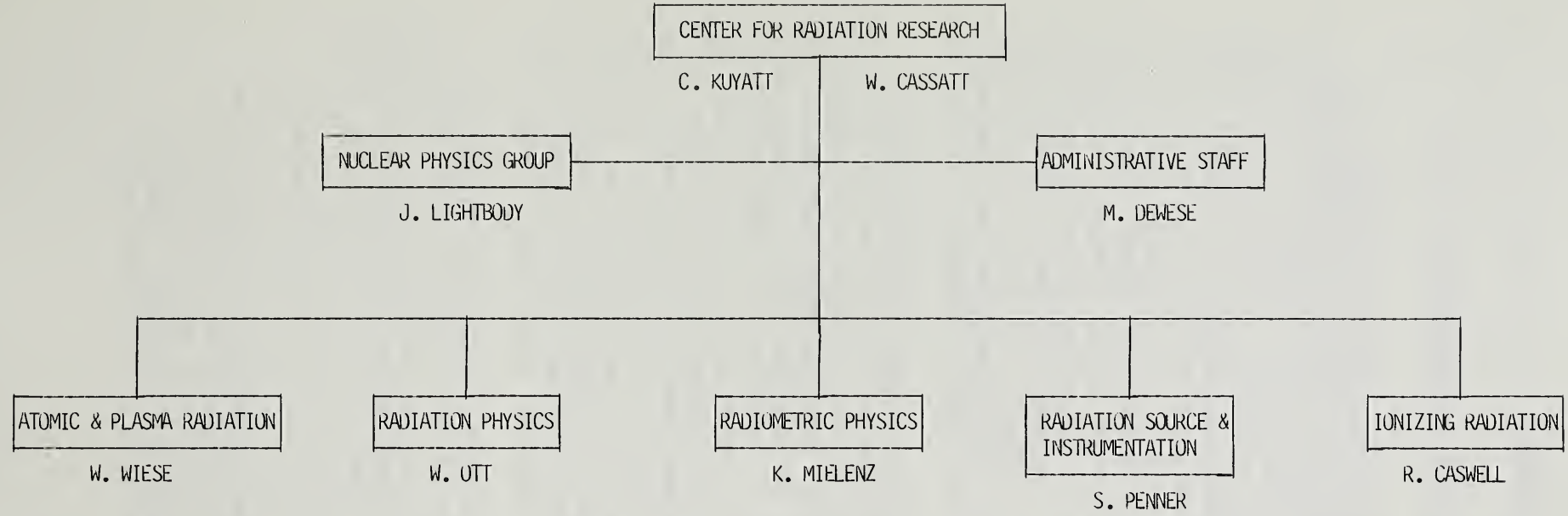

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TECHNICAL ACTIVITIES

Division 531, Atomic and Plasma Radiation

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 to provide a full fundamental understanding of atomic processes in plasmas utilized for technological applications as well as to develop new measurement techniques. Furthermore, well-defined atomic radiation sources are developed as VUV radiometric standards or wavelength standards.

These activities support several areas of science and technology. A part 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 utilized as non-interfering plasma probes. Other areas of direct applications are parts of the Strategic Defense Initiative (SDI), vacuum ultraviolet and x-ray laser development, materials processing by plasmas, plasma chemistry, space astronomy and solar physics. In all these areas, atomic radiation data are one of the basic ingredients, and plasma measurement techniques utilizing the emitted radiation are applied. Our vacuum ultraviolet radiometry work is now providing small calibrated radiation source packages to allow radiometric calibrations on board spacecraft, which are used, for example, on the space shuttle for accurate monitoring of the solar ultraviolet radiation, and are part of the space telescope instrumentation.

The division consists of three technical groups: Atomic Spectroscopy, Atomic Radiation Data, and Plasma Radiation. The division currently has 19 professional physicists, among them 18 Ph.D.s. During 1987 the division has had 10 guest scientists from China (4), Israel (2), France (1), India (1), Soviet Union (1), and Sweden (1).

Some of our significant accomplishments during the past year are:

- Excitation of spectra of very highly ionized atoms mainly using the Omega laser at Rochester University; accurate measurements and identifications have given reference wavelengths and provide valuable comparison for atomic structure calculations that include large relativistic and QED contributions.

- Progress in high-precision laser spectroscopy includes wavenumber measurements with Fabry-Perot wavemeter system at ±1 MHz accuracy level and construction of atomic-beam apparatus, that contains large concentration of atoms in metastable states.

- Completion of compilation of critically evaluated atomic transition probability data for the elements scandium through nickel, in all stages of ionization, to be published as Vol. III of the series "Atomic Transition Probabilities."

- Calculation of QED corrections to term energies of many-electron atoms and ions.

- Measurement of cavity gain and losses for some C^{3+} levels in a theta pinch plasma.

- Characterization of pulsed capillary discharge as irradiance source for the XUV region.

These and other activities are discussed in the following sections, where the principal work of the three technical groups during the past year is described.

I. Atomic Spectroscopy Group

(a) Highly Ionized Atoms

The energy levels and wavelengths for spectra of highly ionized atoms are necessary data for modeling and diagnostics of high-temperature plasmas occuring in tokamaks and other fusion-research machines, x-ray laser research, solar flares, etc. These spectra are also of basic interest for testing atomic calculations including large relativistic and quantum-field (QED) contributions. We have excited very highly charged ions in several sources: the highest temperatures were obtained in plasmas produced by the OMEGA laser at Rochester, and we have also used plasmas obtained with lasers at Los Alamos and NBS, plasmas generated in the TEXT tokamak at the University of Texas, and sliding-spark and vacuum-spark plasmas at NBS. Our new measurements of 3s-3p, 3p-3d, and 3d-4f transitions obtained from Na-like ions in such plasmas extend from Cu^{18+} to Sn^{39+}. The wavelengths were compared with Dirac-Fock calculations including transverse Breit and QED contributions. The overall accuracy of the wavelengths was improved to ±0.007 Å by regularizing the small differences between the experimental and calculated wavelengths, and the results were extended from Ar^{7+} to Xe^{43+}. Errors as large as 0.05 Å in previous measurements of some of the lines have been corrected in this work. The wavelengths range from 9 to 713 Å and will be useful as standards, especially in the 50-500 Å region (J. Reader, V. Kaufman, J. Sugar, and collaborators from NRL).

We also measured the $3p^63d^9\ ^2D\text{-}3p^53d^{10}\ ^2P$ lines in Co-like ions from Ru^{17+} to Au^{52+}. The experimental wavelengths were again compared with predictions of relativistic ab initio theoretical calculations, these comparisons being extended to include our previous results for this sequence up to U^{65+}. Chen (LLNL) has recently shown that electron correlation effects must also be included to obtain calculated wavelengths in good agreement with our accurate experimental values. A regularizing procedure similar to that described above reduced the uncertainty of the wavelengths to ±0.005 Å, which makes them useful as reference wavelengths (8-93Å) (J. Reader, N. Acquista, and NRL collaborators).

Our most recently completed work includes similar results for several other isoelectronic sequences: Fe-like ions to Gd^{38+} and Zn-like ions (J. Reader and collaborators); Mg-like and Ar-like ions of Cu through Mo; many Cd-like and In-like ions; as well as various ions of selenium V. Kaufman and J. Sugar). Detailed comparisons with theoretical calculations have been carried out for all these spectra.

(b) Laser Spectroscopy: High-Accuracy Measurements and Calculations of Atomic Structure

A basic objective of our laser spectroscopy program is to test experimentally the most accurate theoretical calculations for selected atoms. The development of theoretical methods that treat electron-correlation, relativistic, and QED energy contributions accurately and consistently is one of the fundamental problems of current atomic physics. Helium is of special importance because the electron-correlation contributions can be calculated to almost arbitrary accuracy in a non-relativistic approximation, and the inclusion of two-electron relativistic and QED effects is simpler than for atoms having more electrons.

Atomic-Beam Source. We have made good progress in the design and construction of a "metastable" atomic-beam apparatus for rare gases. We are testing the vacuum system and metastable-atom source and have begun assembling parts for the excitation and detection regions. We plan to use this beam source to observe highly excited Rydberg states of helium, beginning with the $2\ ^1S - n\ ^1P$ transitions. Accurate wavenumber determinations for this series should allow determination of the $2\ ^1S$ ionization energy within an error of a few parts in 10^9. This will permit new tests of the most accurate theoretical calculations in helium including two-electron QED effects (C. Cromer and C. Sansonetti).

Measurements with Fabry-Perot Wavemeter. High-accuracy measurements of dye-laser wavelengths are required to realize the full potential of our metastable beam. We have made extensive tests of the Fabry-Perot system developed in our laboratory. This system, which is based on computer acquisition of F-P fringe patterns from an array detector, makes a measurement of any dye-laser wavelength every 1.5 seconds. Using three different interferometer spacer lengths, we have measured more than 40 Doppler-free transitions in molecular iodine. This work has allowed correction for effects of dispersion of reflection phase-change within uncertainties smaller than 2 MHz, and we expect to provide a new list of reference lines in iodine accurate to 1-2 MHz (C. Sansonetti).

Low-Pressure Discharge Source. Development of techniques for detailed investigations of complex atomic spectra is of interest for basic atomic physics and for obtaining data needed for laser physics, plasma physics, astrophysics, etc. We plan to apply state-selective, state-labeling and optical double-resonance techniques to selected complex atomic spectra. We are investigating electric-discharge sources in this connection because they provide both atoms and ions in excited initial states. We have developed a very low-pressure discharge cell to minimize collisional transfer of excitation from laser-excited levels to other

levels. Using double-resonance (two-laser) intermodulation optogalvanic spectroscopy with neon discharges at 10 to 30 mTorr, we have observed resonances having high signal-to-noise (~ 10^3) and find almost no transfer of modulation to neighboring levels (C. Cromer and M.-Q. He).

Helium Calculations. As part of our program on the helium atom, we combined very accurate variational calculations of 1snd and 1snf term energies with previously calculated values for the magnetic and other fine-structure interactions to predict nD and nF ionization energies and fine-structure separations (n = 3-8). Comparisons of the nD energies with other available data gave improved values for the relativistic contributions. The agreement of our calculated nF fine-structure separations with experiment (± 0.1 to ± 1 MHz) is the first confirmation of the Breit fine-structure theory for 1snf configurations. (J. Sims, Center for Applied Mathematics, and W. C. Martin.)

(c) Atomic Energy Levels Data Center

We completed the critical evaluation and compilation of energy levels for all the molybdenum spectra Mo I through Mo XLII (Mo^{41+}). In collaboration with a Japanese group, we have also compiled the wavelengths and energy-levels classifications for all lines of Mo^{5+} through Mo^{41+}; these spectra are of special interest for fusion-plasma research. Our similar collaborative work on compiling all lines for the nickel ions Ni^{5+} through Ni^{27+} was completed and submitted for publication (J. Sugar, A. Musgrove, W. L. Wiese).

We are now reviewing and compiling energy-levels data for all the sulfur and copper spectra. We plan to continue our collaboration with the Japanese group by compiling wavelengths and other data for lines for copper and chromium in all ionization stages above five-times ionized. We have almost finished reviewing and compiling wavelengths and energy-levels classifications for all spectra of scandium as part of our program to build a more complete data base for atomic spectra (V. Kaufman, J. Sugar, W. C. Martin).

We plan to publish a fourth supplement to our Bibliography on Atomic Spectra, covering the period January 1984 through December 1987. In connection with the 20th General Assembly of the International Astronomical Union, to be held in Baltimore next year, we have submitted a report on recent laboratory research on atomic spectra of interest for astrophysics. We periodically supply lists of references on atomic spectral data for fusion-plasma research to be included in bibliographies issued by the International Atomic Energy Agency (A. Musgrove, W. C. Martin).

II. Atomic Radiation Data Group

The work of this group is entirely theoretical and consists of two major areas: (1) theoretical studies of atomic structure and processes, and (2) critical evaluation and compilation of atomic transition probability and spectral line shape data. The first activity involves the development of advanced theoretical methods and their implementation to calculate atomic data. The main areas of activity have been dielectronic recombination, relativistic quantum mechanics, electron correlation, and radiative and collisional transition rates. The critical evaluation and compilation of transition probability and spectral line shape data takes place in the Data Center on Atomic Transition Probabilities, which also maintains an up-to-date bibliography of the literature in these fields.

(a) Theoretical Studies

Substantial progress has been made in our capability to calculate relativistic effects in atomic structure. The extension of Lamb shift calculations for hydrogen-like ions to the $n = 3$ levels along with a critical study of screening corrections have allowed us to take into account all the electrons of the atom in estimating Lamb shift corrections for many-electron atoms. The trends of excitation energies in highly ionized ions of the sodium isoelectronic sequence and X-ray hole state transition energies have both been brought into significantly better agreement with available experimental data than was previously the case. (Y.-K. Kim and P. J. Mohr)

Our computer codes for relativistic distorted wave calculations have been rewritten and generalized to handle electron-impact processes for atoms and ions of arbitrary configuration. Previous versions were only able to calculate excitation cross sections of alkali-like ions. Dr. Wen-Jia Qian, a guest scientist from the People's Republic of China, has begun to participate in the utilization of this program for the calculation of relativistic electron-atom collision cross sections. (Y.-K. Kim and W.-J. Qian)

The current phase of our studies of f-value bounding procedures has ended with the return of Dr. D. Roginsky to Israel. A number of novel variations of upper and lower bounds theorems have been developed for the purpose of tightening the bounds, some of them during Dr. Roginsky's stay here. However, till now the only applications have been model studies on hydrogen. We therefore carried out numerical calculations on the Hartree-Fock approximation for the resonance transitions of lithium and sodium. The purpose was to test the efficacy of the theorems on a many- electron atom and on a model which is known to produce rather accurate f-values. The results, not surprisingly, were mixed; some procedures held up, some did not. We were able to calculate a bounds width for lithium of 3%,

which is approximately equal to the known error for the Hartree-Fock result. (A. Weiss and D. Roginsky)

Our production code for dielectronic recombination rates has been used to calculate rate coefficients for selected ions in the neon, nitrogen, carbon, boron and beryllium isoelectronic sequences. Parametric fits have been made to these data and analytic interpolation formulas developed, which permit interpolation for other ions in these sequences, and which make the information more easily usable in plasma modeling calculations. All these data have been computed in the single configuration, LS coupling approximation. Currently, the codes are being modified to include configuration interaction and intermediate coupling, and the modification of dielectronic recombination rates by the plasma environment is being investigated. (L. Roszman)

During the past year, we hosted a number of atomic theorists, some for an extended period of time, some as regular weekly visitors.

P. J. Mohr (NSF) has spent one day a week, most of this year, working with Y.-K. Kim on computational aspects of QED problems. Recently, we were pleased to have Dr. Mohr join us as a full time staff member. He will be an important participant in the development of better methods to predict quantum electrodynamical effects in atoms and atomic ions.

M. A. Ali (Howard Univ.) also spends one day a week here, working with Dr. Kim on relativistic atomic structure calculations for heavy atoms.

J. P. Desclaux (Grenoble) visited our group for a month to collaborate with Kim on the improvement of relativistic atomic physics codes. His trip was sponsored by a grant from NATO.

D. V. I. Roginsky (Hebrew Univ. of Jerusalem) completed an 18-month visit with us, collaborating with A. Weiss on f-value bounds research.

J. C. Morrison (Univ. of Louisville) spent 10 weeks with us, collaborating with A. Weiss and M. Suskin in setting up the most recent version of the multi-configuration Hartree-Fock codes and studying the multi-configuration referent formulation of perturbation theory.

Wen-Jia Qian (Liaoning Univ., Shenyang, China) has recently joined us for a year's stay to participate in the calculation of relativistic electron-atom collision cross sections.

L. Woltz (Univ. of Florida) has been with us for the past year, collaborating with L. Roszman and W. L. Wiese on problems in the theory of spectral line broadening.

(b) Data Center on Atomic Transition Probabilities

The critical evaluation of atomic transition probability data for the iron group elements scandium through nickel, in all stages of ionization, has now been completed. The typesetting and proofreading of this material preparatory to final publication are now in the final stages. This has been a major undertaking which has occupied us for a number of years now and which represents the third volume of the NBS transition probability tables. Interest in these data remains high in both the astrophysics and fusion communities, which has given rise to a continuous influx of new data in the literature. This in turn has repeatedly slowed the pace of our critical evaluation work as we strived to maintain the compilation as most complete and up-to-date as possible. However, we are now past our cut-off point, and we estimate completion before the end of this calendar year.

The resignation of Dr. Georgia Martin last year was also an important factor in delaying the completion of this compilation, since it places a heavier burden of evaluation and tabulation on remaining staff. Thus, W. L. Wiese spent a good fraction of his year in West Germany (as recipient of the Humboldt Award) with data compilation work for these iron group elements to accelerate the tabulation process. We also had to embark on a search for a replacement for Georgia Martin, a process which was completed last spring with the hiring of Dr. Mark Suskin, a recent graduate in theoretical atomic physics from the Johns Hopkins University. Dr. Suskin has been familiarizing himself with the mechanics of Data Center operations and has recently begun making use of the most recent version of the Froese-Fisher/Hibbert multi-configuration Hartree-Fock computer codes to make f-value calculations for the nitrogen atom.

We continue to monitor the literature, maintaining an up-to-date bibliography on site. We also continue to supply, in six-month intervals, bibliographical reference material for inclusion in the "International Bulletin on Atomic and Molecular Data for Fusion", published by the the International Atomic Energy Agency. Furthermore, we compile in three-year intervals all astrophysically important literature references for the "Reports on Astronomy" published by the International Astronomical Union. A new report covering the period mid-1984 to mid-1987 has been prepared (W. L. Wiese). We have also completed editing a book of spectroscopic data for the elements titanium, chromium and nickel, which will soon be published as part of a series of handbooks for fusion researchers by the Oak Ridge National Laboratory, the so-called 'Red Books' (Editors: W. L. Wiese and A. Musgrove). This volume contains material largely taken from existing NSRDS compilations, including energy levels and wavelengths of spectral lines, assembled in a format convenient for use by fusion research scientists.

III. Plasma Radiation Group

The plasma measurements program provides valuable data and measurement techniques for plasma diagnostics, mainly for temperature and density determinations, for VUV source radiometry, and VUV lasing schemes. The activity in collisional rate coefficients is of critical importance in plasma modeling, especially for fusion-type plasmas and VUV laser schemes. The research on line shapes, atomic transition probabilities, and scattering has impact on gain measurements in lasing media as well as direct bearing on measurements of plasma densities and temperatures of low temperature plasmas which are widely used for technological applications. The studies of population inversion in the theta pinch have led to a better understanding of recombination mechanisms for possible VUV laser schemes. Pulsed plasma source studies have produced promising new VUV radiometric sources. Our portable radiometric standards have been used for many spacecraft calibrations and are still in demand for that purpose.

(a) Collisional Rate Coefficients with the 50 kJ Theta Pinch

Relative excitation rate measurements of N V and O VI lines arising from up to n=5 levels were completed from experiments on the NBS 50 kJ Theta Pinch. These results were compared with theoretical predictions and the agreement between experiment and theory was found to be within combined uncertainties. These rates are needed for plasma electron temperature and density determinations and for modeling of edge plasmas in tokamaks.

The effect of recombination from He-like ions was observed for the first time in the temporal evolution of the intensities of transitions originating from levels of n=4 and n=5 in Li-like ions. A method to deduce the effective recombination rate coefficient was developed utilizing these observations.

The experimental conditions with an electron density of 1×10^{16} cm^{-3} and an electron temperature of 15-20 eV in a C_2H_2 plasma showed a population inversion in the n=4 levels compared with n=3 levels, and in the n=5 levels compared with n=4 levels in C IV. The population ratio of the 4f/3d was measured to be 10 and that of 5g/4f was measured to be 1.6 in our 23 cm long plasma column. Using a confocal mirror cavity, a gain of a factor of 12 was measured on the 2530 Å line in experiments conducted in collaboration with a group from Bell Laboratories. Experiments are underway to further improve the gain (R. Datla, J. Roberts).

(b) Tokamak Spectroscopy

Absolute excitation rate coefficients for Fe XIV and Ni XVI ions were measured spectroscopically for the first time using the TEXT Tokamak. Previous measurements for the Cu XVII ion were verified and measurements were extended to other transition arrays not covered previously. SURF II and branching ratio calibrated spectrometers in the XUV and VUV spectral region down to 150 Å were used to measure absolute spectral line intensities. Computed values of absolute excitation rates in a distorted wave approximation and Mewe's semiempirical formula were found to be in good agreement with the experimental values (R. Datla, J. Roberts).

(c) Calculation of Spectral Line Shapes in Plasmas

We have performed line broadening calculations over a wide range of plasma conditions. The calculations are state-of-the-art in that they include ion dynamic effects, which can be very large for some plasma conditions, and time ordering for electrons, which is also sometimes significant. We have computed profiles and widths for the Balmer alpha transition of neutral hydrogen over the two orders of magnitude in electron density for which experimental results are available. Excellent agreement was found over the full range, while discrepancies of factors of 2 to 5 are observed for certain densities if ion dynamics are not included. We have obtained parallel results for hydrogen-like He^+ for conditions at which experiments are currently being performed. We have also performed calculations over the full range of radiator-perturber reduced mass. We have identified four regions of qualitatively different influence of ion dynamics on the line profiles, and have derived validity criteria for each region. We are continuing work on fully quantal "benchmark" calculations of plasma shifts of hydrogenic lines; the close coupled scattering calculations are completed.

Finally, we have completed an analytic formalism for the broadening of Lyman lines with time ordered ion dynamics included. This is essentially a generalization of the "unified" theory to include overlapping strong collisions, using a trinary collision model. The formalism has been coded for the CYBER computer and excellent results obtained for Lyman alpha. The code is currently being made more efficient so that higher lying transitions can be computed on the CYBER 205 (D. E. Kelleher, D. H. Oza, and J. Cooper (JILA)).

(d) Transfer Standards for VUV

The commercially available Samson source is being tested as a transfer standard for the irradiance calibrations of VUV spectrometers using the Branching Ratio Technique. The branching line pairs of 2s-3p

and 3s-3p transitions of Li-like nitrogen, oxygen and carbon have been observed. The 3s-3p transitions in these ions are in the wavelength region greater than 3000 Å where intensity standards for calibration exist. Therefore, VUV instruments can be calibrated at the wavelengths of 2s-3p transitions using the branching ratio. Presently, experiments are underway to minimize the uncertainty due to self absorption in the 2s-3p transition (J. Roberts, R. Datla, and J. M. Bridges).

(e) Vacuum Ultraviolet Radiometry with Plasmas

Previous to this year we calibrated the irradiance of the Space Telescope Optical Simulator (STOS), which was then used to calibrate the Faint Object Spectrograph (FOS), one of the instruments on the Space Telescope. Upon completion of this calibration, the FOS and the other instruments were incorporated into the Space Telescope, which is to be deployed in orbit by the Space Shuttle. We then performed numerous calibrations of Pt/Cr-Ne and Pt-Ne hollow cathode lamps for the throughput tests of the Space Telescope with its installed instruments. In addition to the FOS, the instruments are the high resolution spectrograph, the wide-field planetary camera, the faint object camera, and the high speed photometer. The throughput tests turned out to be highly successful and even more useful than projected. In the past year as a check, we have recalibrated the hollow cathode lamps which we had originally calibrated for the throughput tests. Also, the data from one of the lamps used in the STOS for the calibration of the FOS was analyzed and published in Applied Optics.

The documentation of our calibration program was completed early this fiscal year and has recently appeared in print as an NBS Special Publication. This publication will be valuable in delineating our program for present and future customers. Also, a condensation of this document will appear in the NBS Journal of Research.

Other notable activities during this fiscal year were our participation in the Eighth Workshop on the Vacuum Ultraviolet Radiometric Calibration of Space Experiments held in Boulder, CO, March 18 and 19 and the upgrading and modification of our 3 m monochromator to enable computer controlled automated operation (J. Klose, J. M. Bridges).

In the past year, progress was made in improving the accuracy of our calibrations. Better accuracy is desired to meet the needs of some users of our services, especially groups involved in radiometric measurements from spacecraft. Experimental setups were designed and put into operation which allow rapid comparisons to be made between two sources running simultaneously. By comparing sources essentially at the same time, errors from changing detector efficiency or degradation of optical

components during a set of measurements are eliminated. With this improved measurement technique, more accurate comparisons between our radiometric sources are possible, and work is in progress to develop an argon arc model with improved stability. Preliminary results indicate a significant improvement in stability is possible, with fluctuations in the source output reduced from the few percent level to less than one percent (J. M. Bridges).

(f) Stark Broadened Widths and Shifts of Non-hydrogenic Ion Lines

Experiments are continuing on the widths and shifts of lithium-like beryllium lines. Beryllium was injected as an impurity into a helium plasma discharge using a laser blowoff technique. The helium plasma is well characterized from previous measurements. Side-on measurements of the pulsed arc source show that within a reasonable time after the firing of the laser we detect beryllium lines showing the beryllium to be well distributed and in equilibrium with the basically helium plasma.

A general survey of what beryllium ion lines can be observed in both the visible and ultraviolet spectral regions has been accomplished. Two strong visible lines have been selected for further detailed study since one has an unexpected line shape (a strong asymmetry in the line with an accompanying forbidden component), and the other is ideal for detailed width and shift measurements. We have also measured the electron temperature of the helium plasma. We do this by observing the He II P_α line which has been previously calculated to an He-Ne laser interferometer for electron density and then observing several O II impurity lines which give the electron temperature using a Boltzmann plot of their relative intensities. These measurements are done over a range of filling pressures and capacitor charging voltages to give us the electron temperature over a wide range of densities which is normally used in the experiment.

A new improved multichannel array detector is being incorporated, which will upgrade our capabilities in measuring the various characteristics of these beryllium ion lines as accurately as possible (T. Pittman).

(g) A wall-stabilized arc operating at a temperature of 12500K has been employed to determine atomic transition probabilities, plasma line widths (Stark widths) and ion broadening parameters of prominent nitrogen lines. Due mainly to the application of computerized data acquisition techniques and precise line profile fittings, accuracy levels of better than ±10% have been reached (Q. Zhu, W. L. Wiese).

(h) The atomic transition probabilities of neutral argon lines have been determined many times because of their importance to plasma diagnostic applications. Nevertheless, many discrepancies in the data exist. Therefore, in collaboration with groups from the West-German Universities of Kiel and Hannover and the National Solar Observatory, Kitt Peak, Tucson, a new unified scale for these transition probabilities has been established. For this joint project, new lifetimes and branching ratios were determined with high precision techniques, and existing literature data were critically evaluated and corrected when appropriate. The new scale achieves full consistency between different transition arrays and agrees with most recent data within ±10% (W. L. Wiese).

INVITED TALKS

Division 531, Atomic and Plasma Radiation

Kim, Yong-Ki, "Relativistic Effects in Electron-Ion Collision Cross Sections," Atomic Physics Seminar, Lawrence Livermore National Laboratory, October 14, 1986.

Kim, Yong-Ki, "Relativistic Effects in Atoms and Molecules," JILA Colloquium, December 16, 1986.

Kim, Yong-Ki, Graduate Course in "Atomic Structure Theory," Seoul National University, July 17 to August 6, 1987.

Kim, Yong-Ki, "Hot Topics in Relativistic Atomic Physics," Seoul National University, Physics Dept. Colloquium, August 7, 1987.

Martin, W. C., "Energy Levels, Ionization Energies, and Lamb Shifts in Helium," Symposium on Atomic Spectroscopy and Highly Ionized Atoms, Hickory Ridge Conference Center, Lisle, IL, August 16-21, 1987.

Reader, Joseph, "Atomic Spectroscopy at NBS," Dept. of Physics Colloquium, Univ. of Lund, Sweden, June 25, 1987.

Reader, Joseph, "Spectra of Highly Ionized Atoms: Comparisons with Relativistic Calculations," 1987 Atomic Physics Gordon Research Conference, Wolfeboro, NH, July 7, 1987.

Reader, Joseph, "Spectroscopy of Highly Charged Ions: How Well Can We Measure; How Well Can We Calculate?", Symposium of Atomic Spectroscopy and Highly-Ionized Atoms, Argonne National Laboratory, August 18, 1987.

Sugar, Jack, "NBS Atomic Data Centers: Review of Recent and Imminent Publications," Atomic Spectroscopy Workshop sponsored by the National Research Council Committee on Line Spectra, Toronto, Canada, June 19-21, 1987.

Wiese, W. L., "Atomic Data Evaluation and Compilations at NBS," Meeting of the Network of Atomic Physics Data Centers, IAEA, Vienna, Austria, September 9, 1986.

Wiese, W. L., "Some Atomic Physics Issues in Fusion Research," Meeting of the German Research Society, Munich, West Germany, November 6, 1986.

Wiese, W. L., "Progress and Challenges in the Determination of Atomic Transition Probabilities," Physics Colloquium, University of Hannover, West-Germany, November 18, 1986.

Division 531, Invited Talks (cont'd.)

Wiese, W. L., "The Wall-stabilized Arc as an Emission Source for Plasma Spectroscopy," Plasma Physics Seminar, Ruhr University, Bochum, West-Germany, January 30, 1987.

Wiese, W. L., "Quantitative Data for Visible and Ultraviolet Spectroscopy," U.S.-Japanese Workshop on Collaborative Work in Fusion Research, Institute for Plasma Physics, University of Nagoya, Japan, March 20, 1987.

Wiese, W. L., "Plasma Spectroscopy with Steady-State Discharges," Physics Colloquium, Fudan University, Shanghai, PRC, March 23, 1987.

Wiese, W. L., "Spectral Line Broadening in Plasmas," Physical Society of Shanghai, PRC, March 25, 1987.

Wiese, W. L., "VUV Spectral Radiometry with Portable Plasma Sources," China Institute of Metrology, Hangzhou, PRC, March 27, 1987.

Wiese, W. L., "Spectroscopy of Highly Ionized Atoms," Physics Colloquium, University of Kassel, West-Germany, May 7, 1987.

Wiese, W. L., "Progress in the Determination of Atomic Transition Probabilities," Physics Colloquium, Institute of Physics, University of Zagreb, Yugoslavia, May 28, 1987.

Wiese, W. L., "Line Broadening in Plasmas - Asymmetries Caused by Ion Broadening," Physics Colloquium, University of Düsseldorf, West-Germany, June 5, 1987.

Wiese, W. L., "Progress and Problems in Atomic Lifetime Measurements," Physics Colloquium, University of Lund, Sweden, June 22, 1987.

Wiese, W. L., "Status of Atomic Spectroscopy Data for the Plasma Edge." Specialists Meeting on the Physics of the Plasma Edge, IAEA, Vienna, Austria, July 9, 1987.

Wiese, W. L., "Some Continuing Puzzles in Atomic Transition Probability Data," Physics Colloquium, Ruhr-University, Bochum, West-Germany, July 13, 1987.

Wiese, W. L., "Methods of Critical Assessment of Atomic Spectroscopy Data," Atomic Physics Meeting, Oxford, United Kingdom, August 2, 1987.

PUBLICATIONS

Division 531, Atomic and Plasma Radiation

Braun, W. Scheer, M.D. and Kaufman, V., The temperature dependence of spectral broadening in the Hg (6^1S_0 - 6^3P_1) multiplet at high optical densities, J. Res. Nat. Bur. Stand. 91, 313 (1986).

Bridges, J. M., "NBS Source Standards", Proceedings of 8th Workshop on VUV Radiometric Calibration of Space Experiments at JILA, Boulder, CO, March 18, 1987.

Bridges, J. M. and Zhu, Q., "Transition Probabilities for Prominent Visible Lines of N I," Bulletin of Am. Phys. Soc., June 1987.

Callaway, J. and Oza, D. H., Scattering of electrons by atomic hydrogen at intermediate energies: Total cross-sections from 12 to 54 eV, Phys. Rev. A 34, 965 (1986).

Callaway J., Unnikrishnan, K. and Oza, D. H., Optical Potential Study of Electron-Hydrogen Scattering at Intermediate Energies, Phys. Rev. A [in press - Sept. 87 issue].

Chen, Guoxong and Nee, T.-J., A local measurement of Ba^+ density temporal evolution J. Appl. Phys. 61, 4707 (1987).

Chen, Guoxong and Nee, Tsu-Jye A., Depolarization of the near-resonance Rayleigh scattering by barium ions, J. Opt. Soc. Am. B 4, 1303, Aug. 1987.

Cooper, J. W., Clark, C. W., Cromer, C. L., Lucatorto, T. B., Sonntag, B. F. and Tomkins, F. S., "Resonant structure in 3p-subshell absorption of excited and ionized manganese, Phys. Rev. A. 35, May 1987.

Datla, R. U., and Roberts, J. R., The $^3P_1$ - $^3P_2$ magnetic dipole transition in the ground configuration of Co XX, J. Opt. Soc. Am. B 4, 428 (1987).

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Ekberg, J. O., Feldman, U., Seely, J. F., Reader, J., and Acquista, N., $3p^63d^9$ - $3p^53d^{10}$ transitions of cobaltlike ions from Sr^{11+} to U^{65+}, J. Opt. Soc. Am. B [in press].

Feldman, U., Seely, J. F., Brown, C. M., Ekberg, J. O., Richardson, M. C., Behring, W. E., and Reader, J., Spectrum and Energy Levels of Br XXV, Br XXIX, Br XXX, and Br XXXI, J. Opt. Soc. Am. B 3, 1605 (1986).

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Jupén, C., Litzén, U., Kaufman, V., and Sugar, J., Ne-like Ca XI-Mn XVI $2p^53\ell$ - $2p^54\ell$ transition arrays and energy levels, Phys. Rev. A 35, 116 (1987).

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Kelleher, D. E. and Saloman, E. B., Rydberg states with anisotropic ion cores: Stark effect, Phys. Rev. A 35, 3327 (1987).

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Nee, Tsu-Jye A. and Chen, Guoxong, Opacity Effects on Near-Resonance-Rayleigh Scattering in a a Barium Plasma, J. Quant. Spectrosc. Radiat. Transfer 37, 425 (1987).

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Oza, D. H., Greene, R. L., and Kelleher, D. E., Stark broadening of H_α and H_β of C^{+5}, Phys. Rev. A 34, 4519 (1986).

Oza, D. H., Autoionisation states ($3\ell 3\ell'$) of helium-like nitrogen ion, J. Phys. B: At. Mol. Phys. 20, L13 (1987).

Pittman, T. L. and Kelleher, D. E., Widths and Shifts of Be Ion Lines, in Spectral Line Shapes, Vol. 4, edited by Reginald J. Exton, (A. Deepak Publishing, Hampton, Virginia, 1987) p. 43.

Pittman, T. L. and Konjević, N., Experimental Study of Stark Broadened N II Lines from States of High Orbital Angular Momentum, J. Quant. Spectrosc. Radiat. Transfer 36, 289 (1986).

Reader, J., Brown, C. M., Ekberg, J. O., Seely, J. F., Feldman, U., and Behring, W. E., $2s^2 2p^5$ - $2s2p^6$ transitions in fluorinelike ions from Zr^{31+} to Sn^{41+}, J. Opt. Soc. Am. B 3, 1609 (1986).

Reader, J., Accurate energies for the $4p^5 5s5p\ ^4S_{3/2}$ and $4p^5 5s4d\ ^4P_{5/2}$ levels of neutral rubidium (Rb I), Phys. Rev. A 36, 415 (July 1987).

Reader, J., Kaufman, V., and Sugar, J., Ekberg, J. O., Feldman, U., Brown, C.M., Seely, J. F. and Rowan, W. L., 3s-3p, 3p-3d, and 3d-4f transitions of sodiumlike ions, J. Opt. Soc. Am. B [in press].

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Roszman, L. J., Dielectronic recombination rates for some ions of the lithium isoelectronic sequence, Phys. Rev. A 35, 2122 (1987).

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Seely, J. F., Ekberg, J. O., Brown, C. M., Feldman, U., Behring, W. E., Reader, J., and Richardson, M. C., Laser-produced spectra and QED effects for Fe-, Co-, Cu-, and Zn-like ions of Au, Pb, Bi, Th, and U, Phys. Rev. Lett. 57, 2924 (1986).

Shirai, T., Ishii, K., Sugar, J., Mori, K, Nakai, Y., and Ozawa, K., Spectral Data for Highly Ionized Molybdenum, Mo VI-Mo XLII, J. Phys. Chem. Ref. Data 16, 327 (1987).

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Sugar, J. and Kaufman, V., The Mg-like spectrum of Cu XVIII, J. Opt. Soc. Am. B 3, 1612 (1986).

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Sugar, J., Kaufman, V., and Rowan, W. L., Resonance transitions in the Mg I and Ar I isoelectronic sequences from Cu through Mo, J. Opt. Soc. Am. B [in press].

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Sugar, J., Kaufman, V., and Rowan, W. L., Spectra of Se XVI to Se XXIV observed in a tokamak plasma, J. Opt. Soc. Am. B [in press].

Veza, D. and Sansonetti, C. J., Ionization of Lithium Vapor by CW Quasi-resonant Laser Radiation, in Spectral Line Shapes, Vol. 4, (A. Deepak Publishing, Hampton, Virginia, 1987), p. 259.

Weber, K.-H. and Sansonetti, Craig J., Accurate energies of nS, nP, nD, nF, and nG levels of neutral cesium, Phys. Rev. A 35, 4650 (1987).

Wiese, W. L., Transition Probabilities (Atomic Physics), in Encyclopedia of Physical Science and Technology, Vol. 14, (Academic Press, New York, 1987), p. 59.

Wiese, W. L., Progress and Challenges in the Determination of Atomic Transition Probabilities, Physica Scripta 35, 846 (1987).

Wiese, W. L. and Jones, Douglas W., Ion Broadening of Heavy Element Lines in Plasmas, in Spectral Line Shapes, Vol. 4, edited by Reginald J. Exton (A. Deepak Publishing, Hampton, Virginia, 1987), p. 3-21.

Wiese, W. L., Improvements in Transition Probability Data, in Highlights of Astronomy, Vol. 7 (Reidel Publishing Co., Dordrecht, Holland, 1986).

Wiese, W. L., The atomic transition probabilities of argon--A continuing challenge to plasma spectroscopy, J. Quant. Spectrosc. Radiat. Transfer [in press].

Woltz, L. A., Quasi-Static Ion Broadening of Isolated Spectral Lines, J. Quant. Spectrosc. Radiat. Transfer 36, 547 (1986).

PUBLICATIONS IN PREPARATION

Division 531, Atomic and Plasma Radiation

Brewer, L. R., Buchinger, F., Ligare, M., and Kelleher, D. E., Resonance-Enhanced Multiphoton Ionization of Atomic Hydrogen.

Clark, Charles W., and Kelleher, D. E., Quadrupole Moments and Tensor Polarizabilities from Fine Structure Splittings of Non-Penetrating Orbitals.

Datla, R. and Kunze, H.-J., Electron impact excitation and recombination into excited states of lithium-like ions, Phys. Rev. A (submitted).

Datla, R. U., Eshhar, S. and Roberts, J. R., Excited level populations in C IV in a recombining θ-pinch plasma (in preparation).

Kelleher, D. E., Oza, D. H., Greene, R. L., Cooper, J., An Overview of the Ion Dynamic Effect in Line Broadening, and a Generalization of the Unified Theory, in preparation for J. Quant. Spectrosc. Radiat. Transfer.

Iglesias, L., Cabeza, M. I., Rico, F., and Kaufman, V., Fundamental configurations of doubly-ionized molybdenum (Mo III) (submitted to Physica Scripta).

Kaufman, V., Sugar, J., and Joshi, Y. N., Wavelengths and energy levels of I V and I VI (submitted to J. Opt. Soc. Am. B).

Klose, Jules Z., Bridges, J. Mervin, and Ott, William R., Radiometric Calibrations of Portable Sources in the Vacuum Ultraviolet (in preparation).

Martin, G. A., Fuhr, J. R., Wiese, W. L., and Weiss, A. W., Atomic Transition Probabilities, Vol. III, Scandium through Nickel--A critical data compilation (to be submitted to J. Phys. Chem. Ref. Data Supplement Series).

Martin, W. C., Atomic spectra and wavelength standards, to be published in Trans. Intl. Astr. Union XX (1988).

Oza, Dipak, Greene, R. L., and Kelleher, D. E., Dependence of the plasma-broadened profiles of hydrogen lines of reduced mass, temperature, and density, submitted to Phys. Rev. A.

Reader, J., Ekberg, J. O., and Feldman, U., $3p^6 3d^8$ - $3p^5 3d^9$ transitions in Fe-like ions from Ru^{18+} to Gd^{38+}, J. Opt. Soc. Am. B (in preparation).

Division 531, Publications in Preparation (cont'd.)

Roginsky, D. V. I., ε-tight upper bounds to expectation values (in preparation).

Roginsky, D.V. I. and Weiss, A. W., The calculation of tighter error bounds for theoretical atomic oscillator strengths (in preparation).

Roszman, L. J., The dielectronic recombination rates for ions of the nitrogen isoelectronic sequence (in preparation).

Roszman, L. J., The influence of ground configuration in metastable states upon the dielectronic recombination of impurity ions in moderate density plasmas (in preparation).

Roszman, L. J., The dielecronic recombination rates for ions of the boron and oxygen isoelecronic sequences (in preparation).

Sims, James S. and Martin, W. C., Variational calculations for ^{4}He I: improved energies for singlet and triplet n D and n F levels (n=3-8) (submitted to Phys. Rev. A).

Sugar, Jack, NBS Atomic Data Centers: Review of Recent and Imminent Publications (submitted to Spectrochim. Acta).

Veza, Damir and Sansonetti, Craig J., Ionization of Lithium Vapor by CW Quasiresonant Laser Light (in preparation).

Wiese, W. L., Atomic Transition Probabilities, submitted to Reports on Astronomy, Intern. Astron. Union.

Wiese, W. L., Critical Assessment of Atomic Spectroscopy Data (in preparation).

Wiese, W. L. and Musgrove, A. (Editors), Spectroscopic Data Tables for Ti, Cr, and Ni, Vol. 7 of Atomic-Data-for-Fusion Series, to be published by Oak Ridge National Laboratory.

Zhu, Q., Bridges, J. M., and Wiese, W. L., Oscillator Strength Measurements for Prominent Spectral Lines of Atomic Nitrogen (to be submitted to Phys. Rev.).

TECHNICAL AND PROFESSIONAL COMMITTEE PARTICIPATION AND LEADERSHIP

Division 531, Atomic and Plasma Radiation Division

Daniel E. Kelleher

Member, International Organizing Committee of the Conference on Spectral Line Shapes.

Yong-Ki Kim

Member of Program Committee, APS Topical Conference on High Temperature Plasmas.

William C. Martin

Chairman, Working Group on Atomic Spectra, International Astronomical Union.

Member, IAEA Network of Atomic Data Centers for Fusion.

James R. Roberts

Member of TEXT Users Organization.

Jack Sugar

Member, OSA Fellows and Honorary Members Committee.

Member, NAS/NRC Committee on Line Spectra of the Elements - Atomic Spectroscopy.

Mark Suskin

Member, NAS/NRC Committee on Line Spectra of the Elements - Atomic Spectroscopy.

Wolfgang L. Wiese

Member of Organizing Committee, International Astronomical Union, Commission on Fundamental Spectroscopic Data.

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

Member, IAEA network of Atomic Data Centers for Fusion.

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

Wolfgang L. Wiese

Co-Chairman, U.S.-Japan Workshop on "Assessment of Spectroscopic Data for Density and Temperature Measurements," March 1987, Nagoya, Japan. (U.S.-Japan Cooperative Fusion Program)

MAJOR CONSULTING AND ADVISORY SERVICES

Division 531, Atomic and Plasma Radiation

1. 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 30 per month. Periodically, special reports are prepared for particular user groups. Thus, W. C. Martin and W. L. Wiese have written updates on atomic data of interest for the astrophysical community for the Transactions of the International Union (IAU), covering the three year period September 1984 through August 1987, and give review reports at the General Assemblies of the International Astronomical Union. J. R. Fuhr and A. Robey submit literature reference lists every six months to the International Atomic Energy Agency (IAEA) for inclusion in their semiannual Bulletin of Atomic Data for Fusion.

2. Y.-K. Kim serves as a consultant to the A Division of the Lawrence Livermore Laboratory on x-ray laser development.

3. J. Z. Klose performed numerous tests and calibrations of four Pt-Ne hollow cathode lamps as part of contract work with Goddard Space Flight Center for the Space Telescope. His work involved close consultation with personnel from the Space Telescope Science Institute.

4. W. C. Martin and J. Reader consult and advise NASA scientists and other astronomers on standard wavelengths for calibration of the High-Resolution Spectrograph for the Space Telescope.

5. J. Reader continues to consult with members of the x-ray laser program at Lawrence Livermore National Laboratory about the spectra of highly ionized atoms in laser-produced plasmas and the wavelength calibration of such spectra.

6. J. R. Roberts serves as a member of the TEXT Users Organization (TUO). TEXT stands for Texas Experimental Tokamak and is a national plasma users facility.

7. J. R. Roberts consulted with members of Bell Labs on population inversion experiments in C^{+3} on the NBS theta pinch.

8. L. J. Roszman advises and consults with the Impurity Transport Modeling Group of the Princeton Plasma Physics Laboratory on electron-ion collision processes and other atomic data as well as the modeling of low density plasmas.

Division 531, Major Consulting and Advisory Services (cont'd.)

9. J. Sugar and W. L. Wiese consulted and advised the Japan Atomic Energy Research Institute (JAERI) on the compilation of spectral lines.

JOURNAL EDITORSHIPS

Division 531, Atomic and Plasma Radiation

W. C. Martin, Co-Feature Editor for Journal of the Optical Society of America B, Special Issue for September 1988, "Atomic Spectroscopy in the Twentieth Century."

J. Reader, Editor, Line 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

D. Kelleher was invited and gave a talk at the Conference on Interfering Resonances and Stabilized States in the Continuum, held in Paris, France, April 6-8, 1987. Most of his airfare was paid by the Conference.

D. Kelleher was invited and gave a talk at the Spectral Line Formation in Plasmas under Extreme or Unusual Conditions Workshop, held in Nice, France, August 31 through September 4, 1987. Per diem expenses were paid by the National Science Foundation.

Yong-Ki Kim was invited by the Univ. of Puerto Rico to explain relativistic atomic physics to their Chemical Physics Program participants. Most of the expenses were paid by the University (March 1987).

Yong-Ki Kim served as a session chairman at the Gordon Conference on Atomic Physics, Wolfeboro, New Hampshire. All expenses were paid by the Conference (July 1987).

Yong-Ki Kim gave a summer graduate course on atomic physics at Seoul National University (Korea). All expenses were paid by the University (July-August 1987).

W. Martin attended and presented a paper at the Symposium on Atomic Spectroscopy and Highly-Ionized Atoms, Lisle, Illinois. Room and board were provided by the conference (August 1987).

J. Reader worked at the Univ. of Lund, Sweden on the interpretation of spectroscopic data for highly ionized Zn-like and Fe-like ions. All expenses including airfare and per diem were paid by the Univ. of Lund (June 1987).

J. Reader attended and presented a paper at the Gordon Conference on Atomic Physics, Wolfeboro, New Hampshire. Registration fee and per diem were paid by the Gordon Research Conference (July 1987).

J. Reader attended and presented a paper at the Symposium on Atomic Spectroscopy and Highly-Ionized Atoms, Lisle, Illinois. Room and board were provided by the conference (August 1987).

C. Sansonetti attended and presented a paper at the Symposium on Atomic Spectroscopy and Highly-Ionized Atoms, Lisle, Illinois. Room and board were provided by the conference (August 1987).

Division 531, Trips Sponsored by Others (cont'd.)

J. Sugar attended and presented a paper at the Symposium on Atomic Spectroscopy and Highly-Ionized Atoms, Lisle, Illinois. Room and board were provided by the conference (August 1987).

W. L. Wiese spent one year at the Ruhr-University, Bochum, West-Germany as recipient of the U.S. Senior Scientist Award of the Alexander von Humboldt Foundation. Air fare to Bochum, attendance of two meetings at Rottach-Egern (March 11-13, 1987) and at Bonn (July 6-7, 1987) convened by the Humboldt-Foundation, and attendance of an Atomic Physics Workshop at Oxford, (August 1-2, 1987) were paid by the Humboldt-Foundation.

CALIBRATION SERVICES PERFORMED

Division 531, Atomic and Plasma Radiation

Type of Service	Customer	SP 250	No. of Tests	Income
Hollow Cathode Lamp	Goddard Space Flight Center	Contract	4	$36.3k
Deuterium Lamp	Goddard Space Flight Center	40030S	3	4.5k
Argon Mini-Arc	Ball Aerospace Systems Division	Contract	1	3k
Deuterium Lamp	University of Colorado	40030S	1	1.5k
Deuterium Lamp	Naval Research Laboratory	40030S	1	1k

SPONSORED SEMINARS AND COLLOQUIA

Division 531, Atomic and Plasma Radiation

Bart Cardon, MIT/Lincoln Laboratory, "Atomic Transition Probabilities,", August 25, 1986.

William Deuchars, University of Strathclyde, Glasgow, Scotland, "Theta-Pinch Research at the University of Strathclyde," September 22, 1986.

Tricia Reeves, University of Kansas, Manhattan, Kansas, "Theoretical Problems in Atomic Data," October 20, 1986.

D. B. Boercker, Lawrence Livermore National Laboratory, "Diffusion and Ion Dynamic Effects on Lyman-α Lines in Dense Plasmas," November 10, 1986.

S. Bliman, Centre d'Etudes Nucléaires de Grenoble, France, "Highly Charged Ions: A New Spectroscopy," November 13, 1986.

Steven Alston, JILA, "Vibrational Excitation in Electron-Molecule Collisions: Towards an *ab initio* Treatment," November 20, 1986.

Stephen M. Younger, Lawrence Livermore National Laboratory, "Giant Resonances in Electron-Impact Ionization," December 5, 1986.

Dennis L. Matthews, Lawrence Livermore National Laboratory, "Livermore Soft X-ray Laser Program," December 10, 1986.

Paul Indelicato, Curie Institute, Paris, "Relativistic Correlation in He-Like Ions, December 11, 1986.

John Morrison, University of Louisville, "Numerical Multi-Referent Perturbation Calculations for Atoms and Diatomic Molecules," March 5, 1987.

Dan V. I. Roginsky, Hebrew University of Jerusalem, "Calculations of Tighter Error Bounds on Atomic Oscillator Strengths," March 13, 1987.

Karl Welge, Universitat Bielefeld, West Germany, "Highly Excited Atoms in Strong Magnetic Fields," April 28, 1987.

Walter R. Johnson, University of Notre Dame, "Problems in Relativistic Many-Body Perturbation Calculations," May 27, 1987.

Vander Mullen, Eindhoven University, The Netherlands, "Plasma Spectroscopy," July 2, 1987.

Division 531, Sponsored Seminars and Colloquia (cont'd.)

Keishi Ishii, Kyoto University, Kyoto, Japan, "The Cobalt Isoelectronic Sequence," July 18, 1986.

Peter Hagelstein, Lawrence Livermore National Laboratory, "Relativistic Atomic Physics Calculations for Model Making,", August 6, 1986.

Indrek Martinson, University of Lund, Sweden, "Recent Advances in Lifetime Measurements for Multiply Ionized Atoms," August 22, 1986.

Division 533, Radiation Physics

The Radiation Physics Division focuses on measurement programs relating to the use of electron, laser, ultraviolet, and soft x-ray radiation in the energy range from about 5 eV (250 nm) to 500 eV (2.5 nm).

In support of this mission, radiation standards and advanced measurement techniques are developed. Through our standards program, the Division provides the central national basis for the measurement of far ultraviolet and soft x-ray radiation. The NBS synchrotron radiation facility and a detector calibration facility based upon well-characterized photoionization chambers serve as national radiation standards. Measurement services are available for the calibration of the quantum efficiency of UV photodiodes and the spectral responsivity of vacuum ultraviolet spectrometer systems.

Through our electron measurements program, new types of electron sources and detectors are developed to investigate the properties of matter on an atomic scale. For example, specially designed spin-polarized electron sources and detectors are used to determine fundamental atomic scattering properties and to measure surface magnetism. An electron tunneling device is being developed to provide "images" of surfaces on an atomic scale and to study relationships between macroscopic material properties and surface microstructure.

With the goals of improving standards and understanding the fundamental physical phenomena upon which they are based, the Division also conducts theoretical and experimental research on the electronic structure of atomic and molecular systems, the interaction of the systems with photon and electrons, and radiation deposition and energy transfer processes. Theories are developed for the scattering and transport of electrons in materials of fundamental and technological interest. New techniques and instrumentation are developed to study radiative reactions with matter, including photoexcitation and photoionization processes and non-linear effects in intense laser fields. Studies are underway to investigate to what extent the properties and behavior of atomic systems can be manipulated by measuring and controlling atomic and molecular states in their local environment.

The Division has two major research facilities, a dedicated synchrotron ultraviolet radiation facility (SURF-II) and a polarized electron research facility.

SURF-II is a dedicated synchrotron radiation facility, consisting of a 300 MeV electron storage ring, a 10 MeV microtron injector, and associated synchrotron radiation beamlines. It produces radiation in a

narrow, intense, highly polarized beam with a continuous and accurately known spectrum from the infrared, through the visible and the far ultraviolet, and into the soft x-ray region. SURF-II is unique among synchrotron light sources by virtue of its uniform and precisely known circular orbit. This allows accurate determination of all the spectral and geometrical properties of the radiation and hence its use as an absolute radiometric standard.

This facility serves staff from our own Division, users from other NBS Divisions, and outside users in radiometric standards and calibration work, optical physics research, surface science, biochemistry, spectroscopy, and other research areas utilizing far ultraviolet radiation. It helps to fill a growing demand for radiation in the ultraviolet and soft x-ray region of the electromagnetic spectrum. Of the 11 light ports at SURF, 6 are now instrumented for user applications and for calibration of optical instruments and transfer standard photodiodes. Some of these ports are shared by more than one experimental station. Three of the remaining ports are utilized for beam current monitoring, electron counting, and machine diagnostics. Most experiments and calibrations can run simultaneously, unless they require special beam parameters.

The polarized electron scattering facility is used to produce and measure beams of spin polarized electrons and is available for collaborative research by NBS and outside scientists in areas of mutual interest on a time-available basis. Three separate, ultra-high vacuum instruments are available. The polarized electron beams have currents in excess of 1 μA, with an optically reversible polarization at energies less than 1 keV and with an energy resolution of ≈0.15 eV.

These electrons are used to probe spin dependent scattering interactions between polarized electrons and surfaces or polarized electrons and atoms. The electron-surface scattering capability can be used to determine surface structure or study surface magnetic phenomena and their dependence on temperature, composition, adsorption, etc. The electron-atom scattering capability can be used to probe spin-orbit and exchange interactions in electron scattering and to completely determine the parameters of a selected collision process.

In relatively new research directions, several innovative electron measurement techniques pioneered at NBS are being further developed in cooperative programs with industry to study the atomic and magnetic microstructure of advanced materials. Magnetic microstructure can be measured with a spatial resolution approaching 100 Angstroms (0.01 microns) by a technique called Scanning Electron Microscopy with Polarization Analysis (SEMPA). An ultrahigh vacuum scanning tunneling microscope has also been constructed to apply the phenomenon of surface-vacuum-surface electron tunneling to investigations on an atomic scale of the nucleation and growth of thin films on clean metallic and semiconductor surfaces.

Division staff are also collaborating on two projects at the National Synchrotron Light Source (NSLS) facility at Brookhaven. The first involves radiation probing of exotic materials with soft x-rays. With colleagues from the U. of Tennessee and Oak Ridge National Labs, we are studying core-hole excitation and soft x-ray fluorescence in solid materials of fundamental and industrial significance such as GaAs, quasi-crystals, and high Tc superconductors. This is being done using an IR-100 award-winning, high sensitivity, soft x-ray emission spectrometer with an efficiency 1000 to 10,000 higher than conventional spectrometers in the energy range 20 eV to 1 keV.

In the second project, Division staff are part of a consortium of 11 principal investigators from 8 major laboratories representing industry, universities, and government. This "Materials Research Group", funded principally by NSF, is preparing to study surface magnetism using spin polarized photoemission techniques on materials prepared with molecular beam epitaxy methods. This work will be done on an undulator beamline at NSLS.

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, industry, and other government agencies. Some highlights of the past year include:

1. Cooperative agreements were made with Eastman Kodak Corporation and Control Data Corporation to initiate joint research on the NBS-SEMPA "magnetic microscope" to determine the magnetic microstructure of thin film magnetic storage devices with sub-micron resolution.

2. Atomic resolution was demonstrated on the NBS scanning tunneling microscope. An area 200 angstroms x 150 angstroms on a (111) crystal surface of silicon was measured with a lateral resolution of 5 angstroms and a vertical resolution of 0.1 angstroms.

3. Analysis of electron-scattering data resulted in a new classification scheme for doubly-excited states of negative ions and in the prediction of possible bound states of alkali-earth negative ions such as Sr^- and Ba^-.

4. The NBS Synchrotron Ultraviolet Radiation Facility (SURF-II) set a new record of 221 mA for maximum stored current, 10% higher than the previous record. At the same time, the lifetime of a stored beam under high current conditions was improved about a factor of 6, the half life being about 1 3/4 hours for a 200 mA stored current.

5. A new soft x-ray measurement program was implemented at Brookhaven-NSLS in collaboration with the U. of Tennessee and Oak Ridge National

Lab. Measurements utilizing a state-of-the-art soft x-ray emission spectrometer were made to study the properties of technologically significant materials such as GaAlAs, Al_6Mn icosahedral quasi-crystals, dilute magnesium and aluminum alloys, solid krypton "bubbles" in Al foil, and high Tc superconductors.

6. High Tc superconductors were studied using synchrotron radiation at NBS-SURF and Brookhaven-NSLS. At SURF, several experiments were made, both by our own staff and users from the NBS Surface Science Division, utilizing photoemission and total electron yield methods to investigate the electronic structure and energy bands of the compounds. At NSLS, the NBS/U. Tennesee/ORNL soft x-ray spectrometer was used to measure local density of states both above and below Tc.

7. The optical isotope shifts for the geologically interesting pair ^{10}Be:^{9}Be in the ^{1}S and ^{1}D Rydberg series have been measured for the first time by resonance ionization mass spectrometry (RIMS). The measurements were performed on samples of less than 10 ng of ^{10}Be, demonstrating the ultrasensitive capability of the RIMS technique. The goal of the program is to exploit enhanced isotopic selectivity in RIMS and develop ultrasensitive isotope abundance measurement capabilities.

8. An x-ray data-evaluation project was completed, in collaboration with the Ionizing Radiation Division (536), providing x-ray attenuation coefficients for all elements Z=1 to 92 in the energy range from 100 eV to 100 keV. This x-ray attenuation information is used in the areas of medical therapy and diagnosis, industrial radiometric gauging and control, materials analysis and modification, and in a broad range of other existing and emerging technologies vital to health care, industrial productivity, and national defense.

9. Twenty major visiting scientist collaborations were active in FY87: three in the Far UV Physics Group; eight in the Electron Physics Group; and nine in the Photon Physics Group.

FAR UV PHYSICS GROUP

The Far UV Physics Group is characterized by the development of radiometric techniques and standards for far ultraviolet radiation and by research on measurement methods utilizing far ultraviolet radiation. The NBS electron storage ring, SURF-II, is operated for radiometric research, for calibration of spectrometer systems and transfer standard detectors, and as a source of VUV/soft x-ray radiation for user-groups within NBS and outside. Additionally, off-SURF experimental research and development in radiometry is carried out, and transfer standard detectors are calibrated and supplied in the wavelength region 4-250 nm.

Far UV Detector Calibrations (L.R. Canfield and N. Swanson)

The far ultraviolet detector radiometry program continues to calibrate photodiodes from the soft x-ray region to the near ultraviolet, 5-254 nm. We also provide a service for recalibrating photodiodes returned by outside users. Since this program began in 1970, several hundred calibrated detectors have been shipped, and recalibrations have been performed on over 100 detectors. During FY 87, 21 new or recalibrated photodiodes were processed.

Windowless photodiodes for the spectral region 5-121.6 nm are fabricated in-house, and working standards of this type are calibrated directly using rare gas photoionization chambers. At wavelengths beyond the range of this direct technique, a special thermopile is used to extend the ionization chamber calibrations to longer wavelengths. The thermopile then serves as a secondary standard with which in-house, commercially-supplied, windowed photodiodes are calibrated. Transfer standards are then prepared for outside users by intercomparison calibrations with the working standards. These transfer standards are of the NBS-constructed windowless type for the short wavelength region, or the commercially-supplied, MgF_2-windowed photodiodes for the 116.4-253.7 nm spectral region. At SURF, the windowless photodiodes are calibrated in the spectral region 5-50 nm. (see Detector Calibration Beamline). All other calibrations of transfer standard photodiodes are carried out using laboratory light sources.

We are currently designing an experimental arrangement which will allow SURF-II to be the absolute standard for detector calibrations from 90-300 nm, i.e. eliminate our dependence on thermopile measurements having quite poor signal-to-noise. We hope to begin developing this new capability in FY 88.

Complete documentation of the far ultraviolet detector calibration program has recently been published as an NBS Special Publication (SP250-2).

SURF II Operations (L. Hughey, R. Madden, and W. Wooden)

The performance of SURF II continues to improve. The average beam current over the past year is about 90 mA, while the average over the last six months is closer to 130 mA. A new record beam of 221 mA was recorded during this period. In addition to this, the beam lifetime at high energy has been improved. SURF II has also operated quite reliably this year. Beam was provided to users 94.5% of the scheduled beam time (nine hours/day; 4 days/week) in FY 87.

A number of improvements made at SURF have been responsible for the higher current and lifetime performance. Vacuum improvements, particularly in the transport line connecting the injector to the storage ring,

resulted in lower ring pressure during injection. This improves the lifetime of the beam at injection and during the early part of the ramp to high energy. Another injection improvement was to optimize the height and duration of the high current pulse which "bumps" the electron beam immediately after injection, allowing it to be captured in a stable orbit.

Another improvement was to re-adjust the magnetic field radial gradient program to achieve the largest possible radial zone having a field index of 0.59 at each magnetic field strength throughout the ramp from injection to full energy. This was a change in acceleration philosophy that resulted in fewer lost electrons during the ramp phase. Finally, a new, constant current filament power supply in the microtron brought about a significant stabilization of the microtron output allowing better fine tuning of all injection parameters. These things in concert are responsible for the significant increase in accelerated current in recent months.

Other improvements have led to increased lifetime of the beam at full energy. The dynamic range of the main rf power supply was increased allowing the maximum rf voltage available at the cavity to be increased; a power splitting coaxial attenuator was installed in the rf feed-line between the final output amplifier and the rf cavity which stopped the electron beam from "talking" to the power amplifier; and a phase-shifter was added to this same rf feed-line to allow adjustments of the effective length of the feed-line. These changes have increased the applied rf power and have given us new tools to use in stabilizing resonant behavior of the beam. Now when the magnetic field gradient and rf power and phase are properly tuned, increased lifetime at full energy is achieved.

Operations staffing at SURF II remains a critical issue. After a long period of recruitment, an electronics engineer was finally hired in January 1987 to fill the vacancy created by the leaving of the SURF engineer in February 1986. Unfortunately, another opportunity lured this new person away six weeks later. We are once again recruiting a replacement. As an additional hardship, the SURF operator/technician retired in February 1987. However, in this case we were fortunate to quickly find a replacement. Thus, we are squeaking through this difficult period, but will be relieved when we are able to hire an electronics engineer to take some of the pressure off our two SURF operations staff members.

SURF-II User Programs (R. Madden)

SURF II was utilized by a variety of NBS and outside users in FY 87 for spectrometer and detector calibrations and for research in surface science, atomic and molecular physics, and UV and soft x-ray optical physics. The heaviest use was seen on the Surface Science beamline, BL-1, and the Spectrometer Calibration beamline, BL-2, followed closely by activity on the Angle-Resolved Photoelectron Spectroscopy (ARPES)

beamline, BL-5, and the Detector Calibration beamline, BL-9. Steady progress in commissioning the High Resolution Spectrometer beamline, BL-3, has also been made, and some lesser activity and considerable upgrading has occurred on the Optical Properties of Materials beamline, BL-8. The following paragraphs give more detail on the programs at each of these experimental stations.

A. Surface Science Beamline, BL-1 (R. Kurtz, T. Madey, and R. Stockbauer, all from NBS Center for Chemical Physics)

We have supported at SURF-II the establishment by the NBS Surface Science Division of an experimental capability to study adsorbed molecules on surfaces. These studies use several SURF-II monochromators and an ultrahigh vacuum system. Photon stimulated desorption (PSD) of ions is being studied to understand desorption mechanisms and energetics. Ion desorption mechanisms for ionically and covalently bonded adsorbates are investigated. Variable wavelength ultraviolet photoemission spectroscopy (UPS) is also utilized to study the electronic structure of metals, oxides, and chemical species adsorbed on these materials.

One of the techniques developed by this group is the measurement of electron attenuation lengths through molecular films. By measuring the decrease of a substrate photoemission peak as a molecular film is condensed and varying the photon energy, the attenuation length can be measured as a function of electron energy. These are the first measurements of their kind in the 20-200 eV energy range and are important in modeling the effects of ionizing radiation on materials and tissue.

The most exciting work this year was the study of the new, high temperature superconductors. Using variable wavelength photoemission, this group, in collaboration with a group from the Naval Research Laboratory, was able to investigate the electronic structure of $Ba_2YCu_3O_7$ above and below its superconducting critical temperature ($Tc \cong 92K$). These results showed that the mechanism for superconductivity in the material did not involve a large change in the electron energy states. This group is now concentrating on the electronic structure and surface chemistry of a variety of high Tc materials.

Work is also continuing on the effects on molecular adsorption of surface defects in TiO_2. This is an important catalytic material and a model compound for the theory of ion desorption.

A new ellipsoidal mirror analyzer (EMA) is being readied for installation on the Surface Science beamline. This is a unique instrument, with only one other operational in the United States. It is capable of measuring kinetic energy and angular distributions simultaneously. It will be used for angular resolved photoemission and ion desorption measurements. A He-cooled sample stage, a side sample preparation chamber, and a sample

transport mechanism are being constructed to produce single crystal thin films of the high Tc superconductors and of semiconductors. When the EMA is installed on BL-1, the present instrument will be moved to BL-8 to continue the electron attenuation length measurements.

B. Spectrometer Calibrations Beamline, BL-2 (M. Furst and T. Hall)

During FY 87 there were 10 user groups who used the SURF II spectrometer calibration facility over a period of 24 weeks. Since the photon flux from the electron storage ring can be calculated from precisely measured parameters, the synchrotron radiation is used as a radiometric standard to characterize absolute instrument response over a range of wavelengths from 4-400 nm. Users were from NASA/Goddard Space Flight Center, Univ. of Texas, North Carolina State University, LASP/Univ. of Colorado, Lawrence Livermore Labs, Air Force Weapons Laboratory, Naval Research Laboratory, and NBS. NASA continues to help support the facility.

There were several new user groups at the facility. One of the new users was a group from the Air Force Weapons Laboratory, who calibrated a spectrometer to be used to measure radiation from neutral particle beam bombardment of various materials. Another new user group was the University of Texas at Austin Fusion Research Center, who calibrated a spatial imaging vacuum monochromator. A group from Lawrence Livermore Laboratory was also new to the facility. They calibrated a spectrograph used for Tokamak plasma diagnostics.

Improvements to the large vacuum chamber for spectometer calibrations are continuing. The chamber provides a vacuum to simulate upper atmospheric conditions for spectrometer calibrations. A new computer has been acquired as a part of a dedicated control system for the vacuum chamber. The new computer system will have a much shorter response time when it is interfaced with user systems. Also, a class 10,000 clean room was completed for users of the vacuum chamber. At the 11.5 meter calibration gimbal, upgraded motor controllers have been installed to facilitate user operation of the gimbal system.

C. Ultra High Resolution Spectrometer Beamline for Atomic and Molecular Physics, BL-3 (M. Ginter, D. Ginter, and J. Proctor, all from the University of Maryland)

The work on a new beamline for a very high resolution, 6.65m normal incidence monochromator is continuing at SURF-II. Researchers from the U. of Maryland and the NRL are the principal investigators on this project, with partial support from the NSF. The goal of this project is to carry out research on the dynamics of energy transfer in atoms and molecules with an energy resolution that is a factor of ten better than photometric instruments currently in service at synchrotron radiation facilities. In a collaborative effort, a similar instrument has been installed and

converted to photometric studies at the KEK Photon Factory in Japan. These instruments will cover the 30-200 nm spectral range with resolving powers of 2×10^5. In addition, our instrument will provide highly polarized radiation to study atomic and molecular systems (polarization > 98% for wavelengths >60 nm).

The high resolution spectrometer was brought into near final focus in a series of tests conducted in Summer 87, and the components were prepared for connection to the SURF beamline. Absorption of SURF-II radiation by argon will be used for final spectral line focus tests. The first experiment will be the Stark effect in parahydrogen. This work will investigate the effects of an electric field upon predissociating and autoionizing states of molecular hydrogen. These measurements will be carried out by a visiting scientist with the Photon Physics Group of the Radiation Physics Division in collaboration with the University of Maryland team.

D. Angle-Resolved Photoelectron Spectroscopy Beamline for Molecular and Chemical Physics, BL-5 (T. Ferrett, J. Hardis, A. Parr, and S. Southworth, all from Div. 534)

In this research program, a high resolution angle-resolved photoelectron spectrometer is used on the high flux, normal-incidence 2m monochromator at SURF to study photoionization processes in atoms and molecules. Wavelength dependent measurements of the photoelectron intensities, branching ratios, and angular distributions are compared with corresponding theoretical calculations in order to develop basic understanding of resonant processes such as those due to autoionization and shape resonances. The high resolution and high sensitivity capabilities of the instrumentation are used to study vibrationally dependent effects and provide a sensitive set of experimental results that challenge the development of the theory of resonant processes in molecules. In addition, the measurements are applicable to phenomena involving the interaction of radiation with atoms and molecules such as occur in the upper atmosphere and astrophysical systems.

The instrumentation was substantially improved during the year. The channeltron photoelectron detectors were replaced with position sensitive detectors which allow a range of kinetic energies (approximately 0.5 eV) to be measured simultaneously. The data collection system is under computer control and makes use of a unique set of programs to efficiently store and display the photoelectron spectra as they are recorded. Newly designed components for the gas nozzle, electrostatic shielding, and photon beam intensity and polarization analysis were also installed. Data analysis has been greatly improved with the addition of a powerful microcomputer, graphics devices, and automation software which allow data analysis to be done concurrently with the data collection.

We have completed studies on H_2 and NO. Angular distribution measurements on H_2 were combined with corresponding measurements made independently at Daresbury Laboratory. The measurements confirmed a small but significant difference with theoretical calculations and imply that an additional interaction needs to be accounted for in the theory. The NO measurements showed strong, non-Franck-Condon effects over a wide energy range and have motivated the development of a theoretical model in which a shape resonance, valence excitation, and Rydberg excitation are combined into a complex autoionizing state.

Additional studies were made on CO, CO_2, and N_2O. Detailed oscillatory structure was measured in the photoelectron parameters of CO and is providing new information on electronic autoionization processes in this system. The measurements are being used to critically evaluate new theoretical methods under development. An extensive set of measurements made on CO_2 were used to characterize the effects of vibronic coupling in this system. This study of nonadiabatic interactions adds a new level of detail to the understanding of molecular photoionization processes. The measurements on N_2O characterized non-Franck-Condon effects arising from a shape resonance in a triatomic molecule and will be compared with theoretical calculations in progress.

E. Optical Properties of Materials Beamline, BL-8: (R. Keski-kuha, GSFC; D. Husk, U. Virginia; and S. Ebner, Div. 534)

This experimental station has a 2.2m grazing incidence monochromator and an experimental chamber outfitted with a reflectometer for studying reflectance as a function of angle of incidence. It has been used by scientists from NASA/Goddard for the study of reflectance of substrate materials for XUV optical systems and for the evaluation of multilayer structures made at Goddard and also provided by Dr. Troy Barbee of Lawrence Livermore Laboratories. The system was also used by scientists from the U. of Virginia to study the linearity of response of phosphors excited by XUV radiation.

A number of improvements of this experimental station have been undertaken this year. A new sample manipulator and ion pump were provided for the experimental chamber, and a gate valve for the monochromator. A new viewport for the entrance slit and a new monochromator drive system are also being designed.

F. Detector Calibration Beamline, BL-9 (L.R. Canfield)

The new detector calibration facility at SURF-II, commissioned last year, has been refined and is routinely producing outgoing calibrations in the range 5-50 nm as part of our transfer standard detector program (see Far UV Detector Calibrations).

This facility has also recently been used to perform total photoemission measurements of high temperature superconducting materials in a collaboration with other groups from NBS, the U. of Tennessee, and abroad. A number of composition and production parameters were varied in barium-yittrium-copper-oxide samples prepared at NBS and were studied at SURF in the region 5-55 nm. The spectra are dominated by the large resonance due to the d→f transitions in barium but also show structure due to copper 3p excitations near 77 eV which may contain valency information.

In addition, a recent modification to this facility has enabled the measurement of the optical properties of alkali nitrates and nitrites in collaboration with Oak Ridge National Laboratory. These samples are being prepared in thin film form on plastic substrates and studied in transmission. Other groups have expressed an interest in doing collaborative work using this new capability, including an interest by fusion diagnosticians to develop energy selective detectors by proper choice of photoemissive surface and accompanying filter.

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 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.

This year, we have made very significant advances in our electron-atom collision experiments. Our spin dependent scattering measurements provide so much detail and control of parameters as to exceed the capability of all current theoretical models. In particular, our superelastic measurements require a new theoretical formalism to describe the results. This new theoretical framework was also developed by us in conjunction with the experiments.

We have continued to study interfacial phenomena. As collaborators in a national effort, centered at the Brookhaven NSLS, we have begun experiments aimed at determining the spin dependent band structure of a new class of magnetic materials we will create in situ by molecular beam epitaxy.

We have continued to increase and focus our efforts toward the study of microscopic phenomena and their influence on the macroscopic properties of surfaces. A major emphasis is on magnetic phenomena and structure. We have improved our instrumentation by adding a scanning Auger microprobe facility to increase our capabilities in the study of magnetic micro-

structure. We have also brought on-line an ultrahigh vacuum scanning tunneling microscope and obtained atomic spatial resolution for the first time. Additionally, most of our experiments are being adapted to the use of the technique of molecular beam epitaxy to grow thin overlayer films, permitting us to study interfacial phenomena.

Electron - Atom Collision Studies (M.H. Kelley and J.J. McClelland)

Our purpose is to study, in as complete a manner as possible, the interactions between electrons and atoms in low energy collisions. We employ optical state preparation techniques to prepare beams of electrons and atoms in well defined quantum states and perform scattering measurements to determine the effect of atomic state preparation on the spin polarized incident electrons. When the atoms are optically-pumped, they are prepared in selected states of spin and orbital angular momentum. The measurement of the spin dependent effects in the collision provides direct information about spin dependent interactions, such as the exchange or the spin-orbit interaction, and consequently provides substantially more information than is available in conventional differential cross section measurements.

The elastic measurements were performed at an incident electron energy of 54.4 eV and at scattering angles in the range from 20° to 135°. Most surprising was that for even a light target such as sodium, the spin-orbit interaction played a significant role in the scattering, producing a spin dependence with a magnitude comparable to that due to exchange. Current state-of-the-art theoretical calculations, which include exchange but not the spin-orbit interaction, cannot reproduce our measurements of either the exchange or the spin-orbit spin dependences, indicating that further theoretical work is necessary.

In addition to the experimental studies of superelastic scattering in sodium, we have developed a theoretical framework with which to describe our results. In this framework we treat the electrons as scattering into one of two independent channels in which the spins of an incident electron and atom couple to form either a singlet or triplet composite spin state. Because the spin-orbit interaction is negligible for the inelastic collisions, this composite spin is conserved in the collision. From our measurements, we determine the ratio between the cross sections for triplet versus singlet scattering, and determine the orbital angular momentum imparted to the atom in collisions via either channel. Comparison with theory shows that, while the best available calculations are in substantial agreement with our measurements, there are important disagreements which point out the shortcomings of the theoretical models.

Our current efforts are directed at extending the energy range in which these measurements are possible. Our aim is to provide measurements of spin dependances for both elastic and superelastic scattering. This

provides theoreticians very detailed information about both of the dominant channels for electron scattering, and hence serves as an important benchmark for evaluting calculations.

Magnetic Microstructure Research (J. Unguris and R.J. Celotta)

Recently we have emphasized research investigating sub-micron magnetic structures using Scanning Electron Microscopy with Polarization Analysis (SEMPA). The SEMPA technique was developed at NBS and basically involves the combination of an ultrahigh vacuum scanning electron microscope (SEM) with detectors that measure the spin polarization of the secondary electrons. When a magnetic sample is scanned by the SEM, the secondary electrons that are emitted retain the spin orientation that they had in the solid and therefore are directly related to the magnetization in the region probed by the incident electron beam. In practice this means that magnetic structures can be resolved with a spatial resolution of about 10 nm (0.01 microns), which is the highest resolution available of any technique for looking at magnetic microstructure in reflection. In addition, because the escape depth of the secondary electrons is approximately 2 nm, SEMPA is an ideal probe of surface and thin film magnetism.

We have recently exploited the surface sensitivity of SEMPA to study the magnetic structures of ultra-thin Fe films that were epitaxially grown on Ag and Cu crystals. Because the lattice structure of the thin film is strongly affected by the substrate, the thin film magnetic properties can differ radically from those of bulk Fe. By adding Fe evaporation sources to our SEMPA apparatus, we were able to observe how the magnetic structure evolved as the film thickness changed. Magnetic domain structures could be observed with as little as three monolayers of Fe present. This work was done in collaboration with the Naval Research Lab.

In addition to this fundamental scientific research, we have also continued collaborating with private industry to use SEMPA to investigate more applied problems. For example, we worked with researchers from Eastman Kodak Corporation to study the magnetic properties of new materials for thin film magnetic recording heads.

We are also close to completing construction of a new SEMPA facility which will be centered about a scanning Auger microprobe. The Auger microprobe will provide us with a way of determining elemental composition with about the same spatial resolution and from the same area as the magnetic and topographic images. This microscope also features improved Au film polarization detectors and an enhanced image processing system to speed up data acquisition and analysis.

We have established joint research efforts with industry, other government laboratories, and universities. We have received a multitude of samples from major corporations interested in exploring the applicabil-

ity of this new technique to outstanding scientific and technological problems of concern. We expect these collaborative efforts to be scientifically fruitful, intellectually stimulating, and mutually beneficial.

Scanning Tunneling Microscopy (R. Dragoset, R. Young, S. Mielczarek, and D. Pierce)

As part of our shift in emphasis toward the physics of microstructures, we constructed and began operating a scanning tunneling microscope to improve our understanding of the fundamental atomic processes involved in the nucleation and growth of thin films on clean metallic and semiconductor surfaces. We have successfully operated the instrument in air, scanning gold and pyrolytic graphite surfaces, and we have measured the regular structure of a mechanically fabricated diffraction grating. While working in a high vacuum environment, we studied the result of the diamond-turning process used to fabricate extremely smooth mirrors. We have completed the installation of this system in a standard ultrahigh vacuum surface analysis chamber. In addition to scanning tunneling microscopy, this chamber allows LEED measurements, Auger spectroscopy, ion-sputtering, and sample installation, heating, cooling, and cleaning. The control of sample cleanliness and preparation available to us in this new system has recently permitted us to obtain topographic maps with atomic resolution of a Si(111) crystal. They clearly show the 7x7 reconstruction.

Now that we have an atomic resolution instrument on-line in a UHV system, our primary interest is the characterization of thin-film growth structures. Our initial plans include observing surface changes after sub-monolayer deposition of an evaporate on a Si(111) crystal surface. We will attempt to perform evaporation in situ in order to scan the same area of the surface before and after evaporation. We hope to correlate changes in surface structure after evaporation with the character of the surface before deposition (e.g. defects).

Polarized Photoemission Studies of Magnetic Systems (R. Celotta and D. Pierce)

Two years ago we began plans to collaborate with AT&T Bell Laboratories and Brookhaven National Laboratory to employ spin-polarized, angle-resolved photoemission to study surface magnetism. This effort has been greatly expanded in scope by the addition of a large number of prominent collaborators to form a Materials Research Group (MRG). The NSF-supported MRG consists of eleven principal investigators from the following institutions: AT&T Bell Labs, NSLS-Brookhaven National Laboratory, Argonne National Laboratory, Northwestern U., Rice U., U. of Texas at Austin, Naval Research Laboratory, U. of California at Irvine, and our own Group at NBS.

The focus of the effort will be to study both bulk materials and epitaxial ferromagnetic mono-, bi-, tri- and multi-layer materials. Investigations will include ground state magnetic properties, testing local density theory predictions, surface magnetic critical phenomena, spin-dependent photo-excitation, and energy- and wave-vector- resolved electron spectroscopy. Because of the increasing importance of interfaces and multilayered structures, the experimental station will include a molecular beam epitaxy apparatus for fabricating unique magnetic multilayered structures.

A component of this research will be aimed at improving the photon flux available from the U05 beam port on the NSLS x-ray storage ring. Our MRG has been designated as an insertion device team and will be installing a new undulator to provide a greatly enhanced photon flux for use in spin-polarized photoemission experiments. We have begun the initial experiments at NSLS using an existing experimental chamber and undulator. A molecular beam epitaxy system is being installed now, and contracts are being finalized for a new undulator and optical monochromator system.

This effort in understanding exotic magnetic structures will complement our effort in magnetic microstructure (SEMPA) and physical and electronic microstructure (STM) and greatly enhance our ability to understand the macroscopic physical properties of matter through study of their microscopic structure.

Spin Polarized Inverse Photoemission (L. Klebanoff, R. Jones, D. Pierce)

Studies of ferromagnetic metal surfaces using the spin polarized electron source developed in this group have continued productively over the last year. By using our polarized electron gun to observe the effects of the exchange interaction, we are able to measure the local net alignment of spins in the surface of a ferromagnet. The short mean free paths for elastically scattered electrons make this technique extremely surface sensitive, unlike neutron scattering which is used to study bulk magnetic phenomena. In the past several years we have focused on a spin polarized inverse photoemission (SPIPES) technique to study some transition metal surfaces.

Inverse photoemission complements photoemission studies by yielding energy and momentum resolved information about the unoccupied band structure at the surface. An electron incident upon the sample can undergo a radiative transition and become bound in a vacant orbital of the solid. The flux of 9.7 eV photons emitted from the sample is measured as a function of the energy, angle of incidence, and spin of the electrons. Since the energy, momentum, and spin are conserved, the final state is well defined. Because of its spin selectivity, SPIPES is applicable to a large number of areas of current interest in ferromagnetic materials.

In the past year, we completed and submitted for publication a SPIPES investigation of the clean Ni(001) surface and the c(2x2) absorption systems O/Ni(001) and S/Ni(001). For clean Ni(001), we found a minority-spin character for the unoccupied 3d band, but an essentially non-magnetic character for the Ni 4sp band. These spin-dependent results confirm previous spectral assignments made for Ni(001). No spin dependence of the Ni(001) image potential surface state was found.

Our investigations of Ni(001) chemisorption yielded surprising results. No evidence was found for a C(2x2) oxygen-induced antibonding state at the Surface Brillouin zone center, $\bar{\Gamma}$. This finding is in direct contradiction with published experiments and theoretical predictions. The chemisorbed oxygen does not significantly alter the intrinsic magnetization of the observed minority-spin 3d spectral peak. Chemisorbed sulfur produced qualitatively different results. The presence of a c(2x2) sulfur overlayer produces a small intensity enhancement at the Ni 3d IP peak, and reduces the observed spin dependence of the peak by four-fold. These variations suggest the possible existence of a sulfur-induced unoccupied state of majority spin character just above the Fermi level at $\bar{\Gamma}$. Such a state would play a central role in the mechanism by which sulfur destroys surface magnetism.

We are currently investigating the electronic and magnetic properties of ultra-thin epitaxial metallic films deposited on metallic substrates with SPIPES. The first thin film systems under study, monolayer and multilayer cobalt grown in situ on situ on Cu(111), have already yielded interested results. We have measured the energies of the unoccupied minority and majority spin cobalt d bands as well as a surface electronic state in cobalt films ranging from 0.8 to 9 monolayers. Changes in both the spin character and energy of the d band features are directly related to film thickness. These observations may lead to significant conclusions about the relationship between the electronic structure of a metallic monolayer film, which is a quasi two dimensional system, and the electronic structure of the corresponding three dimensional bulk metal.

Electron Theory (D. Penn)

A new, general formula was proposed for determining electron inelastic mean free paths (IMFPs) for 200-2000 eV electrons in solids. The new formula is based on separate IMFP calculations for 27 elements and 4 compounds using a previously developed algorithm. This formula is believed useful for determining the IMFP dependence on electron energy for a given material and the material-dependence for a given energy. The new formula should also be a reasonable guide to electron attenuation lengths that have been difficult to determine with the needed accuracy.

Also studied was the process of Auger decay in the interaction of metastable helium with metal surfaces. When metastable helium atoms

approach the surface of a metal, an Auger decay can take place in which a metal electron falls into an empty 1s state of helium and a second electron (the Auger electron) is ejected. Measurements of the total number of Auger electrons ejected from nickel for opposite spin-polarizations of metastable helium show a difference (normalized) that increases from 0 to 10% as the kinetic energy increases. We have formulated a theory for this asymmetry. In contrast to the standard interpretation, we find the sp-electrons to be of crucial importance. Whereas the d-electrons carry the main magnetic moment, the sp-electrons have the largest overlap with the helium.

Finally, the interaction between two test charges in a solid was studied. This interaction can be described in terms of a total dielectric function that includes electronic and lattice polarization. Stability requirements place restrictions on the dielectric function. These restrictions, which have previously been determined for the case of a uniform media, have been generalized to the inhomogeneous case. Some implications for superconductivity have been investigated. A total dielectric function for the electron-lattice system was derived in the mean field approximation, and it was shown that the resulting phonon modes are determined by the usual dynamical matrix.

PHOTON PHYSICS GROUP

The Photon Physics Group investigates the interaction of electromagnetic fields on atoms and molecules in various environments in support of radiation measurements and standards programs important to NBS and the outside technical community. This work includes theoretical and experimental studies on the electronic structure of atomic and molecular systems in field free environments and in strong external fields. The group has specialized in ionization phenomena and in nonlinear or multiphoton laser-atom interactions. Studies are currently focused on molecular excitation dynamics, shell contraction in atoms, multiphoton transitions, atoms in high electric and magnetic fields, and the structure of highly excited atoms. Collaborative work is directed toward ultrasensitive analysis through resonant multiphoton ionization, the measurement of picosecond VUV pulses by nonlinear cross correlation techniques, and the identification of highly excited atomic states suitable for a soft x-ray laser. For many of the activities, synchrotron radiation from NBS-SURF-II or Brookhaven-NSLS is used as a source of tunable vacuum ultraviolet and soft x-ray radiation.

Ultrasensitive Trace Analysis (T. Lucatorto and C. Clark)

This is a collaborative effort with the Mass Spectrometry Group in the NBS Center for Analytical Chemistry having the goal of developing a resonance ionization mass spectrometric (RIMS) capability with sub part-

per-billion isotopic abundance sensitivity. Present thermal ionization mass spectrometers have an ultimate isotopic abundance sensitivity of about one part in 10^7. By putting isotopic selectivity into the resonance ionization step, we hope to improve the overall sensitivity by three to five orders of magnitude.

Because of the lack of cw lasers capable of producing significant intensities in the ultraviolet, most RIMS applications have employed pulsed lasers. Our RIMS studies have used special narrow bandwidth pulsed lasers to perform isotopically selective ionization. Preliminary results with the isotope pair ^{10}Be: ^{9}Be show laser selectivities in excess of 3000:1, which would, in principle, increase the overall isotopic abundance sensitivity from $1:10^7$ to $1:3x10^{10}$. However, due to the poor duty factor of the pulsed laser (roughly $1:10^5$), the sample utilization efficiency is very low, with the result that sensitivities of only $1:10^7$ are attainable with practical samples.

The problem of poor sample utilization efficiency is perhaps the single most troublesome limitation for RIMS. To attack this problem, we have begun studies on pulsed laser desorption as a method of atomization that is matched to the duty cycle of the ionization laser. Preliminary results show that this technique can produce significant enhancements in efficiencies for relatively volatile elements such as Fe, but only produces marginal improvements for the more refractory elements such as Ta and Os. Three mechanisms limiting the effectiveness of the laser desorption technique are laser plasma formation, thermally induced exfoliation, and molecular binding. The pulsed laser desorption method is being modified to the pulsed laser evaporation of a thin film in an attempt to reduce the effects of these mechanisms.

In another effort done in collaboration with the Radiometric Physics Division (534), we are pursuing the development of a novel "storage ring" mass spectrometer for krypton isotopic abundance analysis in the sub-part-per-trillion range. The storage ring concept utilizes a combination of selective laser excitation and resonant charge exchange to recirculate a krypton ion beam along a set of prescribed orbits in a racetrack configuration. By combining the selectivity inherent in the laser excitation, the charge exchange, and the magnetic orbit filtering, this method should provide abundance sensitivities much higher than any of the presently available techniques.

Resonance Ionization Mass Spectrometry Data Service (E. Saloman)

The techniques of Resonance Ionization Spectroscopy (RIS) and Resonance Ionization Mass Spectroscopy (RIMS) have demonstrated high elemental sensitivity and the potential for almost 100% efficiency. They should become most valuable tools for analytical chemistry. For these techniques to meet their potential, they must be made available to practicing analyt-

ical chemists. Presently much of the information needed to apply RIS and RIMS is scattered in several atomic data bases, which generally contain much more information than the chemists would need. Our goal is to provide a handbook to supply the RIS schemes and atomic data that would allow the techniques to be applied to analytical needs without a major literature study in advance for each element to be measured.

This kind of data has been collected at NBS for seven decades. It is the objective of this project to organize the available data and supplement it with calculations where gaps exist to provide the needed information to permit the application of RIS and RIMS to routine use in analytical chemistry. Initial funding has been obtained and appropriate data sheets are being developed in collaboration with the RIS - RIMS community, including the Institute for Resonance Ionization Spectroscopy at the University of Tennessee.

Soft X-ray Emission Spectroscopy Using Synchrotron Light Excitation
(D.L. Ederer)

Soft x-ray fluorescence can provide important information about the electronic states of solid state materials. Fluorescence measurements can be used to study the properties of alloys, impurities, clusters, surface layers, organics, and other fragile compounds. A novel, high sensitivity soft x-ray spectrometer especially designed for fluorescence measurements has been in operation at the NSLS for over a year now and is the proud accomplishment of a joint NBS-University of Tennessee-Oak Ridge National Laboratory collaboration. This experiment has proved to be one of the best instruments in the world for soft x-ray fluorescence measurements.

The unique capabilities of the instrument has attracted a number of collaborators including scientists at the University of Utah, the University of Hawaii, the University of Connecticut, the University of Uppsala, AT&T Bell Laboratories, and NBS colleagues from the Institute of Materials Science and Engineering and the Institute for Computer Science and Technology. Through collaboration with our IMSE colleagues, we have studied the electronic structure of the icosahedral phase of an aluminum manganese alloy, as well as the electronic structure of the $Ba_2YCu_3O_{7-\delta}$ superconducting ceramics. This last area of research has been included as part of the scientific case for a DoC initiative on high temperature superconductors. A few of the highlights of this program are:

a) High Tc Superconductors:

The p-type density of states peak about 4 eV below the Fermi energy at all four different atomic sites. We confirm that copper has a valence of +2, and there is no change in the electronic structure as the temperature is changed from room temperature to below Tc.

b) Quasicrystals:

Several calculations predict an enhancement in the density of states near the Fermi energy. We observe a diminution in the density of states at the Fermi energy. One calculation predicts a rather large chemical shift in the Fermi energy as the symmetry changes from octagonal to icosahedral. We observe no significant chemical shift. In fact the major change observed in the spectrum is due to the alloying process rather than the phase change.

c) Al-GaAs and GaAs-P Semiconductor Compounds:

This collaboration with AT&T Bell Labs yielded the chemical shift as a function of aluminum concentration, which follows the change in the width of the band gap obtained from optical measurements. The slope of the chemical shift changes at the concentration where the alloy switches from an indirect to a direct semiconductor.

During the next year we will be continuing our studies of the high temperature superconductors and commence studies on implanted species of importance to the semiconductor industry. A new monochromator will be added to the instrumentation to allow for narrow band irradiation. We will also study radiation damage in the alkali halides, important window materials used in UV lasers.

Polarized Fluorescence Studies (D.L. Ederer)

A series of studies done in collaboration with the University of Maryland and the University of Central Florida has been carried out at SURF using the polarization of the synchrotron radiation beam as a probe of molecular and atomic photoionization dynamics. In helium we made the first measurements of the angular distribution of the 304 Å radiation following photoionization. This distribution reflects the alignment of the ion with the electron in a 2p orbital. The alignment is related to the ratio of the photoionization cross section to final continuum states of d symmetry to the total cross section for ionization and excitation of the electron to a 2p orbital. The measurements were in good agreement with close coupling calculations and complemented other experiments that measure the correlation among the electrons in this fundamental two electron system. The results were published in Phys. Rev. Letters.

We have made measurements on the alignment of O_2^+ for two different ionization channels. We have observed that the A state channel of the ion exhibits pronounced structure which correlates well with the known positions of autoionizing Rydberg states, whereas the polarization signal in the b channel of the ion has broad and less prominent features. A paper on this subject has been accepted for publication in the Journal of Chemical Physics.

Photoabsorption of Laser-Ionized Species (T. Lucatorto and C. Clark).

Our group has a unique capability to measure the VUV photoabsorption (between 8 nm and 65 nm) of laser-excited and laser-ionized atoms. The IR-100 award-winning instrumentation includes a state-of-the-art, VUV spectrometer with a 1024 channel photoelectric detector, a 20 ns pulsed VUV source, several pulsed tunable dye lasers, a high temperature (up to 2500°C) heat-pipe oven, and a mode-locked laser capable of powers of 0.3 GW for durations as short as 30 ps.

Photoabsorption studies of laser-excited and laser-ionized atoms have uncovered the dramatic effects of relatively small changes in electron screening on orbital collapse. During the last year we completed an analysis of the 5p-photoabsorption of Ba^{++} and performed a preliminary analysis of the 3p photoabsorption of $Mn(3d^54s^2\ ^6S)$, $Mn^*(3d^54s4p\ ^8P)$, and $Mn^+(3d^54s\ ^7S)$ in collaboration with visiting scientists.

The objective of the research on Mn(Z=25) is to explain why the 3p photoabsorption of $Cr(3d^54s\ ^7S)$ with Z=24, which displays a well-developed Rydberg series, differs so dramatically from the analogous photoabsorption in Mn and other neighboring elements which have a single broad resonance and several much weaker features. It is hoped that by obtaining a detailed spectrum of $Mn^+(3d^54s^7S)$, which is isoelectronic to the Cr, we may provide a key element in finding the explanation for the puzzling difference between Cr and the other transition metals. Obviously the difference in screening between the Mn^+ and Cr systems has a crucial influence on the structure of the $3d^5$- and $3d^6$- based configurations which play a central role in the 3p photoabsorption spectra. A theoretical effort is being pursued in parallel to the experimental work.

This work is a collaboration with the Atomic and Plasma Radiation Division.

Development of a Measurement Program to use the Time Structure of the Electron Beam at SURF (D.L. Ederer)

A new class of experiments are being planned for SURF which will utilize both lasers and synchrotron radiation. Synchrotron radiation is a source of pulsed VUV radiation that can be used to produce excitation leading to chemical reactions. By probing a sample of excited molecules undergoing a reaction with a laser-locked to the storage ring radio frequency, we may obtain detailed information on the dynamics of the chemical reaction. The mode locked ND:YAG laser with the doubler and Q switch has arrived and will eventually be installed on the SURF Storage Ring.

During the waiting time for the laser arrival, we have been exploring some potential new directions for the pump-probe program through a collaborative research program at AT&T Bell Laboratories. At Bell Labs a sub-picosecond laser is used to produce a plasma rich in XUV radiation which is then monochromatized. A portion of the laser beam is combined with the monochromatic XUV beam to conduct pump-probe experiments. The goal of this work is to make a VUV- visible cross correlation on core excitons in alkali-halides which will allow sub-picosecond measurements of VUV pulses.

Our long-term collaboration to study laser-prepared states with the Université de Paris-Sud in Orsay, France, is winding down. Measurements of the partial photoionization cross section from the 5d metastable state in barium vapor were published in Phys. Rev. Letters. In this work, we showed that inner core correlations between the 5d electron and the electrons in the 4d sub shell were responsible for structure in the 5d photoionization cross section. A review of photoionization from excited states, co-authored by D. Ederer and F. Wuilleumier, will be published early in 1988 as a book chapter in Advances in Atomic and Molecular Physics entitled "Photoionization and Collisional Ionization of Laser Excited Atoms Using Synchrotron Radiation."

Atomic and Molecular Theory (C.W. Clark)

Theoretical work in the Photon Physics Group continued its focus on problems of core- and multiply-excited states. The main accomplishments of the past year in this area were:

1) Conclusion of the analysis of isotope shifts in the ^1S and ^1D series of ^9Be and ^{10}Be;

2) Identification of the principal features in 3p photoabsorption by Mn^+;

3) Systematic classification of low energy p-wave shape resonances in electron-atom scattering;

4) Completion of a comparative study of photoabsorption and electron energy loss spectroscopy of metallic Ce near the 4p excitation threshold;

5) Work on the development of a general computer code for computation of two-photon transition probabilities; and

6) Formulation of a procedure for the computation of high-order multi-photon processes in atomic hydrogen by a Sturmian functions approach.

In addition, a project to investigate certain radiative corrections to the energy levels of high-Z ions was started. Other theoretical work was done during this period to directly assist experimental efforts in the group:

1) Analysis of soft x-ray fluorescence spectra and total photoemission yield spectra of new high-Tc superconducting compounds;

2) Participation in the proposal and design of an experiment to measure the Stark effect in para H_2; and

3) Proposals for new atomic physics experiments on the RIMS apparatus.

This work was done in collaboration with guest scientists from the University of Delaware, the Australian National University, and the Royal Holloway & Bedford New Colleges.

X-Ray Attenuation Cross Sections (E. Saloman)

A comparison has been carried out, in both tabular and graphical form, over the energy range 0.1-100 keV between the National Bureau of Standards' data base of experimental attenuation coefficients (total absorption cross sections) and cross sections obtained using two widely used sets of absorption cross section values: the semi-empirical set of recommended values produced by Henke et al. and a theoretical set of recommended values calculated by Scofield (and extended at our request down to 0.1 keV). We also evaluated whether Scofield's calculation should be subject to a renormalization from a Hartree-Slater to a Hartree-Fock atomic model and determined that the experimental data tend to argue against such renormalization.

A bibliography of the NBS data base has been produced in conjunction with this comparison. The results of this work were issued as NBS Internal Reports 86-3431 and 86-3461. A compilation of experimental and theoretical x-ray attenuation coefficients for this energy range has been prepared in collaboration with H. Scofield of Lawrence Livermore National Laboratory. It is expected to be published early next year.

This work is a collaboration with the Ionizing Radiation Division.

Relativistic Multi-Configuration Calculation of Atomic Properties (E. Saloman)

Relativistic multi-configuration Dirac-Fock methods have been applied to the calculation of atomic and ionic energies and transition probabilities. The initial study being carried out is an investigation of the energies and oscillator strengths in the ground state configuration of the sulfur isoelectronic sequence. Results have been obtained already for 31

members. They demonstrate striking effects in the f-values corresponding to atomic numbers where different configurations become important. Calculation of the rest of the members of this sequence will take place next year.

This work is a collaboration with the Atomic and Plasma Radiation Division.

Electric Field Effects (E. Saloman)

This program studies the effect of electric fields on the absorption cross sections and autoionization rates of atoms and molecules. We have investigated the effect of electric fields on autoionizing Ba states using multi-color, multi-photon laser excitation. We have completed a theoretical and experimental investigation of the Stark effect on Rydberg states with anisotropic ion cores. The results of this investigation have been published in Physical Review. Further work on this project has been temporarily suspended.

This work is a collaboration with the Atomic and Plasma Radiation Division.

SPONSORED WORKSHOPS, CONFERENCES, AND SYMPOSIA

Division 533, Radiation Physics

C.W. Clark organized a meeting on the Atomic Physics of Beryllium, NBS, December 12, 1986.

C.W. Clark organized and chaired the Symposium on Formation and Decay of Multiply Excited States, IV International Conference on Multiphoton Processes, Boulder, CO, July 15, 1987.

R.P. Madden organized, jointly with JILA and Ball Research Corporation, the 8th Workshop on the Vacuum Ultraviolet Radiometric Calibration of Space Experiments, Boulder, CO, March 18-19, 1987.

D.T. Pierce organized and chaired the Symposium on Magnetic Microstructure, Conference on Magnetism and Magnetic Materials, Baltimore, MD, November 18, 1986.

INVITED TALKS

Division 533, Radiation Physics

1. Celotta, R.J., "New Ways of Observing Microstructure: The STM and SEMPA," Physics Colloquium, City College of New York, NY, November 5, 1986.

2. Celotta, R.J., "Polarized Electron Microscopy of Magnetic Surfaces," Meeting of the American Vacuum Society, Minneapolis, MN, November 11, 1986.

3. Celotta, R.J., "Polarized Electron Microscopy of Magnetic Surfaces," Colloquium, 3M Corporation, Minneapolis, MN, November 12, 1986.

4. Celotta, R.J., "Magnetic Microstructure of Amorphous Alloys Studied Using Scanning Electron Microscopy with Polarization Analysis," 31st Conf. on Magnetism and Magnetic Materials, Baltimore, MD, November 17 1986.

5. Celotta, R.J., "New Directions in Electron Microscopy," Philosophical Society of Washington, Cosmos Club, Washington, D.C., December 5, 1986.

6. Celotta, R.J., "Scanning Electron Microscopy with Polarization Analysis," Colloquium, Chemistry Dept., University of Maryland, College Park, MD, February 27, 1987.

7. Celotta, R.J., "Scanning Tunneling and Scanning Polarization Microscopy," Physics Colloquium, Johns Hopkins University, Baltimore, MD, April 2, 1987.

8. Celotta, R.J., "Scanning Electron Microscopy with Polarization Analysis-SEMPA," Electron Microscopy Society of America, Annual Meeting, Baltimore, MD, August 5, 1987.

9. Celotta, R.J., "Scanning Electron Microscopy with Polarization Analysis: Studies of Magnetic Microstructure," American Vacuum Society, Annual Meeting, Anaheim, CA, November 2, 1987.

10. Clark, C.W., "Excited States of Atoms and Negative Ions," Atomic Physics Colloquium, University of Virginia, Charlottesville, VA, November 12, 1986.

11. Clark, C.W., "Doubly-Excited States of Negative Ions," Physics Colloquium, College of William and Mary, Williamsburg, VA, February 13, 1987.

12. Clark, C.W. "Atomic Negative Ion Resonances," International Conference on the Physics of Electronic and Atomic Collisions, Brighton, England, July 27, 1987.

13. Clark, C.W. "Summary Remarks," Atomic Spectra and Collisions in External Fields, Royal Holloway and Bedford New College, Egham, England, July 31, 1987.

14. Clark, C.W., "Theory of Highly Excited Atoms in Electric and Magnetic Fields," Symposium on Atomic Spectroscopy and Highly Ionized Atoms, Hickory Ridge Conference Center, Lisle, IL, August 17, 1987.

15. Dragoset, R.A., "Scanning Tunneling Microscopy of a Diamond-turned Surface and a Grating Replica," SPIE Conference on Metrology: Figure and Finish, Los Angeles, CA, January 15, 1987.

16. Ederer, D.L., "X-Ray Fluorescence in Dilute Alloys," Workshop on New Directions in Soft X-Ray Near Threshold Phenomena, Monterey, CA, March 3, 1987.

17. Ederer, D.L., "X-Ray Fluorescence in Low Z Metals," University of Maryland Baltimore County, Baltimore, MD, March 15, 1987.

18. Ederer, D.L., "Pump and Probe Experiments with Lasers and Synchrotron," Brookhaven National Laboratory, Islip, NY, July 14, 1987.

19. Ferrett, T.A., "Shake-up, Shake-off, and Shape Resonances in Near Threshold Photoemission," Workshop on New Directions in Soft X-ray Near-Threshold Phenomena, Pacific Grove, CA, March 2, 1987.

20. Ferrett, T.A., "High-resolution Photoelectron Spectroscopy of Gaseous CO and CO_2 Using Synchrotron Radiation," Daresbury Laboratory, Warrington, England, September 1, 1987.

21. Ferrett, T.A., "High-resolution Photoelectron Spectroscopy of Gaseous CO and CO_2 Using Synchrotron Radiation," National Research Council Laboratory, Frascati, Italy, September 8, 1987.

22. Hughey, L.R., "Radiometry Using Synchrotron Radiation at NBS-SURF," Council for Optical Radiation Measurements, NBS, Gaithersburg, MD, May 28, 1987.

23. Johnson, B.C., "Transition Probabilities for Astrophysical Plasmas," Carnegie Institute of Washington, Washington, DC, April 11, 1987.

24. Johnson, B.C., "Experimental Study of Laser-Induced Collisions," Rice University, Houston, TX, November 17, 1986.

Division 533, Invited Talks (cont'd)

25. Johnson, B.C., "Kinetics of Associative Ionization in Heteronuclear Collisions," Meeting of the Division of the Atomic, Molecular, and Optical Physics of the American Physical Society, Cambridge, MA, May 18, 1987.

26. Lucatorto, T.B., "Ultrasensitive Isotopic Analysis With RIMS: Application to $^{10}Be:^{9}Be$," Twenty-ninth ONRL-DoE Conference on Analytical Chemistry in Energy Technology, Knoxville, TN, October 1, 1986.

27. Lucatorto, T.B., "Resonance Ionization Mass Spectrometry for Long-lived Radionuclide Assay," Thirty-second Annual Conference on Bioassay Analytical and Environmental Radiochemistry, NBS, October 22, 1986.

28. Madden, R.P., "UV Radiometric Calibration of Space Experiments at NBS-SURF II," Symposium on Solar Irradiance Measurements, Vancouver, Canada, August 21, 1987.

29. Madden, R.P., "By What Means Can Better Flux Calibrations Be Achieved," Eighth Workshop on the VUV Radiometric Calibration of Space Experiments, JILA/NBS, Boulder, CO, March 19, 1987.

30. Madden, R.P., "SURF II Performance and Research Activities," Synchrotron Radiation Instrumentation Conference, University of Wisconsin, Madison, WI, June 22, 1987.

31. Ott, W.R., "UV and Soft X-ray Measurements Services", Region 3 Local Chapter of the National Conference of Standards Laboratories, Lexington Park, MD, January 21, 1987.

32. Ott, W.R., "Radiation Standards and Calibrations: Documentation Available from NBS," Workshop and Symposium on Innovation: Key to the Future, National Conference of Standards Laboratories, Denver, CO, July 14, 1987.

33. Ott, W.R., "UV and Soft X-Ray Measurement Services at NBS," Workshop and Symposium on Innovation: Key to the Future, National Conference of Standards Laboratories, Denver, CO, July 16, 1987.

34. Ott, W.R., "Industrially-Significant NBS Developments in the Physical Sciences," Government/Industry Technology Transfer Conference, Nashville, TN, August 7, 1987.

35. Penn, D.R., "Electronic Structure and Theory of Superconductivity," NBS, Boulder, CO, July 16, 1987.

Division 533. Invited Talks (cont'd)

36. Pierce, D.T., "Scanning Electron Microscopy with Polarization Analysis: High Resolution Images of Magnetic Microstructure," 5th Pfefferkorn Conference on Physical Aspects of Microscopic Characterization of Materials, Bruggen, Germany, October 10, 1986.

37. Pierce, D.T., "The Ga-As Polarized Electron Source and Its Application," Perkin-Elmer Corporation, February 23, 1987.

38. Pierce, D.T., "Scanning Electron Microscopy with Polarization Analysis," IBM Research Labs, Zurich, Switzerland, April 6, 1987.

39. Pierce, D.T., "SEMPA: High Resolution Imaging of Magnetization," Eidgenossische Technische Hochschule, Zurich, Switzerland, April 8, 1987.

40 Pierce, D.T., "Experimental Study of Surface Magnetism with Polarized Electrons," 9th European Conference on Surface Science, Lucern, Switzerland, April 15, 1987.

41. Pierce, D.T., "Electron Spin Polarization Analyzers for Use With Synchrotron Radiation," 5th National Conference on Synchrotron Radiation Instrumentation, Madison, WI, June 22, 1987.

42. Pierce, D.T., "Polarized Electron Microscopy," Adriatic Research Conference on Scanning Tunneling Microscopy, Trieste, July 29, 1987.

43. Pierce, D.T., "Experimental Studies of Surface and Thin Film Magnetism with Polarized Electrons," Sandia National Laboratory Seminar, Albuquerque, NM, September 8, 1987.

44. Unguris, J., "Imaging Magnetic Microstructures Using Scanning Electron Microscopy with Polarization Analysis," Seminar, Physical Electronics, Eden Prairie, MN, July 11, 1986.

45. Unguris, J., "Investigations of Magnetic Microstructures Using Scanning Electron Microscopy with Polarization Analysis (SEMPA)," Gordon Conference on Electron Spectroscopy, Wolfeboro, NH, July 17, 1986.

46. Unguris, J., "Microscopy with Spin Polarized Electrons," Inter/Micro-86, Chicago, IL, July 22, 1986.

47. Unguris, J., "Spin Polarized Electron Studies of Magnetic Materials," Physics Colloquium, University of Maine, Orano, Maine, November 4, 1986.

Division 533, Invited Talks (cont'd)

48. Unguris, J., "Scanning Electron Microscopy with Spin Polarized Electrons", 31st Conference on Magnetism and Magnetic Materials, Baltimore, MD, November 18, 1986.

49. Unguris, J., "Magnetic Microstructure Imaging using Scanning Electron Microscopy with Polarization Analysis", Microbeam Analysis Society Meeting, Kona, HI, July 16, 1987.

PUBLICATIONS

Division 533, Radiation Physics

Callcott, T.A., Tsang, K.L., Zhang, C.H., Ederer, D.L., and Arakawa, E.T., A High Efficiency Soft X-ray Emission Spectrometer for use with Synchrotron Radiation Excitation, Rev. Sci. Instrum. 57, 2680 (1986).

Canfield, L.R., New Far Ultraviolet Detector Calibration Facility at NBS, Appl. Opt. 26, 3831 (1987).

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McClelland, J.J., Kelley, M.H. and Celotta, R.J., Spin-Orbit and Exchange Effects in Elastic Scattering of Spin-Polarized Electrons from Spin-Polarized Na Atoms, Phys. Rev. Lett. 58, 2198 (1987).

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Southworth, S.H., Parr, A.C., Hardis, J.E., Dehmer, J.L., and Holland, D.M.P., Calibration of a Monochromator/Spectrometer System for the Measurement of Photoelectron Angular Distributions and Branching Ratios, Nucl. Instr. and Meth. A 246, 782 (1986).

Travis, J.C., Fassett, J.D., and Lucatorto, T.B., Resonance Ionization Mass Spectroscopy, RIS 86, G.S. Hurst ed., Inst. Phys. Conf. Ser. No. 84 (Inst. of Physics 1986).

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Unguris, J., Hembree, G.G., Celotta, R.J. and Pierce, D.T., Summary Abstract: Scanning Electron Microscope with Polarization Analysis Studies of Magnetic Materials, J. Vac. Sci. Technol. A 5, 1976 (1987).

PUBLICATIONS IN PREPARATION

Division 533, Radiation Physics Division

Callcott, T.A., Tsang, K.L., Zhang, C.H., Ederer, D.L., and Arakawa, E.T., Soft X-Ray Emission Spectra and the Bonding of Aluminum (to be published, J. De Physique).

Callcott, T.A., Tsang, K.L., Zhang, C.H., Ederer, D.L., and Arakawa, E.T., Area Detectors for X-Ray Spectroscopy (submitted, Nucl. Inst. & Meth.).

Celotta, R.J., Unguris, J. and Pierce, D.T., Scanning Electron Microscopy with Polarization Analysis - SEMPA (to be published, Proc. Electron Microscopy Society of America, 1987).

Celotta, R.J., Unguris, J. and Pierce, D.T., Summary Abstract: SEM Polarization Analysis: Studies of Magnetic Microstructure (to be published, J. Vac. Sci. Technol.).

Celotta, R.J., Advances in Microscopy: Scanning Tunneling and Electron Polarization Microscopy, Applied Surface Science (in press).

Dragoset, R.A. and Vorburger, T.V., Scanning Tunneling Microscopy of a Diamond-turned Surface and A Grating Replica (to be published, SPIE Conference Proceedings, 1987).

Ederer, D.L., Schaeffer, R., Tsang, K.L., Zhang, C.H., Callcott, T.A., and Arakawa, E.T., Electronic Structure of the Icosahedral and Other Phases of Aluminum-Manganese Alloys Studied by Soft X-Ray Emission Spectroscopy (in preparation).

Ferrett, T.A., Lindle, D.W. Heimann, P.A., Brewer, W.D., Becker, U., Kerkhoff, H.G., and Shirley, D.A., Lithium 1s Mainline and Satellite Photoemission: Resonant and Nonresonant Behavior, (to be published, Phys. Rev. A).

Ferrett, T.A., Schmidt, V., Roy, P., Parr, A.C., Hardis, J.E., and Dehmer, J.L., Vibrationally-resolved Photoemission Cross Sections and Asymmetry Parameters for the $\tilde{X}$, $\tilde{A}$, $\tilde{B}$, and $\tilde{C}$, States of CO_2^+ (in preparation).

Heimann, P.A., Lindle, D.W., Ferrett, T.A., Liu, S.H., Medhurst, L.J., Piancastelli, M.N, Shirley, D.A., Becker, U., Kerkhoff, H.G., Langer, B., Szostak, D., Wehlitz, R., Shake-off on Inner-shell Resonances of Ar, Kr, and Xe, (to be published, J. Phys. B).

Jimenez-Mier, J., Caldwell, C.D., and Ederer, D.L., Oscillator Strength Distribution of Fluorescence from Photoionization Produced He+(n=2) (in preparation).

Division 533, Publications in Preparation (cont'd)

Jones, R.K., Klebanoff, L.E., Pierce, D.T. and Celotta, R.J., Spin-Resolved Inverse Photoemission Study of Ni(001) and its Chemisorption (to be published, Phys. Rev. B.).

Jones, R.K., Klebanoff, L.E., Pierce, D.T. and Celotta, R.J., Spin Resolved Inverse Photoemission of Ultra-thin Epitaxial Cobalt Films on Cu(111) (in preparation).

Lucatorto, T.B., Hutchinson, J.M.R, and Whitaker, T.J., Exploiting the Optical Isotope Shift for Ultrasensitive Isotopic Analysis with Lasers, Proc. of the 1986 Annual Meeting of the American Nuclear Society (Reno, NV, June 1986) (to be published).

Matthew, J.A.D., Netzer, F.P., Clark, C.W., and Morar, J.F., Giant 4p Quadrupole Resonances in the Rare Earths (to be published, Europhysics Letters).

McClelland, J., Scholten, R.E., Kelley, M.H. and Celotta, R.J., Spin Sensitivity of a Channel Electron Multiplier (submitted, Rev. Sci. Instr.).

Parr, A.C., Southworth, S.H., and Dehmer, J.L., Shape Resonance Effects in Photoionization of NO (in preparation).

Parr, A.C, Hardis, J.E., Southworth, S.H., Feigerle, C.S., Ferrett, T.A., Holland, D.M.P., Quinn, F.M., Dobson, B.R., West, J.B., Marr, G.V., and Dehmer, J.L., Vibrationally Resolved Photoelectron Angular Distributions for H_2 in the Range 17 eV $\leq h\upsilon \leq$ 39 eV (submitted, Phys. Rev. A).

Penn, D.R., Tanuma, S., and Powell, C.J., Inelastic Mean Free Paths; Energy and Material Dependence (in preparation).

Penn, D.R., Allen, P., and Cohen, M., Total Dielectric Function: Algebraic Sign, Electron-Lattice Response, and Superconductivity (submitted, Phys. Rev).

Penn, D.R., Apell, P., and Monreal, R. Spin Polarization of Secondary Electrons in Metastable Helium-Nickel Interactions (in preparation).

Pierce, D.T., Hembree, G.G., Unguris, J. and Celotta, R.J., SEMPA: High Resolution Image of Magnetic Microstructure (to be published, Scanning Electron Microscopy, 1987).

Pierce, D.T., Experimental Studies of Surface Magnetism with Polarized Electrons (to be published, Surface Science).

Pierce, D.T., Celotta, R.J., Kelley, M.H. and Unguris, J., Electron Spin Polarization Analyzers for Use with Synchrotron Radiation (to be published, Nucl. Instr. Meth).

Division 533, Publications in Progress (cont'd)

Roy, P., Ferrett, T.A., Schmidt, V., Parr, A.C., Southworth, S.H., Hardis, J.E., Bartlett, R., Trela, W., and Dehmer, J.L., A Study of Vibronic Coupling in the C State of CO_2^+ (to be published, J. de Physique).

Roy, P., Ferrett, T.A., Schmidt, V., Parr, A.C., Southworth, S.H., Hardis, J.E., Bartlett, R., Trela, W., and Dehmer, J.L., A Dynamical Study of Vibronic Coupling: the $\tilde{C}$ State of CO_2^+ (in preparation).

Tsang, K.L., Zhang, C.H., Callcott, T.A., Canfield, L.R., Blendall, J., Ederer, D.L., Clark, C.W., Wassdahl, N., Rubensson, J.E., Bray, G., B.C., Nordgren, J., Martensson, N., Nyholm, R., and Cramm, S., Soft X-ray Absorption and Emission Spectra and the Electronic Structure of $Ba_2YCu_3O_{7-x}$ Superconductor, Proc. of the 14th International Conference on X-rays and Inner Shell Processes (to be published, J. de Physique).

Tsang, K.L., Zhang, C.H., Callcott, T.A., Canfield, L.R., Blendall, J., Ederer, D.L., Clark, C.W., Wassdahl, N., Rubensson, J.E., Bray, G., B.C., Nordgren, J., Martensson, N., Nyholm, R., and Cramm, S., Soft X-ray Absorption and Emission Spectra and the Electronic Structure of $Ba_2YCu_3O_{7-x}$ Superconductor (to be published, Phys. Rev B. Rapid Communication).

Unguris, J., Celotta, R.J., Pierce, D.T. and Hembree, G.G., Magnetic Microstructure Imaging using Scanning Electron Microscopy with Polarization Analysis (to be published, Analytical Electron Microscopy, 1987).

Wen, J., Travis, J.C., Lucatorto, T.B., Johnson, B.C., and Clark, C.W., Measurement of Isotope Shifts of Two-Photon Transitions in Beryllium (to be published, Phys. Rev. A.).

Wuilleumier, F.J., Ederer., D.L., and Picqué, J.L., Photoionization and Collisional Ionization of Laser Excited Atoms Using Synchrotron Radiation (to be published, January 1988, chapter in "Advances in Atomic and Molecular Physics," Volume 23).

Zhang, C.H., Tsang, K.-L., Callcott, T.A., Ederer, D.L., and Arakawa, E.T., The Al $L_{2,3}$ and Mg Double Ionization Emission Spectra of Dilute Al in Mg Alloys (submitted, Phys. Rev. B).

TECHNICAL AND PROFESSIONAL COMMITTEE PARTICIPATION AND LEADERSHIP

Division 533, Radiation Physics Division

Robert J. Celotta

Member, General Committee, International Conference on the Physics of Electronic and Atomic Collisions.

Member, NML EEO Committee, 1986-87.

Charles W. Clark

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

Member, Organizing Committee, IV International Conference on Multi-photon Processes, 1987.

Member, Organizing Committee, 1987 Conference on Atomic Spectra and Collisions in External Fields.

Thomas B. Lucatorto

Co-chairman, 1989 International Conference on the Physics of Electron and Atomic Collisions.

Member, Program Committee, 4th International Symposium on Resonance Ionization Spectroscopy and its Applications, 1988.

Co-chairman, Local Organizing Committee, 4th International Symposium on Resonance Ionization Spectroscopy and its Applications, 1988.

Co-chairman, 1987 Workshop on Advanced Laser Techniques in Chemical Analysis.

Robert P. Madden

Chairman, Optical Society of America Nominating Committee.

Member, Calibration and Stability Working Group of the Ozone Trends Panel.

Coordinator, International Radiometric Intercomparison of Solar Irradiance Experiments.

Member, International Committee for the International Conference on Vacuum Ultraviolet Radiation Physics.

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

Member, Editorial Advisory Board, Optics Communication.

Member, Middle Atmospheric Program International Working Group on Solar Spectral Irradiance Measurements, 1981-1987.

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

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

Member, Advisory Committee for the Laboratory of Laser Energetics, University of Rochester, Rochester, NY.

Member, Optical Society of America Objectives and Policy Committee.

Member, Synchrotron Radiation Facility Working Group (Department of Energy).

Member, NBS-NML Classification Committee for the NBS Personnel Demonstration Project.

Stanley R. Mielczarek

Member, NBS Property Review Board.

William R. Ott

Member, International Working Group for Middle Atmosphere Program on Solar Spectral Irradiance Measurements, 1981-1987.

Member, Local Organizing Committee for the 4th International Symposium on Resonance Ionization Spectroscopy and Its Applications, 1987-88.

Chairman, NBS-CRR Calibrations Advisory Committee, 1985-87.

Chairman, NBS-NML Performance Review Panel, 1986-87.

Member, NBS-NML Classification Committee for the NBS Personnel Demonstration Project.

Daniel T. Pierce

Member, Editorial board, Review of Scientific Instruments.

Member, Editorial board, Journal of Electron Spectroscopy.

Chairman, 1988 Gordon Conference on Electron Spectroscopy.

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

Vice Chairman, Executive Committee, Surface Science Division of American Vacuum Society, 1987.

Program Chairman, 1987 American Vacuum Society (Surface Science Division) Meeting in Anaheim.

Member, Organizing Committee, 1987 International Colloquium on Magnetic Films and Surfaces.

Member, Scientific Advisory Committee, 9th European Conference on Surface Science, 1987.

MAJOR CONSULTING AND ADVISORY SERVICES

Division 533, Radiation Physics

1. R.J. Celotta and D.T. Pierce consulted on the production and detection of polarized electrons with researchers from Brookhaven, AT&T Bell Labs, Bell Communications Corporation, University of Texas, Princeton, Kimball Physics Corporation, Rice University, University of Oklahoma, City College of New York, MIT, Argonne National Laboratory, Jet Propulsion Laboratory, Perkin Elmer Corporation, and the Naval Research Laboratory.

2. C.W. Clark advised a group at Princeton Plasma Physics Laboratory on atomic physics problems associated with x-ray laser development.

3. D.L. Ederer consulted with Denise Caldwell of the University of Central Florida on angular distribution of fluorescence in helium.

4. D.L. Ederer consulted with Richard Freeman of AT&T Bell Labs on pump-probe experiments involving lasers and synchrotron radiation.

5. W.R. Ott consulted with scientists and principal investigators at Goddard Space Flight Center on new possibilities for radiation standards and inflight radiometric calibration of spectrioradiometers.

6. W.R. Ott consulted individually with industrial scientists from Dupont, 3M, Uniroyal, and about 10 other corporations at a Technology Transfer Conference and discussed cooperative research and licensing opportunities at NBS.

JOURNAL EDITORSHIPS

Division 533, Radiation Physics

R.J. Celotta, Series Editor, Methods of Experimental Physics.

C.W. Clark, Topical Editor, Atomic Spectroscopy, Journal of the Optical Society of America B.

D.T. Pierce, Editoral Board, Review of Scientific Instruments.

D.T. Pierce, Editoral Board, Journal of Electron Spectroscopy.

TRIPS SPONSORED BY OTHERS

Division 533, Radiation Physics Division

R.J. Celotta presented a talk at a Physics Colloquium, City College of New York, NY, November 5, 1986.

R.J. Celotta presented a talk at a meeting of the American Vacuum Society, Minneapolis, MN, November 11, 1986.

C.W. Clark consulted on x-ray laser development at Princeton Plasma Physics Laboratory, Princeton, NJ, October 15, 1986.

C.W. Clark presented a talk at the University of Virginia, Charlottesville, VA, November 12, 1986.

C.W. Clark consulted on x-ray laser development at Princeton Plasma Physics Laboratory, Princeton, NJ, February 6, 1987.

C.W. Clark presented a talk at College of William and Mary, Williamsburg, VA, February 13, 1987.

C.W. Clark consulted on x-ray laser development at Princeton Plasma Physics Laboratory, Princeton, NJ, April 6, 1987.

C.W. Clark attended and chaired a session at the Gordon Conference on Atomic Physics, Wolfeboro, NH, July 5-11, 1987.

C.W. Clark attended the symposium on Atomic Spectroscopy and Highly Ionized Fields and presented a talk, Hickory Ridge Conference Center, Lisle, IL, August 17, 1987.

D.L. Ederer consulted on collaborative physics experiments at the University of Central Florida, Orlando, FL, October 22, 1986.

D.L. Ederer attended a workshop on New Directions in Soft X-Ray Near Threshold Phenomena, Monterey, CA, March 1-4, 1987.

T.A. Ferrett presented an invited talk at the Workshop on New Directions in Soft X-ray Near-Threshold Phenomena, Pacific Grove, CA, March 1987.

B.C. Johnson visited labs and presented a talk at the Weiss School of Natural Sciences, Houston, TX, November 14, 1986.

D.R. Penn consulted with M. Cohen for a week at Berkeley on Superconductivity, U. of CA at Berkeley, Berkeley, CA, May 1987.

D.T. Pierce presented a talk at Perkin Elmer Corp., Minneapolis, MN, February 23, 1987.

Division 533, Trips Sponsored by Others (cont'd)

D.T. Pierce presented a talk at the Synchrotron Radiation Conference, Madison, WI, June 25, 1987.

D.T. Pierce attended an abstract selection meeting in Anaheim, June 28-29, 1987.

J. Unguris presented a talk at a Physical Electronics Corp. seminar, Eden Prairie, MN, 1986.

J. Unguris presented a talk at the Gordon Conference on Electron Spectroscopy, Wolfeboro, NH, 1986.

J. Unguris presented a talk at Inter/Micro-86, Chicago, IL, 1986.

J. Unguris presented a talk at a Physics Colloquium, University of Maine, Orano, Maine, November 4, 1986.

CALIBRATION SERVICES PERFORMED

Division 533, Radiation Physics

Type of Service	Customer Type*	SP 250 Item No.	Number of Calibrations or Tests
Far UV radiometric transfer standard detectors (photo-diode calibrations)	1,4-8	N.A.	21
Spectrometer calibrations using SURF as an absolute source	5-7	N.A.	12
Totals			33

*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.

SPONSORED SEMINARS AND COLLOQUIA

Division 533, Radiation Physics

Baldwin, Ken, Australian National University, "Emission Spectrum of Helium Excimers Formed in a Nozzle Beam," April 24, 1987.

Barth, Jochen, BESSY, "Spectroscopic Ellipsometry with Synchrotron Radiation," March 12, 1987.

Blazewicz, Perry, Oak Ridge National Laboratory, "Non-Linear Spectroscopic Processes in Xenon and Krypton," December 4, 1986.

Brown, Louis, Carnegie Institute of Washington, Department of Terrestrial Magnetism, "Geochemical Applications of ^{10}Be Dating Techniques," December 12, 1986.

Buncick, Milan, Oak Ridge University, "Optical Absorbence of Silver Ellipsoidal Particles," July 30, 1987.

Chang, Tu Nan, University of Southern California, "Configuration Interaction in Quasi-Two Electron Atoms", May 14, 1987.

Codling, Keith, University of Reading, "Femtosecond Dynamics of Multiphoton Multiple Ionization of Molecules Using a Picosecond Laser," July 31, 1987.

Dietz, Eberhard, Der Johann Wolfgang Goethe Universität, "Temperature Dependent Photoelectron Spectroscopy on 3d Metals," June 15, 1987.

Fairbank, William, Colorado State University, "Fundamental Experiments Using Lasers and Single Atom Detection," January 22, 1987.

Falco, Charles, University of Arizona, "Metallic Multilayers for X-ray Optics," November 3, 1986.

Frank, Cal, Cornell University, K-Shell Inelastic X-ray Scattering in Coincidence with Fluorescence," May 28, 1987.

Huennekens, John, Lehigh University, "Near Infrared Spectra of Alkaline Molecules," April 16, 1987.

Kerner, Jonathan, Lawrence Berkeley Laboratory, "Absolute Characterization of Filters, Multilayers, Transmission Gratings, and Photocathodes," July 9, 1987.

Klein, Jeffrey, University of Pennsylvania, "Applications of ^{26}Al and ^{10}Be to Studies of Earth Surface Properties," January 13, 1987.

Korevaar, Eric, Western Research Corporation, "Atoms in Crossed Electric and Magnetic Fields," March 27, 1987.

Li, Jia-Ming, Chinese Academy of Sciences, "Molecular Rydberg States," June 30, 1987.

Milchberg, Howard, AT&T Bell Labs, "Studies of Plasmas Produced by Sub-Picosecond Lasers," December 15, 1986.

Mitroy, James, JILA, "Electron Impact Excitation of Be^+: Status of Experiment and Extensive Close-Coupling Calculations," December 12, 1986.

O'Neill, David, University of Wisconsin, "Cr/Au 110: Two Dimensional Electronic Structure of Monolayer and Bilayer Chromium Films," March 23, 1987.

O'Mahony, Patrick, University of London, "Rydberg Atoms in Magnetic Fields," December 5, 1986.

Schmidt, Volker, Universität Freiburg, "Important Electron Correlations in Atomic Physics," April 21, 1987.

Westbrook, Chris, University of Michigan, "Precision Measurements of the K-rate of Ortho-Positronium," December 29, 1986.

Windt, David L., University of Colorado, "Optical Properties of Materials in the XUV and Soft X-ray Region," April 28, 1987.

Wunner, Günther, Universität Tübingen, "Magnetic Rydberg Atoms: A Gateway to Quantum Chaos," December 10, 1986.

TECHNICAL ACTIVITIES

Division 534, Radiometric Physics

Introduction

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

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

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

Fiscal year 1987 was a year of transition for Division 534. The loss of personnel incurred during FY86 continued with the retirement of V. Weidner, resignation by R. Schaefer, and termination of G. Jaafari. This made it necessary to restructure the Division. The former Spectroradiometry and Photodetector Groups were combined into the Spectral Radiometry Group. Dr. Albert C. Parr, formerly with the Photon Physics Group of the Radiation Physics Division (533) of CRR, was asked to take charge of this Group. Six scientists were hired to ensure the continuation of ongoing work and the implementation of new programs in advanced radiometry:

Mr. Stephen C. Ebner	Mr. Charles E. Gibson
Dr. A. Barry Hillard	Dr. Jonathan E. Hardis
Dr. Stephen H. Southworth	Dr. Alan L. Migdall

Dr. Tricia Ferrett came to the Division as a postdoctoral fellow to work on the ARPES project at SURF. Several others joined as temporary employees or guest scientists.

To help in focusing on programmatic responsibilities, to facilitate technical planning, and to simplify the prioritization and allocating of resources, the activities of the Division were divided into "projects," as listed below. The project leaders who will be in charge of the day-to-day technical management of these projects are shown in parentheses.

Advanced Radiometry (Hardis)
Thermal Radiometry (Saunders)
Photodetector Metrology (Zalewski)
Laser Spectrometry (Migdall)
Facilities Development (Fowler)
Spectrophotometry (Hsia)
Photometric R&D (McSparron)
Radiometric Measurement Services (Walker)

The progress made during the year in each of these eight projects is detailed in the following reports by the three Group Leaders of the Division.

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

This Group is responsible for establishing a solid scientific basis for optical radiometry. Specifically, the Group:

- performs research leading to new, advanced approaches to radiometric measurements;
- applies the concepts arising from this research to the development of specific new measurement methods and standards for optical radiometry;
- extends and improves NBS measurement services in optical radiometry by extending the range of the parameters calibrated and by upgrading the equipment and techniques used.

Advanced Radiometry

This effort includes the Kr^+ ion charge exchange light source development as well as some collaborative projects in the use of synchrotron radiation. The Kr^+ project entails studying the charge exchange of a Kr^+ beam with neutral rubidium vapor. After the collision, the krypton is left in a neutral metastable state which can then be laser excited. The excited state decays with the emission of two photons, one on the uv and one on the near ir. Alternatively, the metastable state can be reionized and the process used as an isotope selective process for mass analysis. The Kr^+ ion source and ion optics have been parameterized and design considerations for the full project have been formulated. A postdoctoral scientist who will work exclusively on this project has been recruited and will join the project in FY-88.

The Spectral Radiometry Group has assumed the responsiblity for the Angle Resolved Photoelectron Spectroscopy (ARPES) experiment at the NBS synchrotron ultraviolet radiation facility (SURF-II). This activity, which was the principal activity for Parr before he joined the Group, is being funded for the near future to allow for the sensible completion of the SURF phase of the work. It is expected that this project will evolve into a collaboration at another synchrotron facility in the next several years, and correspondingly the emphasis by the Radiometric Physics Division will decrease. Other new options in radiometry, including the use of superconductor technology to obtain very sensitive bolometers, are being explored in conjunction with the NBS Boulder labs.

Thermal Radiometry

A first round of direct radiometric measurements of the temperature of a freezing-gold blackbody work has been completed, and the results have undergone preliminary analysis. The results indicate agreement with the accepted value for the freezing point of gold at the 0.1 K level. The margin of experimental error is, however, consistent with the downward redefinition, which seems to be the intent of the international temperature community. We feel that further effort in this project is warranted, particularly if the temperature region above the melting point of silver is given to radiometry for temperature scale realization. This project has taken the lead in developing a program of imaging radiometry. It is also actively refurnishing the blackbody calibration facilities. New modern facilities for calibration and research capability will be completed during the next year or so, which will leave the Group with a much improved posture in its calibration responsibilities. Collaboration with other Groups in the Division is underway on the development of new optical pyrometry capability. Saunders finished a collaboration with Bruening on remodeling the lamp spectral flux facility. Incandescent spectral flux standards have been calibrated, and a new automation of the facility has been installed. Saunders has also participated in intercomparisons of the argon mini-arc and the NBS storage ring as absolute radiometric sources. These results indicate good overall agreement between the various radiometric standards maintained by NBS.

Photodetector Metrology

This project has as its principal activity the development of detector based radiometry in the visible, near uv, and near infrared. The DRIP calibration program and the various international intercomparisons are also a part of the responsibilities of this project. The first round of the CIE intercomparison is underway, and the international intercomparison for the CCPR has been completed. Zalewski has prepared a draft publication on this latter effort for publication in the near future.

These efforts are part of a long term program in maintaining an international effort in detector based radiometry and in exploring the benefits and limitations of the procedures which have evolved at NBS over the last few years.

In collaboration with Andor (guest scientist), a set of three photopically corrected detectors has been calibrated against the absolute detector base. Because of their higher precision and accuracy, detectors calibrated in this manner could be used to improve the photometry effort at NBS. These detectors are being intercompared with luminous lamp standards. In a separate collaboration with Eppeldauer (guest scientist), a very low level detector package with built-in amplifiers has been constructed and tested. This effort is primarily directed at the near infrared region and could offer considerable improvement in NBS measurement capabilities.

The calibration documentation for the detector calibration services has been completed and is undergoing final review in preparation for release and publication. It is anticipated that new services to be offered as special tests will be developed in the near future. This will include special calibration of photodiodes outside the DRIP program, as well as perhaps extending the wavelength coverage of the measurements in the detector program.

Laser Spectrometry

Laser heterodyne technology has been developed which allows for optical transmission measurements over at least 10 orders of magnitude to about 1% accuracy. This has been demonstrated at the HeNe wavelength and is now being implemented in the infrared. RF attenuation can be accurately measured and this precision can transferred to the optical attenuation within the heterodyne scheme of measurement. The applicability of this technique in other areas of spectrophotometry is being explored.

Facilities Development

NBS accepted the responsiblity to develop a national Low Background Infrared (LBIR) calibration facility, which is funded by DoD. This facility, which will occupy three lab modules, will be a large cryogenically cooled vacuum chamber suitable for calibration of low background blackbody sources. This facility will be operated by a new employee to the group, Mr. Steve Ebner, who comes with a background in facilities management and in radiometric calibrations. The cryogenic system has been installed and tested. The large vacuum chamber has been designed and bids for its construction are being solicited. The effort by Fowler in developing water bath blackbodies has had some minor technical

difficulties in that the purchased water baths are not regulating temperature to the desired accuracy. A new water bath has been acquired and the results look promising for a rapid and successful completion of this project.

Spectrophotometry (J. J. Hsia, Group Leader)

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

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

The FY87 accomplishments of the Group in four key areas are presented below.

Spectrofluorimetry

The purpose of this project is to develop measurement methods and transfer standards to assess the performance of fluorescence spectrometers used for analytical chemistry, non-destructive testing, and appearance measurements.

The first phase is to study sintered mixtures of inorganic phosphors and polytetrafluoroethylene (PTFE) powder with emission spectra in the blue, green, yellow and orange spectral regions. In addition to previous investigations of the effects of concentration, excitation wavelength, irradiation and temperature on the corrected emission spectra, Eckerle has studied this year the polarization effect, the uniformity of samples, and the usefulness of the "blank" PTFE sample. Several sets of samples have been sent out for user comments.

Limits on the polarization effects of the four colored samples have been established by measuring the four possible combinations of excitation

and emission polarization (SP, SS, PS, PP). The uniformity study showed that only the yellow sample exhibited slight nonuniformity in the long wavelength region. A study of the blank PTFE sample on the reference and two commercial spectrofluorimeters revealed that this sample can be used as a diagnostic tool for second order-radiation and stray excitation radiation.

Dr. Chen of the National Institute of Health and Dr. Williams of the Perkin Elmer Corporation have commented favorably on the usefulness of these prototype samples for calibrating spectrofluorimeters. ASTM subcommittee E13.01 is circulating a set of samples among members to evaluate their applicability in chemical application. Dr. McKinnon of the National Physical Laboratory (UK) has indicated that these samples would not be suitable as spectral radiance factor standards for the appearance industry. Other materials are required for this application.

UV-VIS-NIR Spectrometry

Calibration Services

Calibrations, standards, and test methods in the wavelength range from 200 nm to 2.5 μm are needed by the coating, optics, non-destructive testing, energy, safety, space, agriculture, appearance, photography, printing, textile, paint, and chemical industries. In FY87, calibration services totaling $22K were performed. Barnes provided special calibrations of spectral transmittance, specular reflectance, diffuse reflectance, and opacity. Eckerle provided measurement assurance services for transmittance and retroflectance. Two new calibration documents were published:

"NBS Measurement Services: Regular Spectral Transmittance," Eckerle, K.L., Mielenz, K.D., and Weidner, V.R., NBS Special Publication 250-6, July 1987.

"NBS Measurement Services: Spectral Reflectance," Weidner, V.R., and Hsia, J.J., NBS Special Publication 250-8, July 1987.

Gray Scales

Gray reflectance standards with diffuse surfaces are needed to calibrate the linearity of spectral reflectometers by instrument manufacturers and users. Weidner has produced uniform gray diffusers with reflectances below 50% by sintering mixtures of PTFE and black powders. A technical breakthrough in producing uniform gray diffusers with reflectance above 50% has been achieved by Collins and Barnes. They have developed a method to prepare finer PTFE powders, and have achieved better mixing before sintering. In addition, they have found a method of

pre-selecting the proper PTFE/black powder ratio to obtain the required reflectance of the sintered sample.

Automation Conversion

The reference spectrophotometer for reflectance has been the basic instrument used by NBS to establish U.S. national scales of specular reflectance, 6°/hemispherical reflectance factor and 45/0° reflectance factor. The data acquisition and control units of this instrument have become outdated, and are now being converted to IBM-GPIB systems. Zhu has completed the software conversion of subroutines to control new stepper motor drivers, the high voltage power supply, a new relay module, a new lock-in amplifier, and a new digital voltmeter. He has completed the conversion of all computer programs for measurements. All hardware and software are now ready for final tests.

Transmission Densitometry

Measurements of transmission density are used for quality control of photographic and printing products and for non-destructive testing. Fink has calibrated 360 x-ray step tablets (SRM 1001) and 180 photographic step tablets (SRM 1008) for the calibration of transmission densitometers in the transmission density range 0 to 4. He has evaluated bid microcopy resolution charts for determining the resolving power of photographic systems. The reference transmission densitometer (Inverse Fourth Instrument) has been fitted by Fink and Popenoe with a new receiver consisting of an opal glass, a sample plate with grooves for applying vacuum or pressure, a small section of glossy-aluminum cone, an averaging sphere, filters and a photomultiplier. The new receiver was built to conform to the new ANSI Standard PH2.19-1986.

Infrared Spectrometry

Measurement services in the infrared spectral region are needed by instrument manufacturing, coating, optical, glass, and DoD related industries. The purpose of the long-wavelength infrared spectrometry project is to establish infrared measurement capabilities from 2.5 to 25 μm for transmittance, diffuse reflectance and specular reflectance. The plan is to develop dual systems with dispersive and Fourier transform (FT) infrared spectrometers. This year's efforts have concentrated on establishing the infrared transmittance measurement capability with a monochromator-based infrared spectrometer, and on planning the diffuse reflectance instrumentation.

Lin has completed investigations on linearity and interreflection. A modified double-aperture method for the linearity determination of the spectrometer has been developed. Using this new method, linearity

measurements have been performed at different wavelengths, slit widths, and transmittances.

Three types of interreflections were analyzed and methods of eliminating them were developed. Sample-to-source-to-sample interreflections were as large 0.02 or 0.03 transmittance units. Sample-to-source-to-reference beam interreflections were approximately 0.001 or 0.002 transmittance units. Blocking optical filter-to-sample-to-blocking optical filter interreflections were about 2×10^{-3} of the sample transmittance. The results after correcting for all interreflections with the sample normal and angled to the beam agreed within 2×10^{-3} transmittance units. This is consistent with theory.

The FTIR-based spectrometer used in the diffuse reflectance mode has had some operational difficulties due to the geometry of the liquid nitrogen cooled detector. The liquid N_2 was not adequately contained, resulting in temperature instability of the HgCdTe detector. The system is being redesigned to solve the problem and to operate more efficiently.

Bidirectional Scattering Distribution Function (BSDF)

The objective of this project is to develop a national facility for BSDF measurements. This year's effort was to conduct a comprehensive analysis of the required configuration for such a facility, and to coordinate a worldwide investigation of BSDF measurements.

The definition, measurement equations and BSDF measurement methods have been reviewed, and a preliminary plan has been developed. The mechanical configurations of BSDF facilities in other countries have been reviewed, including those of the FGR, Italy, Japan, PRC, and USSR. The dark currents of silicon photodiodes, and the effect of the earth's magnetic field on photomultiplier response have been studied.

A worldwide investigation of measurements of the reference materials such as PTFE and $BaSO_4$ powders has been planned by Hsia within CIE Committee TC2-11 on Gonioreflectometry. He planned and chaired the session on gonioreflectometry for the ISCC Williamsburg Conference, and advised Daoust of the Rochester Institute of Technology on instrumentation and measurements of gonioreflection properties of PTFE and $BaSO_4$ powders.

Radiometric Measurement Services Group (D. A. McSparron)

The Group maintains the national scales for radiance temperature, spectral radiance, spectral irradiance, luminous intensity, luminous flux and color temperature. Access to these scales is provided through 29 specific calibration services performed on a routine basis. Research and development projects are undertaken to extend and improve these scales.

Activities such as intercomparisons (domestic and international), measurement assurance programs, intermediate laboratory support programs, consultations, special calibrations, and ad hoc experiments are undertaken to insure that measurements made in laboratories outside NBS have acceptable levels of accuracy.

Overall, the past year has been one of consolidation for the Group. Several projects begun in previous years have been completed. Substantial progress has been made in modernizing the calibration facilities. Direct calibration billings increased by 9.5% and directly funded calibration work for other government agencies increased by 20% from last year's depressed level. The combined effect was an overall increase of 11%.

Documentation

The Group's contribution to the NBS-wide project to provide full documentation of all routine calibration services was completed. The documents prepared address the quantities measured, services offered, equipment and procedures used, and particular attention was paid to the preparation of complete uncertainty statements. Four documents were produced by the Group and published in the NBS Special Publication 250 series:

Calibration Services	Authors	Publication
Spectral Radiance	Walker, Saunders and Hattenburg	SP250-1
Radiance Temperature	Waters, Walker, and Hattenburg	SP250-7
Photometry	Booker and McSparron	SP250-15
Spectral Irradiance	Walker, Saunders, Jackson and McSparron	SP250-20

Three companion articles describing the scientific basis for these calibrations have been prepared for publication in the NBS Journal of Research (radiance temperature and spectral irradiance) or Metrologia (spectral radiance).

Spectroradiometric Measurement Services

Pyrometric Calibration Facility

Waters continued the development of the new photoelectric pyrometer for performing radiance temperature calibrations. This instrument, which

employs refractive optics, an extended-red photomultiplier detector, and interference filters to restrict the bandpass to about 1 nm, was used to calibrate 25 tungsten strip lamps, 5 visual pyrometers, and 2 sets of absorbing glass filters. The gold point heat-pipe blackbody was compared with the reference datum maintained on the extremely stable, Quinn-Lee, vacuum tungsten lamp. A difference of about 0.5 K was observed and this difference will be investigated in the coming year. Considerable thought and effort were expended in developing a specification for a variable temperature blackbody to be incorporated in this facility. At present, visible and infrared pyrometers must be calibrated on the Facility for Automatic Spectroradiometric Calibrations (FASCAL). These FASCAL measurements are severely limited by the small opening (2 mm diameter) in the FASCAL blackbody. In order to acquire some hands-on experience with measurement problems associated with infrared pyrometers, Walker performed two special calibrations on FASCAL. The first involved the calibration of three silicon-cell based infrared pyrometers, and the results were limited by the small target area available. The second involved the evaluation of a commercial variable temperature blackbody. This test blackbody was determined to be unsuitable because of its limited temperature range (1000 to 1500 K) and long stabilization times (approximately 90 minutes after a temperature change of 50 K). A specification for a blackbody with a temperature range from 1000 K to 2500 K and a 25 mm diameter opening was developed. Delivery is expected in November 1987.

FASCAL

The shifting of the bulk of the pyrometric calibration load to the new pyrometer allowed time for the first steps in FASCAL moderization. Walker, Jackson, and Gibson converted the instrument control and data reduction programs to 16-bit, PC-family machines. Plans have been developed to replace the 15-year old interface system with modern GPIB components. Popenoe has developed plans to provide the facility with a ceiling mounted lamp station that will allow source-to-receiver distances ranging up to 3 m. Implementation of these improvements is expected in the coming year.

Spectral Irradiance Intercomparison

At the October 1986 Consultative Committee on Photometry and Radiometry (CCPR) meeting, it was decided to conduct an intercomparison of national scales of spectral irradiance. The work is to be completed before the next CCPR meeting in the fall of 1990. NBS will serve as the pilot lab for this intercomparison. Participating national laboratories will obtain lamps from the National Physical Laboratory (UK), measure them, send them to NBS for comparison measurements, and then remeasure the lamps. Preliminary work at NBS is now underway. It is expected that NBS will perform the comparison measurements in the fall of 1988.

Photometry

International Intercomparisons

The international intercomparison of national photometric units, begun under the auspices of the CCPR in 1982, was completed. Results were reported at the October 1986 meeting of the CCPR. The results may be summarized as follows:

	Candela	Lumen
Number of participating national laboratories:	15	11
Average quotient of BIPM value (cd or lm) to values obtained by participating laboratories:	0.990	1.007
Standard deviation of quotients:	0.77%	0.58%
Quotient of BIPM and NBS values:	0.985	0.997

The spread in the candela and lumen values reported by the different national laboratories was slightly better than in previous intercomparisons. Because of the much wider range of techniques now used for realizing photometric scales, the results were viewed as giving confidence to the new definition of the photometric base unit. From the above table it can be seen that the ratios of the NBS luminous intensity and luminous flux values to the world mean were 0.990/0.985 = 1.005 and 1.007/0.997 = 1.010 respectively. These differences fall well within the quoted uncertainties of 1.0% and 1.4%, respectively, for routine NBS calibrations. Nevertheless, research will be undertaken to investigate these observed differences. It should be noted that the intercomparison showed the NBS candela and lumen to be consistent with each other to 0.5%.

Calibration Facilities Upgrade

Booker, Breski, and Wilkinson have continued the program to replace obsolescent photometric calibration facilities with a modern photometric bench. The bench is now nearing completion and routine operations are expected to begin in the fall of 1987. Andor characterized four photopically-corrected silicon cells on the Division's detector spectral response instrument and spectrophotometers. The first use of these cells was a comparison of the detector-based scale they incorporated with the blackbody-based scale incorporated by working-lamp photometric standards.

The observed agreement was better than 0.5%. This very encouraging result will greatly facilitate an orderly revision of the routine photometric calibration procedures to incorporate the new cells.

Spectral Flux Standards

The program to provide the U.S. lighting industry with geometrically-total, spectral flux standards reached a major milestone with the issuance of the incandescent lamp standards. The overall program involves NBS calibrating one incandescent lamp type and one non-incandescent lamp type for issuance to secondary labs and major U.S. lamp manufacturers. From these lamps, industry will derive spectral and photometric standards for all types of high-intensity discharge lamps. The work is coordinated through the Lamp Testing Engineer's Conference (LTEC). NBS will oversee the results through a secondary lab support program. During the past year, Bruening, He, and Saunders completed the spectral distribution measurements on the incandescent lamps. Jackson, Walker, and Gibson performed spectral irradiance measurement on FASCAL which completed the incandescent lamp calibration. Bruening and Saunders have begun the characterization of the high pressure sodium lamps (HPS) selected by He as suitable for calibration. Issuance of these HPS lamps is expected in the December 1987/January 1988 period.

INVITED TALKS

Division 534, Radiometric Physics

Bruening, Robert, "The National Capital Section of the Optical Society of America 1962-1987, Historical Notes," National Capital Section of the Optical Society of America, Arlington, VA, March 21, 1987.

Hsia, J.J., "National Scales of Spectrometry in the U.S.," CORM/USVG Conference, Oxford, England, September 13-23, 1986.

McSparron, Donald, "NBS Radiometric Measurement Services," NCSL Region 8 Meeting, Lexington Park, MD, Jan. 21, 1987.

McSparron, Donald, "Radiation Thermometry Calibration Program at NBS," NASA Noncontact Temperature Measurement Workshop, NASA Headquarters, Washington, D.C., April 30, 1987.

McSparron, Donald, "Photometric Standards," Council for Optical Radiation Measurements - Gaithersburg, MD, May 28, 1987.

Mielenz, Klaus, "Fluorescence Spectrometry in Analytical Chemistry and Color Science," CORM/UVSG Conference, Oxford, England, September 13-23, 1986.

Mielenz, Klaus, "Intrinsic Standards in Spectrophotometry," 1987 NCSL Conference, Denver, CO, July 12-16, 1987.

Mielenz, Klaus, "Radiometric Measurement Services at NBS," 1987 NCSL Conference, Denver, CO, July 12-16, 1987

Parr, Albert, "Radiometric Intercomparison using Synchrotron Radiation," 1987 NCSL Conference, Denver, CO, July 12-16, 1987.

Parr, Albert, "Future Directions in Molecular Photoionization Using Synchrotron Radiation," Workshop on New Direction in Soft-x-ray Near Threshold Phenomena, Asilomar, CA, March, 1987.

Parr, Albert, Progress Report on LBIR Facility, SDC, Huntsville, ALA, April, 1987.

Parr, Albert, "LBIR Facility at NBS," Report to Calibration Review Committee, Hanscom AFB, May, 1987.

Saunders, Robert, "Goldpoint Freezing Point Determination," IMEKO TC-2 Meeting, Braunschweig, Germany, September 14, 1987.

Schaefer, A.R. and Fox, N.P., "Tunable Dye Laser Spectrometry," CORM/UVSG Conference, Oxford, England, September 13-23, 1986.

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Division 534, Radiometric Physics

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Bruening, R. J., Spectral Irradiance Scales Based on Filtered Absolute Silicon Photodetectors, Applied Optics, Vol. 26, March 15, 1987.

Eckerle, K. L., Mielenz, K. L., and Weidner, V. R., NBS Measurement Services: Regular Spectral Transmittance, NBS Special Publication 250-6, July 1987.

Parr, A. C., Polikoff, E., Dehmer, J. L., and Leroi, G. E., Fluorescence Polarization Studies in Autoionization in CS_2, J. Chem Phys., 86, 2557 (March, 1987)

Piancastelli, M.N., Lindle, D.W., Ferrett, T.A., and Shirley, D.A., Reply to Comment on The Relationship Between Shape Resonances and Bond Lengths, J. Chem. Phys. 87, 3255 (1987).

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Walker, J. H., Saunders, R. D., and Hattenburg, A. T., The NBS Scale of Spectral Radiance, Metrologia, Fall, 1987.

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Walker, J. H., Saunders, R. D., Jackson, J. K., and McSparron, D. A., NBS Measurement Services: Spectral Irradiance Calibrations, NBS Special Publication SP 250-20, October 1987.

Waters, W. R., Walker, J. H., and Hattenburg, A. T., NBS Measurement Services: Radiance Temperature Calibrations, NBS Special Publication SP 250-7, October 1987.

Waters, W. R., Walker, J. H., and Hattenburg, A. T., The NBS Scale of Radiance Temperature, Journal of Research of the National Bureau of Standards, Vol. 92, No. 1, January-February 1987.

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Weidner, V. R. and Hsia, J. J., NBS Measurement Services: Spectral Reflectance, NBS Special Publication SP 250-8 (July 1987).

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Zalewski, E. F., The NBS Photodetector Spectral Response Calibration Transfer Program, NBS Special Publication SP 250-18.

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Division 534, Radiometric Physics

Becker, U. Langer, B., Kerkhoff, H.G., Kupsch, M., Szostak, D., Wehlitz, R., Heimann, P.A., Liu, S.H., Lindle, D.W., Ferrett, T.A., and Shirley, D.A., Observation of Many New Argon Valence Satellites Near Threshold (to be published, Phys. Rev. Lett).

Dehmer, J. L., Dill, D. and Parr, A. C., "Shape Resonances in Molecular Fields," to be published in Fundamental Processes of Atomic Dynamics

Geist, J. and Migdall, A. L., "Analytic representation of the silicon absorption coefficient in the intermediate and high energy indirect gap region, to be published.

Dehmer, J.L., Dehmer, P., Parr, A.C, Hardis, J.E., Southworth, S.H., and Ferrett, T.A., Resonant Photoionization in the $\tilde{X}$ State of CO in the Photon-energy Range 17-20 eV (in preparation).

Dehmer, J.L., Parr, A.C., Roy, P. Hardis, J.E., and Ferrett, T.A., Triply Differential Photoelectron Spectroscopy of Autoionization in the $\tilde{X}$ and $\tilde{A}$ States of Co Between 17 and 20 eV (in preparation).

Ferrett, T.A., Lindle, D.W., Heimann, P.A., Piancastelli, M.N., Kobrin, P.H., Kerkhoff, H.G., Becker, U.E., Brewer, W.D., and Shirley, D.A., Shape-resonant and Many-electron Effects in the S 2p Photoionization of SF_6 (in preparation).

Ferrett, T.A., Piancastelli, M.N., Lindle, D.W., Heimann, P.A., and Shirley, D.A., Si 2p and 2s Resonant Excitation and Photoionization of SiF_4 (in preparation).

Ferrett, T.A., Dehmer, J.L., Hardis, J.E., and Parr, A.C., Vibrationally-resolved Study of the $\tilde{A}$ State of N_2O in the Range $17.4 \leq h\nu \leq 26.0$ eV (in preparation).

He, M.G. and Bruening, R.J., "Study of the Stability of High Pressure Sodium Discharge Lamps for Use as Standards of Geometrically Total Luminous Flux", to be published as an NBS Technical Note.

Hsia, J.J., "National Scales of Spectrometry in the U.S.," to be published in Symposium on Advances in Standards and Methodology in Spectrometry, Oxford, UK.

Lean, J., Saunders, R. and VanHoosier, M., "Linearity Studies of UV Photodetectors", to be published in Proc. of UV Workshop.

Lindle, D.W. and Ferrett, T.A., Resonant Interaction Between Correlation Satellites and Double Ionization (in preparation).

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McSparron, D.A., Radiation Thermometry Calibration Program at NBS, NASA Conference Publication.

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Mielenz, K. D., "International Intercomparisons of Photometric Base Units", to be published in J. Res. NBS.

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Parr, A. C., Southworth, S.H., Hardis, J. E. and Dehmer, J. L., "Resonance Structure in the Vibrationally Resolved Photoelectron Branching Ratios and Angular Distributions of the $2\pi^{-1}$ Channel of NO", WERB approved for publication in J. Chem. Phys.

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Schaefer, A.R. and Fox, N.P., "Tunable Dye Laser Spectrometry," to be published in Symposium on Advances in Standards and Methodology in Spectrometry.

Thomas, D. and Zalewski, E., "CCPR Detector Intercomparison," to be published in Metrolgia.

Walker, J. H., Saunders, R. D., Jackson, J. K., McSparron, D. A. "The NBS Scale of Spectral Irradiance," to be published in Journal of Research of the National Bureau of Standards.

Zalewski, E.F. and Thomas, D.B., An Intercomparison of Absolute Detector Response Measurements at 633 and 488 nm.

TECHNICAL AND PROFESSIONAL COMMITTEE PARTICIPATION AND LEADERSHIP

Division 534, Radiometric Physics

Robert Booker

Member, U.S. National Committee of the CIE

Robert J. Bruening

Past President, National Capital Section of the Optical Society of America

Julius Cohen

Member, ASTM E-07 Committee on Nondestructive Testing, Section E-07.10.04 on Infrared Methods.

Member, ASTM E710.04 Other NDT Methods (infrared)

Kenneth L. Eckerle

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

Laurence E. Fink

Alternate, ANSI PH2 on Photographic Sensitometry and PH2-28 on Densitometry

Jack J. Hsia

Director, Inter Society Color Council.

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

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

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

NBS Representative, ANSI PH2, Photographic Sensitometry, PH2-28, Densitometry.

Member, ASTM D-1.26 Subcommittee, Optical Properties of Paint, Varnish, Lacquer and Related Products.

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

Jack J. Hsia (Cont'd)

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

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

Member, ASTM E-07.03, Task Group for Fluorescent Penetrant Measurement Standards.

Secretary, CORM/NBS Task Force on Spectrophotometry.

Donald A. McSparron

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

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

Member, Lamp Testing Engineers' Conference.

Klaus D. Mielenz

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

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

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

Member, IES Subcommittee C012, Nomenclature.

Vice Chairman, CORM Task Force on Spectrophotometry.

Member, OSA International Affairs Committee.

Albert Parr

Member, Queen Match Calibration Review for SDC.

Member, Organizing Committee, National Synchrotron Instrumentation Conference.

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

Albert Parr (Cont'd)

Member, Organizing Committee, Local Co-chairman Chemical Low-Level Light Detector Conference

Robert D. Saunders, Jr.

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

Member, IES Photobiology Committee.

Member, CIE TC2-05, Distribution Temperature.

A. Russell Schaefer

Member, CIE TC2-06, Absolute Spectral Responsivity.

Douglas B. Thomas

Member, ASTM E44, Solar Energy Conversion.

William R. Waters

Member, ASTM E-20, Temperature Measurement.

Edward F. Zalewski

Chairman, CIE TC2-06, Absolute Spectral Responsivity.

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

JOURNAL EDITORIALSHIP

Division 534, Radiometric Physics

Alman, D. H., Hsia, J. J., and Johnson, N. L. (Program Committee), Appearance, 1987 Williamsbury Conference Proceedings, Inter-Society Color Council, Feb. 8-11, 1987.

STANDARDS COMMITTEE MEETINGS

Division 534, Radiometric Physics

ASTM Committee E12 Meeting, NBS, May 26-27, 1987.

CORM Annual Meeting, NBS, May 28-29, 1987.

LTEC, NBS, May 27, 1987.

MAJOR CONSULTING AND ADVISORY SERVICES

Division 534, Radiometric Physics

R. L. Booker and D. A. McSparron provided consultation to respresentatives of Minolta Corporation on luminance standards and measurements.

R. L. Booker provided consultation to the FAA on the conspicuous daytime marking of tall towers.

J. J. Hsia provided consultation to H. Heydt and C. Peterson of General Electric in Lanham, Maryland, on using pressed PTFE and black powder to normalize signals from area array detectors.

J. J. Hsia provided consultation to Roy Berns of the Rochester Institute of Technology on gonioreflectometry.

J. J. Hsia provided consultation to L. Lewellen of Newark Air Force Research Laboratory on infrared transmittance measurement.

K. L. Eckerle provided consultation to J. Seely of Reflexite Company on retroreflectance calibration.

K. L. Eckerle provided consultation to B. Brekke of the Norwegian Research Institute of Electricity Supply on retroreflection instrumentation.

K. L. Eckerle provided consultation to P. Armatis of Lawrence Livermore Laboratory on spectrophotometric measurement methods.

D. A. McSparron provided consultation to B. Guenther of NASA on spectral radiance and spectral irradiance calibration problems.

D. A. McSparron attended the Annual Laboratory Review of NAVY Metrology Research and Development Requirements meeting at Corona, California, and provided consultation on the status and future directions of the NBS infrared standards program.

J. H. Walker and W. R. Waters provided consultation to R. Holman of Corning Glass Company on the calibration of infrared pyrometers and blackbodies.

E. F. Zalewski and D. A. McSparron provided consultation to representative of the Army Night Vision Laboratory on low light level uv irradiance and detector responsivitiy calibrations.

STANDARD REFERENCE MATERIALS

Division 534, Radiometric Physics

1. SRM 1001, X-Ray Film Step Tablet

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

2. SRM 1008, Photographic Step Tablets

   For 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, Microscopy Resolution Tests Charts

   For determining the resolving power of microscopy systems.

4. SRM 2061, Reflection Step Tablets

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

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

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

6. SRM 2003b, First Surface Aluminum Mirror for Specular Reflectance from 250 to 2500 nm. SRM 2011, First Surface Gold Mirror for Specular Reflectance from 600 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, 2014 Didymium-Oxide Glass, Wavelength Standards between 400 and 760 nm.

Division 534, Standard Reference Materials (cont'd)

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

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

MEASUREMENT ASSURANCE SERVICES

Division 534, Radiometric Physics

1. Transmittance MAP Service

   Provides a means for a laboratory to assess the accuracy of its spectral transmittance measurement capabilities from 92% to 0.1% in the visible region.

2. Retroreflectance MAP Service for Coefficient of Luminous Intensity

   Provides a means for a laboratory to assess the accuracy of its coefficient of luminous intensity measurement capabilities for bead sheeting and prismatic cube-corner retroreflectors and to assess the conformance to the spectral specification of its retroreflectometers.

CALIBRATION SERVICES PERFORMED

Division 534, Radiometric Physics

Type of Service	Customer	SP250	Number of tests
Pyrometry		35010C thru 35070S	27
	Defense & Aerospace		18
	Instrument & Cal labs		3
	Foreign		1
	Electrical & Materials		5
Spectroradiometry		39010C thru 39070S	45
	Defense & Aerospace		18
	Instruement & Cal labs		11
	Lighting & Photography		8
	Foreign		2
	Electrical & Materials		6
Photometry		37010C thru 37180S	24
	Defense & Aerospace		7
	Instrument & Cal labs		3
	Lighting & Photography		9
	Foreign		2
	Electrical & Materials		3
Spectrophotometry		38010C thru 38100S	22
	Defense & Aerospace		3
	Instrument & Cal labs		10
	Foreign		1
	Electrical & Materials		8
			118

TRIPS SPONSORED BY OTHERS

Division 534, Radiometric Physics

J.J. Hsia, Laboratory Visit to the Optical Division, National Institute of Metrology, partially sponsored by Protocol Agreement between NBS and the Chinese State Bureau of Metrology, Beijing, May 26-28, 1987.

SPONSORED SEMINARS AND COLLOQUIA

Division 534, Radiometric Physics

J. Cohen, HDL Seminar on Automated Laser Inspection System (6/17/87)

Dr. W. Erb, PTB, Germany, "Gonioreflectometry and Reflectometry", Dr. W. Czepluch, BAM, Germany, "Photometric Characteristics of Materials and Measurements of Gloss", Radiometric Physics Division Seminar, February 5, 1987.

Dr. S. Shaefer, Carnegie-Mellon University, Pittsburgh, "Computer Vision and the Optics of Materials", Radiometric Physics Division and Robot Systems Division Joint Seminar, March 19, 1987.

Dr. L. Shirley, Institute of Optics, University of Rochester, "Characterization of Transmission Diffusers - Theory and Experiment", Radiometric Physics Division, March 27, 1987.

Prof. U. Oppenheim, Israel, "Infrared Reflectometry and Radiometry in the Technion-Israel Institute of Technology", Radiometric Physics Division, April 23, 1987.

TECHNICAL ACTIVITIES

Division 535, Radiation Source and Instrumentation

ACCELERATOR RESEARCH

CW Racetrack Microtron Project (P.H. Debenham)

The joint NBS-Los Alamos project, "Research on CW Electron Accelerators Using Room-Temperature RF Structures," has been funded by the DoE Division of Nuclear Physics for the past eight years. The goal is to develop technology for room temperature, cw electron accelerators. To meet this goal we have been designing, constructing and testing a 185 MeV, 500 μA cw racetrack microtron (RTM). The RTM, which is shown in Fig. 1, is approximately 85% complete. The success of the project is reflected in its many technical contributions. These include: a reliable, room-temperature, rf accelerating structure with a high cw accelerating gradient; a 100 keV beam chopping and bunching system; a high-quality 5 MeV injector; microtron end magnets with excellent field uniformity; and simple, precise, beam profile scanners.

Late in 1986 the DoE Division of Nuclear Physics announced it had decided to phase out support of the project in FY87 and not provide funds for completion of the 185 MeV RTM. The decision was based on the judgment that although the accelerator and nuclear physics research that could be done with the full RTM are valuable, they do not justify the projected completion cost. A major factor was DoE's prior decision to use superconducting (cryogenic) rather than room-temperature rf structures in its premier new accelerator for nuclear physics, CEBAF. DoE emphasized the high quality of the RTM project staff and expressed satisfaction with their performance.

DoE has provided funds through mid-FY 1988 for measuring the emittance of the 5 MeV injector and for evaluating the performance of the rf power distribution system with full power to all four linac sections. This requires completion of the RTM to the point where beam from the injector can be accelerated to 17 MeV in one pass through the RTM linac, deflected through 180 degrees by one end magnet for momentum analysis, and stopped in a temporary beam stop between the end magnets. We have made good progress towards these goals in FY 1987.

In October and November, 1986 the 65 kV klystron power supply was restored to operation with a redesigned variable transformer stage. (The new design was discussed in last year's report.) Simultaneously, the water system which cools the high power rf distribution waveguide was upgraded for better reliability, and a large filter was added to the facility cooling water system. The RTM linac and associated rf power distribution and vacuum systems were connected to the control system at this time.

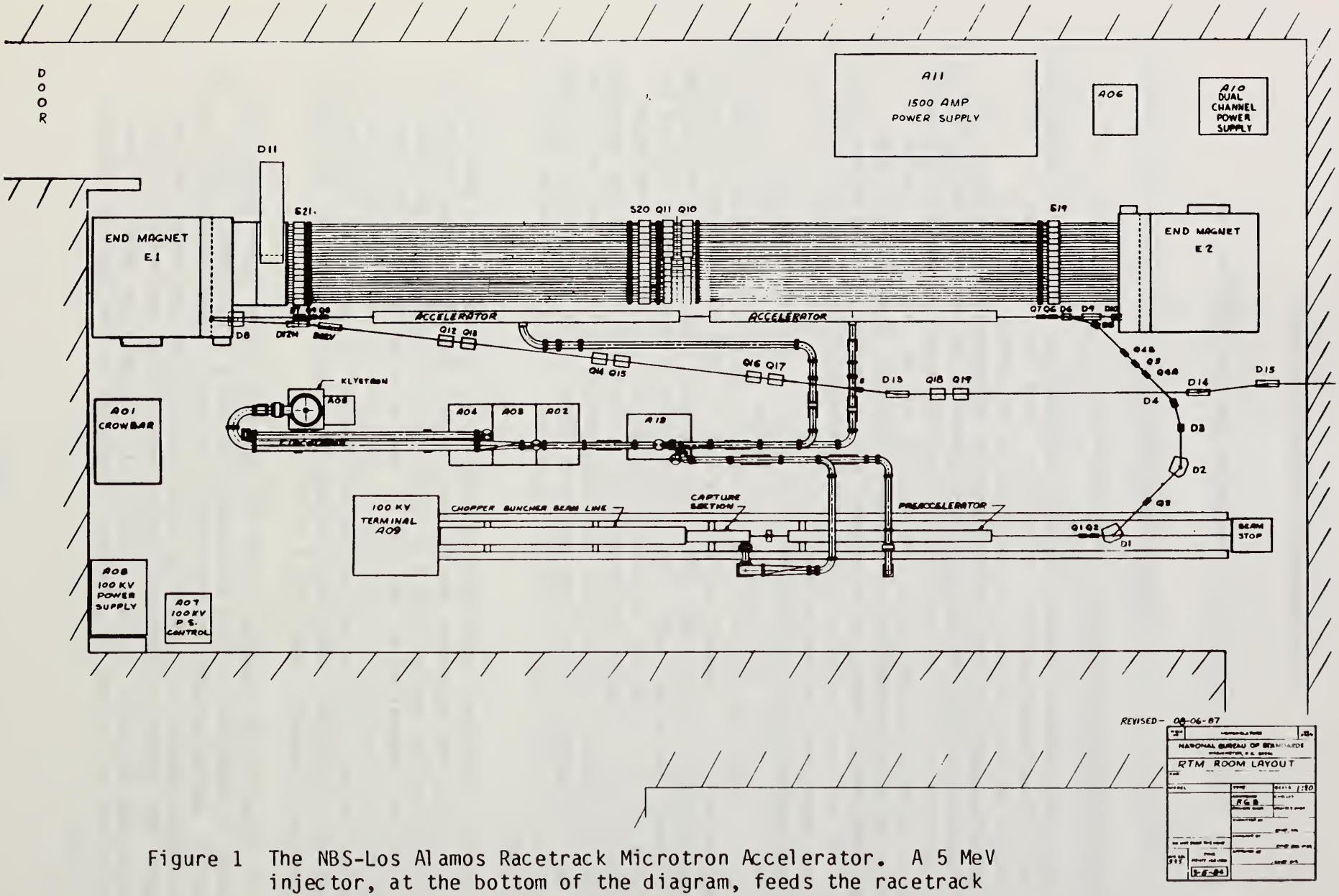

Figure 1 The NBS-Los Alamos Racetrack Microtron Accelerator. A 5 MeV injector, at the bottom of the diagram, feeds the racetrack microtron. In the microtron, a pair of 180° end magnets recirculates the beam through a 12 MeV linear accelerator up to 15 times for an energy gain of up to 180 MeV. The beam may be extracted after any number of recirculations by moving magnet D11 to the desired return line.

From December, 1986 to May, 1987 we operated the injector in order to measure its beam parameters. We first tested the performance of our beam profile scanners with the 5 MeV beam. Detailed results may be found in Reference 1. Good performance was achieved with both pulsed and cw beams after eliminating several noise sources. We were able to measure cw beam widths as small as 50 μm fwhm, the design value of position resolution. The beam scanners were then used to measure the transverse emittance and energy spread at beam currents between 150 μA and 600 μA and energies from 4 MeV to 5.5 MeV. This work is described in Reference 2. The results are spectacular. The measured, normalized emittance was between 0.3 μm and 0.9 μm over this range of current and energy, with an average of 0.6 μm. This is almost an order of magnitude improvement over our design value of 5 μm. The measured energy spread was 5 keV, and indirect measurements indicated a longitudinal emittance of no more than 5 keV·degrees, considerably better than our design value of 20 keV·degrees. A final determination of longitudinal emittance will be made during the next period of operation early in 1988.

RF power was applied to the RTM linac for the first time in March. In two weeks of operation the linac was rf-conditioned to 50% of maximum voltage. Stability of the rf field strength and phase was measured and found to be better than ± 0.05% and ± 0.2°, respectively, in all four linac sections. Field and phase variations of up to ± 0.2% and ± 1.4° are tolerable. These results were reported at the 1987 Particle Accelerator Conference (PAC) in March.[3] We had resumed rf-conditioning the RTM linac in July, after completing the injector beam measurements, when the new variable transformer stage of the klystron power supply failed after 600 accumulated hours of operation. The failure was apparently caused by defective insulation in the bucking transformer. The manufacturer has

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[1]R.I. Cutler, J.C. Owen, and J.K. Whittaker, Performance of Wire Scanner Beam Profile Monitors to Determine the Emittance and Position of High Power CW Electron Beams of the NBS-Los Alamos Racetrack Microtron, to be published in the Proceedings of the 1987 Particle Accelerator Conference, Washington, DC, March 16-19, 1987.

[2]M.A. Wilson, R.L. Ayres, R.I. Cutler, P.H. Debenham, E.R. Lindstrom, D.L. Mohr, S. Penner, J.E. Rose, L.M. Young, and J. Stovall, Performance of the 5 MeV Injector for the NBS-Los Alamos Racetrack Microtron, to be published in the Proceedings of the 1987 Particle Accelerator Conference, Washington, DC, March 16-19, 1987.

[3]R.I. Cutler and L.M. Young, Performance of the High Power RF System of the NBS-Los Alamos Racetrack Microtron, to be published in the Proceedings of the 1987 Particle Accelerator Conference, Washington, DC, March 16-19, 1987.

rewound and tested the transformer, and will reinstall the variable transformer at NBS the first week of October. We plan to finish conditioning the RTM linac in October.

A total of 17 magnets, including one quadrupole design and seven different dipole designs, will be used to transport the 5 MeV beam from the injector to the RTM for single-pass acceleration. By April, 1987 these magnets had all been assembled, field-mapped, and shown to meet all specifications. We reported many of these results at the 1987 PAC.[4,5] Following completion of injector beam measurements in May, we removed the temporary 45 degree beam stop and began assembling the 5 MeV transport and RTM axis beam lines. Currently all 5 MeV transport beamline magnets have been installed, and installation of the axis beamline is under way. We expect to complete installation of these beamlines in November, connect them to the control system in December, and begin accelerating beam with the RTM linac in January, 1988.

Free Electron Laser Facility (S. Penner)

A. Background

A study was initiated in FY 1986 to investigate the suitability of the NBS RTM as the electron beam source for a free electron laser (FEL). The study was funded by the Office of Naval Research, and performed in collaboration with Drs. Phillip Sprangle and Cha-mei Tang of the Naval Research Laboratory (NRL). Based on this design study, we submitted a response to an announcement by the Strategic Defense Initiative Office (SDIO) for funding facilities for performing research in biomedical and materials sciences applications of FELs. The proposal, developed jointly by NBS and NRL, requests $4.9 million from SDIO over three years. NBS would, in addition, supply a new laboratory building, three staff scientists salaries, RTM operation as needed to test and calibrate the FEL, and some general purpose equipment. The new laboratory, a 2000 ft^2 building located above the existing linac facility, would house the experiments using the FEL radiation. Since it would be shielded from the underground space containing the RTM and FEL, there would be no significant background

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[4] P.H. Debenham, S.S. Bruce, S. Penner, and M.A. Wilson, The Injection Chicane of the NBS-Los Alamos Racetrack Microtron, to be published in the Proceedings of the 1987 Particle Accelerator Conference, Washington, DC, March 16-19, 1987.

[5] M.A. Wilson, P.H. Debenham, S. Penner, and S.S. Bruce, Orbit Reversing Magnets for the NBS-Los Alamos Racetrack Microtron, to be published in the Proceedings of the 1987 Particle Accelerator Conference, Washington, DC, March 16-19, 1987.

radiation from the RTM (or linac) in this area. We proposed that the FEL radiation be used by NBS staff and external collaborators for programs in atomic physics, molecular spectroscopy, biophysics, surface sciences, and FEL technology. Outside users from such institutions as the Uniformed Services University of the Health Sciences (USUHS) and Electro-Optics Branch of the Center for Devices and Radiological Health of the FDA have expressed interest and enthusiasm for using the facility for biomedical research applications.

Our proposal was one of nine submitted in October 1986, in response to the announcement, and one of two selected for funding by the Office of Naval Research (ONR), which manages the Medical/Materials FEL program for SDIO. A contract for developing the facility has been negotiated with ONR, and the first increment of funding received in April 1987. We started design work for the FEL immediately upon receiving funding, using staff of the RTM project, while we began recruiting for the additional staff needed for the FEL development. We have already hired one new physicist for the project (Carol Johnson, formerly an NBS Postdoc with Tom Lucatorto of Division 533).

B. FEL Fundamentals

An FEL extracts energy from an electron beam in the form of a coherent beam of nearly monochromatic radiation. The principle of operation is as follows: A relativistic electron beam is passed through a "wiggler," wherein an array of permanent magnets produces a periodic strong transverse magnetic field. The electron beam emits synchrotron radiation in a narrow cone centered on its direction of propagation through the wiggler due to the transverse oscillations of the electrons in the magnetic field. Synchrotron radiation from successive periods of the wiggler will be coherent when the wavelength, λ, of the radiation satisfies the relationship

$$\lambda = \frac{\lambda_w}{2\gamma^2}\,(1 + K^2),$$

where λ_w is the wiggler period, γ is the electron energy in units of electron rest energy, and K is the "wiggler parameter" which is proportional to the strength of the magnetic field and is typically of order unity. The "spontaneous, coherent" radiation is reflected back through the wiggler by a mirror, then reflected again to copropagate with the electron beam. Beam electrons are bunched at the optical wavelength by the electromagnetic fields of the radiation, and thus emit still more radiation. (In a quantum mechanical analysis of the process, additional coherent radiation is stimulated by the presence of the original radiation, hence the use of the term laser in describing the device.) In travelling once through the wiggler, the radiation field is amplified with some "gain," the necessary energy being extracted from the electron beam. If the gain

per pass is greater than the sum of all losses per pass, the radiation will build up on successive passes until saturated equilibrium occurs. Losses are due to mirror reflectivity, diffraction effects, and the "out-coupling" of some of the radiation for external use.

The expected small energy spread, emittance, and beam stability of the RTM are very important factors in FEL performance. The operating energy range of the RTM is suitable for producing radiation in the wavelength range of about 0.25 μm to 10 μm spanning the range from the near UV, through the visible and near IR. The emitted light is extremely intense (hundreds of watts, time averaged, for a 100 kW electron beam) and nearly 100% spatially coherent. The light beam has the same time structure as the electron beam, i.e. pulse lengths of a few picoseconds, and its frequency bandwidth should be just the transform limit of the pulse length (<0.1% in the visible region). In addition to the fundamental laser radiation, significant amounts of spontaneous coherent radiation are emitted at the odd harmonics of the fundamental. For some applications, useful amounts of radiation would be available at wavelengths of order 30 nm. The combination of high power, easy tuneability over a very large range, spatial coherence, reasonably small bandwidth and a continuous train of very short pulses makes an FEL an extremely useful tool for a very wide variety of applications including photochemistry, surface science, atomic and molecular physics, and biophysics.

The ONR-funded feasibility study showed that the gain of an FEL based on the design peak current of the RTM would be marginal (i.e. 1-3 percent per pass) even with a very long, precise, and expensive wiggler. The problem is the relatively small peak current of the CW microtron, 140 mA, limited by the available RF power at design beam energy. We examined the possibility of increasing the peak current by recapturing some of the electron energy in the RTM by beam recirculation. This proved not to be useful because of the small longitudinal phase space acceptance of the RTM (compared to the degraded longitudinal emittance of the beam which has generated laser light). We next considered enhancing the peak current without increasing the average current by injecting electrons during only a fraction of the RF cycles, i.e. by not filling every RF "bucket." For example, if we fill only one bucket in 32, the average current is within the power limit for peak current up to 3.4 A. With peak currents in excess of 2 A, the FEL single-pass (small signal) gain is in the range 8-30% with a 3.6 m long wiggler, having a 2.8 cm period for wavelengths in the range 0.2 - 2 μm. For longer wavelengths, a shorter wiggler is used. There are several possible methods for generating the required pulses of electrons for subharmonic injection. The method which appears most attractive is to use a short-pulse mode-locked laser operating at a subharmonic of the RF frequency to produce electrons by photoemission from a suitable cathode material.

C. Progress

In the first five months of the FEL project, we have progressed rapidly in designing the facility. Major areas of work are the wiggler, optical cavity, injector modification, electron beam transport, and building modification. Progress to date is described below.

1. Wiggler

Our detailed design of the wiggler began with a very fruitful two-day visit to NBS by Klaus Halbach of Lawrence Berkeley Laboratory. We also visited FEL laboratories and prospective commercial wiggler vendors throughout the country.

The final version of the wiggler technical specifications was delivered to the Contracting Specialist along with a purchase requisition and related documents on June 8, approximately seven weeks ahead of schedule.

On July 14, the Acquisition Plan for the wiggler was sent to DoC. The Plan was approved on July 29. The Request for Proposals (RFP) was issued in mid August. We are hoping to award a contract for the wiggler in January, 1988 for delivery and acceptance by October 1989.

2. Optical Cavity

The optical cavity of the FEL encloses the "gain medium" within the wiggler. The round-trip transit time of the cavity must be precisely commensurate with the electron beam repetition period. We have chosen a cavity length of 8.06 m, corresponding to a round-trip transit time of 128 RF periods. This permits an electron beam period equal to the RF period divided any power of two, which is a highly flexible and easily realizable condition. The nominal electron beam period is 32 RF periods, corresponding to a beam repetition frequency of 74.375 MHz.

A calculation has been performed to predict the FEL power output as a function of wavelength for the baseline case where the photocathode pulse frequency is 74.375 MHz. These calculations indicate that an FEL average power exceeding 50 watts can be achieved at the fundamental frequency for all wavelengths between 0.2 and 10 μm, assuming a peak electron beam current of 2 A and a pulse length of 3 pS. These power levels should be regarded as minimum capabilities. Significantly larger power output can be obtained by some or all of the following possibilities: (1) doubling or quadrupling the photocathode pulse frequency, (2) increasing the electron beam current

and/or pulse length, (3) tapering the wiggler, (4) increasing the outcoupling above the 3% assumed in the calculations.

The cavity mirrors will be multi-layer dielectrics in order to minimize cavity losses and thermal damage to the mirrors. The limited bandwidth of these mirrors will be the determining factor in the range of rapid tuneability of the FEL. Diffraction losses have been estimated to be of order 10^{-4} over most of the FEL tuning range, increasing to a maximum of 0.6% at 10 μm, due to the aperture of the wiggler vacuum chamber.

Outcoupling from the cavity will be through the downstream mirror. The preferred method is a partially-transmitting (~3%) mirror, but a small-bore on-axis hole coupler will be used when far UV output is desired.

3. Injector Modifications

We are proceeding with the development of a photocathode injector system after determining that this offers both cost and performance advantages over a thermionic gun subharmonic injector. A commercially available mode-locked laser system will illuminate a suitable photoemitter (probably cesium-antimony). We will receive assistance in gun design from SLAC personnel, and will have the advice and collaboration of a group at LANL who have developed a system whose performance exceeds our requirements.

4. Electron Beam Transport

Physics design of the electron beam transport system has been completed. The emittance of the RTM electron beam is expected to be small enough that the beam envelope is entirely within the optical mode profile in the wiggler for maximum electron-photon coupling. The acceptance of the beam transport channel, including the wiggler vacuum chamber is large enough that the defining aperture of the system is the linac section of the RTM. After traversing the wiggler, the electron beam will be deflected by a dumping magnet into a shielded beam dump to minimize radiation damage effects to the wiggler and optical components.

5. Building Modification

A preliminary design of the new 2000 ft^2 research area has been completed. Cost estimates by the NBS Plant Division are in agreement with our earlier estimates. They are proceeding with detailed architectural/engineering design and specifications with the goal of beginning construction in the spring of 1988.

D. Schedule and Program

The RTM construction is scheduled to be completed in November 1988, and the FEL facility in March 1990. Contacts with prospective users of the facility, both within and outside of NBS are being made, with the goal of having a strong user organization in place before completion of the facility.

LINAC OPERATIONS (J. Broberg)

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. Due to the changes in program direction, the Linac has been used mostly for neutron cross section standards and radiography. We also have supplied beam to a group from the Naval Surface Weapons Center for transition radiation studies.

The Linac Operations staff, in spite of its small size, continues to achieve 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, constructing, and installing mechanical components. All of the beam time, except for 94 hours, used by the Naval Surface Weapons Center, was run for the Neutron group. We have supplied 1475.5 hours of actual beam time to the Neutron group (for a total of 1569.5 hours) at an efficiency approaching 99%. The unscheduled maintenance was 19 hours of air conditioning outage and 8 hours of Linac down time.

The RTM-FEL is operational to the extent that testing is now necessary. Since the 60 degree water cooling system will not permit both the Linac and the RTM-FEL to operate simultaneously, their operations must be scheduled jointly. The long range plan is to operate the Linac approximately 1/3 of the time and RTM-FEL 2/3 of the time. With our operational staffing and assuming at least 80% efficiency of operation this should give us about 1200 hours of Linac time and about 2400 hours of RTM-FEL time per year.

RADIATION INSTRUMENTATION

Electronic Instrumentation Maintenance and Construction (J.K. Whittaker, J. Owen)

Electronics instrumentation maintenance and construction for the experimental programs of the Center for Radiation Research is a continuing responsibility of the Radiation Instrumentation Group in the Division.

Due to a long lasting shortage of technicians (we have two) in the Group we have had to confine Group activities to the construction of instrumentation not otherwise available. Repair and maintenance is limited to instrumentation produced in our laboratory and to specialized items such as accelerators. This year 51 instruments and pieces of equipment have been constructed and 48 repaired.

Instrumentation Design and Construction (J.K. Whittaker, N.D. Wilkin, A.B. Marella, J.C. Owen, L.A. Shuman)

Design and construction of experimental and system data acquisition and control instrumentation is a continuing and important element of the Radiation Instrumentation Group activities. This year the Electron Physics Group has been given priority support for their efforts in constructing a scanning tunneling electron microscope (STM) and building accessory equipment for a scanning electron microscope. For the STM not only was severe electronic noise problems solved but a new and stable servo positioning system was constructed enabling the Electron Physics Group to obtain stable pictures of a surface. Other examples of instrumentation design for this year include: instrumentation for the Regional Calibration centers; an automatic computer-controlled sample changer; interlock systems; automatic control and data acquisition systems for the 300 kV and 100 kV X-ray machines (X-ray standards); detector electronics, wire-scanner amplifiers, radiation monitors, counting system, microcalorimetry temperature controller, and neutron dosimetry instruments.

Instrumentation Support for Physics and Chemistry Projects (J.K. Whittaker, N.D. Wilkin, A.B. Marella)

Consulting and systems instrumentation assistance has been provided to scientists in programs relating to neutron physics, electron physics, pulse radiolysis (both CRR and CAC), X-ray dosimetry, radiation chemistry, analytical chemistry, physical chemistry, reactor radiation, vacuum ultraviolet physics, RTM construction, nuclear physics and the CRR Center Office.

A new HP 350C computer has been received and will be set up for computer-aided design and computer-aided engineering purposes as soon as the software can be obtained. Software for these operations is expensive and will have to be installed slowly due to lack of funds. The effective payback period for CAD and CAE systems is very short due to greatly improved productivity but this does not make funding any easier. The system is compatible with presently installed systems of lesser capability and we look forward in the future to being able to synthesize and simulate both digital and analog systems.

The wire-chamber detector for electron physics has been completed but has yet to be tested (due to technician labor shortage). High voltage tests have been successful and the gas handling components are on hand.

Consultation by the Group expert staff continues to be important to CRR and many other centers in NBS. The cooperative program with the Center for Chemical Physics relating to pulse radiolysis and Van de Graaff accelerator operations has entered its initial phase very successfully. Of particular importance is the cooperative program with the Harry Diamond Laboratories in programs relating to fuze measurement instrumentation and other subjects which continue outstandingly well.

Computer Systems (N.D. Wilkin, A.B. Marella)

Some 35 computer systems, mainly Hewlett-Packard and PC types have been installed this year together with numerous types of software including several CAD systems. The bookkeeping operations of the Group have just been computerized on a database system, thus enabling the Group to keep track of its many operations in construction, repair and maintenance.

Guest Scientists

This year we have been fortunate to welcome Mr. Danny Tirosh from the Nuclear Research Center, Negev, Israel. Mr. Tirosh is the Head of the Environmental Engineering and Electronics Division at that Laboratory and initially he will be designing and constructing analog electronics data acquisition apparatus for pulse radiolysis experiments. In addition Mr. Li-chun Dai, a final year student at the University of Maryland will be with us until next June.

Radiation Instrumentation Standards (L. Costrell)

The Division provides national leadership in the standardization of nuclear instrumentation. The standards work falls into three categories as follows: (a) National Voluntary Standards - The Division plays an active role in the development and processing of Standards of the Institute of Electrical and Electronic Engineers (IEEE) and the American National Standards Institute (ANSI) and participates in the associated policy boards. L. Costrell serves as Chairman of ANSI Committee N42 on Radiation Instruments and as Secretary of the IEEE Nuclear Instruments and Detectors Committee. In these capacities he has processed a considerable number of ANSI and IEEE standards, serves on the ANSI Nuclear Standards Board, and is a member of its Planning Committee.

(b) 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 U.S. and a continuous coordination effort is required, involving contact with numerous laboratories and manu-

facturers. Similar management, direction and maintenance services 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 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 with commercial equipment now available and systems in operation or in preparation in numerous 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).

The Nuclear Instrument Module (NIM) system[1,2] has had a phenomenal acceptance in laboratories and industry throughout the world. There is a continuous coordination requirement involving contact with numerous laboratories and manufacturers and the resolution of questions that arise. In order to allow and encourage exploitation of technological development without impairing compatibility and interchangeability, continued vigilance and direction is essential and is provided. The shift from discrete components to integrated circuits and the increasing use of computers and microprocessors necessitates continued accommodation to those devices. Work is proceeding on updating the NIM standard in the light of recent developments and practice. Also, the division continues to provide information regarding the CAMAC standards.[3]

The FASTBUS standard, previously issued as a Department of Energy Report,[4] has been updated and issued as a standard of the Institute of

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

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

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

[4] "FASTBUS Modular High Speed Data Acquisition and Control System," DOE Report DOE/ER-0189, December 1983.

Electrical and Electronics Engineers (IEEE) and the American National Standards Institute (ANSI).[5] It has also been approved as an international standard of the IEC, to be issued as IEC Publication 935.[6]

The software standard, "FASTBUS Standard Routines" dated March 1987 has been issued as DOE Report DOE/ER-0325.[7]

The NIM and CAMAC standard instrumentation projects have resulted in a savings of at least 1.9 billion 1982 dollars according to a study conducted for the Department of Energy by a firm of economics consultants.[8] 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[9] and the balance of 200 million dollars to the CAMAC instrumentation system developed by the ESONE Committee of European Laboratories with the active collaboration of the U.S. NIM Committee and the CRR. The report 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 measurable data were available." The total worldwide savings can be reasonably projected to be double the U.S savings.

(c) International Electrotechnical Commission - L. Costrell serves as Technical Advisor to the U.S. National Committee of the IEC for IEC Committee TC45 on Nuclear Instruments. He serves as Chief U.S. Delegate to TC45, as Chairman of the Working Group on Detectors and as a member of the working groups on Interchangeability and on Terminology. Numerous IEC draft documents were prepared and reviewed resulting in a number that were

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

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

[7] "FASTBUS Standard Routines," Department of Energy Report DOE/ER-0325, March 1987.

[8] "Benefit Analysis of Selected Accomplishments 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.)

[9] "Standard Modules for Nuclear Instrumentation," NBS Report 8137, December 5, 1963, L. Costrell.

published and others that are to be published. These include documents that are technically identical to the NIM, CAMAC and FASTBUS standards.[1,2,3,5] Similarly, the international standard on test procedures for germanium semiconductor detectors is to be technically identical to ANSI/IEEE Std 325.

MECHANICAL INSTRUMENTATION

Mechanical Instrumentation Services (D. Mohr)

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

Instrumentation Design and Construction (D. Mohr)

Design and construction of mechanical devices is an ongoing and important element of the mechanical instrumentation group activities. Examples of these devices built this year are: nonmagnetic, high vacuum chambers for the RTM end magnets and for the small dipole magnets on the RTM injection system and main accelerator axis; support structures and precision optical alignment fixtures for various RTM dipole magnets.

The single CAD/CAM workstation is operational and has allowed us to design the magnet chambers much more cost effectively. Two additional units are currently on order and will, when operational, help us to achieve the extremely tight mechanical design schedules of both the RTM and the FEL.

Installation and Maintenance of Facilities (D. Mohr)

Another major element of our activities is installation and maintenance of major facilities. Examples this year are: installation and alignment to ±.001" of six RTM dipole magnets; a 500 gpm cooling water filtration system; rebuilt vacuum pumps for SURF, Linac and the 3 MeV Van de Graaff; maintained the mechanical and vacuum equipment on the linac to allow in excess of 90% beam efficiency.

The group staff continues to provide consultation service to other groups in CRR and other NBS organizations. The staff is also consulted by people outside NBS who build and operate accelerators worldwide.

INVITED TALKS

Division 535, Radiation Source and Instrumentation

Debenham, P.H., "Ultrasensitive Laser Isotope Analysis in an Ion Storage Ring," Ninth Conference on the Application of Accelerators in Research and Industry, North Texas State University, Denton, TX, November 12, 1986.

Penner, S., "RF Linac Based Free Electron Lasers," 1987 Particle Accelerator Conference, Washington, DC, March 16, 1987.

Penner, S., "NBS Free Electron Laser Facility," NBS Special Seminar, Gaithersburg, MD, June 15, 1987.

Penner, S., "NBS/NRL Free Electron Laser Facility," Ninth International Free Electron Laser Conference, Williamsburg, VA, September 16, 1987.

PUBLICATIONS IN PREPARATION

Division 535, Radiation Source and Instrumentation

Cutler, R.I., Owen, J.C., and Whittaker, J.K., Performance of Wire Scanner Beam Profile Monitors to Determine the Emittance and Position of High Power CW Electron Beams of the NBS-Los Alamos Racetrack Microtron, to be published in the Proceedings of the 1987 Particle Accelerator Conference, Washington, DC, March 16-19, 1987.

Cutler, R.I., and Young, L.M., Performance of the High Power RF System of the NBS-Los Alamos Racetrack Microtron, to be published in the Proceedings of the 1987 Particle Accelerator Conference, Washington, DC, March 16-19, 1987.

Debenham, P.H., Bruce, S.S., Penner, S., and Wilson, M.A., The Injection Chicane of the NBS-Los Alamos Racetrack Microtron, to be published in the Proceedings of the 1987 Particle Accelerator Conference, Washington, DC, March 16-19, 1987.

Penner, S., RF Linac Based Free Electron Lasers, to be published in the Proceedings of the 1987 Particle Accelerator Conference, Washington, DC, March 16-19, 1987.

Tang, C.M., Sprangle, P., Penner, S. and Maruyama, X.K., Analysis of FEL Performance Utilizing the National Bureau of Standards' (NBS) CW Microtron, to be published in the Proceedings of the 1987 Particle Accelerator Conference, Washington, DC, March 16-19, 1987.

Wilkin, N.D., Downing, G., and Whittaker, J.K., Alpha Particle Detector Using RAM Cell Upset (in preparation).

Wilson, M.A., Ayres, R.L., Cutler, R.I., Debenham, P.H., Lindstrom, E.R., Mohr, D.L., Penner, S., Rose, J.E., Young, L.M., and Stovall, J., Performance of the 5 MeV Injector for the NBS-Los Alamos Racetrack Microtron, to be published in the Proceedings of the 1987 Particle Accelerator Conference, Washington, DC, March 16-19, 1987.

Wilson, M.A., Debenham, P.H., Penner, S., and Bruce, S.S., Orbit Reversing Magnets for the NBS-Los Alamos Racetrack Microtron, to be published in the Proceedings of the 1987 Particle Accelerator Conference, Washington, DC, March 16-19, 1987.

TECHNICAL AND PROFESSIONAL COMMITTEE PARTICIPATION AND LEADERSHIP

Division 535, Radiation Source and Instrumentation

Robert L. Ayres

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

Member, IEEE P1014/VMEbus Standard Committee

Member, NBS RIF Assignment Panel

Member, Science and Technical Pool, Science Panel, Committee on Interagency Radiation Research and Policy Coordination (CIRRPC)

U.S. Representative, Life Sciences Working Group of the International Committee for Radionuclide Metrology

Louis Costrell

Chairman, ANSI Technical Committee N42, Nuclear Instruments

Chairman, DoE National Instrumentation Methods (NIM) Committee

Chairman, IEC/TC45 Working Group-9 on Radiation Detectors

Chief U.S. Delegate, International Electrotechnical Commission (IEC), Technical Committee on Nuclear Instruments (IEC/TC45)

Member, ANSI Technical Committee N41, Controls, Instrumentation, and Electrical Systems for Nuclear Power Generating Stations

Member, IEC/TC45 Working Group-1 on Classification and Terminology

Member, IEC/TC45 Working Group-3 on Interchangeability

Member, 1987 Particle Accelerator Conference Organizing Committee

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

Secretary, Institute of Electrical and Electronics Engineers Nuclear Instruments and Detectors Committee of IEEE Nuclear and Plasma Sciences Society (IEEE/NPSS)

Technical Advisor, U.S. National Committee of IEC

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

Roy I. Cutler

Assistant Arrangements Chairman and Treasurer, 1987 Particle Accelerator Conference

Philip H. Debenham

Technical Consultant, DoE CEBAF Review Committee

Member, NSF Small Business Innovation Research Review Panel

Member, 1987 Particle Accelerator Conference Program Committee

Eric R. Lindstrom

Editor, Proceedings of the 1987 Particle Accelerator Conference

Samuel Penner

Chairman, 1987 Particle Accelerator Conference

Member, GBFEL/TAG

Julian K. Whittaker

Member, ASTM Committee D-22 on Methods of Sampling and Analysis of Atmospheres

Member, DoC Industry and Trade Administration, Electronic Instrumentation Technical Advisory Committee

Neil D. Wilkin

Member, Editing Committee for IEEE Nuclear and Space Radiation Effects Conference Publication

Member, Electronics Storeroom Committee, NBS

Senior Member, Institute of Electrical and Electronics Engineers

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

Mark A. Wilson

Member, Organizing Committee for Heavy Ion Fusion Symposium, Washington, DC, May 27-29, 1986

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. S. Penner serves as a consultant to the U.S. Army Strategic Defense Command on particle accelerator issues related to programs in Free Electron Lasers and Neutral Particle Beam Weapons.

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

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

TECHNICAL ACTIVITIES

Division 536, Ionizing Radiation

The functions of the Ionizing Radiation Division are summarized in the following table:

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

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

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

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

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

  - Medicine
  - Industry
  - States
  - Other Federal Agencies

- Develops and operates well-characterized sources of electrons, photons, and neutrons to provide:

- Primary radiation standards and fields
- Well-characterized beams of radiation for research on radiation interactions and for measurement methods development.

The group structure of the Ionizing Radiation Division was changed October 1, 1987 to establish the Office of Radiation Measurement as a separate group, rather than attached to the Division Office. The current group structure is:

Ionizing Radiation Division (R. S. Caswell)
Radiation Theory (M. J. Berger)
Radiation Chemistry & Chemical Dosimetry (M. G. Simic)
Neutron Measurements & Research (O. A. Wasson)
Neutron Dosimetry (J. A. Grundl)
Radioactivity (D. D. Hoppes)
X-ray Physics (J. W. Motz)
Dosimetry (R. Loevinger)
Office of Radiation Measurement (E. H. Eisenhower).

Dr. Loevinger has requested that he be relieved of his Group Leader duties to return to research. It is expected that a new group leader will be identified shortly.

Some of the major thrusts of the Ionizing Radiation Division for FY-1988 are:

(1) Research leading to a scientific basis for predicting, measuring, and modifying ionizing radiation effects in chemical and biological systems;

(2) Improving NBS radiation facilities for providing radiation beams and measurement instrumentation to characterize both the short-lived intermediates and the end products of radiolysis induced by ionizing radiations;

(3) Designing, construction, and funding of a high-energy electron and photon dosimetry facility on the race-track microtron;

(4) Advancing the science of state-of-the-art, real-time x-ray radiography;

(5) Dissemination of newly-developed ionizing radiation standards and improvement of the accuracy of present standards;

(6) Identification of organizations in the private, state, and federal sectors to construct and operate secondary calibration laboratories for important radiation measurements; and

(7) Identification of technical or industrial organizations to manage accreditation programs for each of the three sectors of secondary laboratories.

I. Radiation Theory Group

Cross Sections: Photons (M. J. Berger, J. H. Hubbell, E. B. Saloman, & H. M. Gerstenberg)

- A data base and computer program have been developed which can be used to calculate, with a personal computer, photon cross sections for scattering, photoelectric absorption and pair production, in any element, compound or mixture, at energies from 1 keV to 100 GeV. This work has been described in report NBSIR-87359.

- Extensive comparisons have been made of all available experimental, recommended and theoretical photon attenuation coefficients (total cross sections) in the energy region 100 eV to 100 keV. A paper on this work has been published as an NBSIR report, and has since been thoroughly revised and accepted for publication in Atomic and Nuclear Data Tables. This paper will also include a comprehensive bibliography, with references to approximately 20,000 data points from several hundred publications.

- A complete set of Photonuclear Data-Abstract Sheets has been published as a fifteen volume work and distributed to 45 research and educational institutions throughout the world. These abstract sheets cover most classes of experimental nuclear data leading to information of the electromagnetic matrix elements between the ground and excited states of a given nucleus. The set, containing nearly 7200 abstract sheets and covering 89 chemical elements from hydrogen through americium, represents a 27-year history of the study of electromagnetic interactions.

Cross Sections: Electrons (M. J. Berger, S. M. Seltzer, & Ruqing Wang)

- Cross sections for emission of bremsstrahlung by electrons (differential in the energy of the emitted photons) from recently published tables by the group have been organized on a computer-readable data file, presently stored on the CYBER 855. This file contains cross sections for all elements, Z=1 to 100, for energies from 1 keV to 10 GeV. Work is in progress to download and organize these data for storage on use on a personal computer.

- Systematic calculations were made of the cross section for the elastic scattering of electrons by atoms. These were done by a partial wave expansion, involving the numerical solution of the Dirac equation. The potential used was derived from relativistic Hartree-Fock wave functions. Scattering cross sections (at 65 deflection angles, for 11

electron energies from 1 keV to 1024 keV) have been obtained for all elements with atomic numbers Z=1 to 100. For several elements, such cross sections have also been calculated with Thomas-Fermi potentials, and with solid state potentials from the muffin-tin model.

- The new elastic scattering cross sections have been used as input for improved calculations of angular multiple scattering according to the Goudsmit-Saunderson method, and results have been obtained which are more accurate at low energies than the standard multiple-scattering theory of Moliere. Preliminary results of this work were presented by R. Wang (guest scientist from PRC) at the March meeting of APS.

Cross Sections: Neutrons (J. J. Coyne & E. J. Axton)

- Substantial progress has been made in the analysis and critical evaluation of the cross sections for the nuclear interactions between neutrons and carbon nuclei, and this information is being incorporated into more accurate calculations of kerma factors. An internal report on the nuclear-physics aspects of this work has been prepared, and an improved kerma tabulation is in progress.

Radiation Protection (M. J. Berger, S. M. Seltzer, C. M. Eisenhauer, & G. Barnea)

- A paper has been published in the Journal of Spacecraft and Rockets in which calculations are reported pertaining to the shielding of space vehicles against electrons, and in particular, secondary bremsstrahlung originating within the shield. These calculations were done for radiation environments in typical shuttle and geosynchronous orbits. It was demonstrated that considerably improved shielding can be obtained through the replacement of an aluminum shield by a composite shield of the same total mass thickness with an inner lining of lead.

- A final report was prepared for the Federal Emergency Management Agency (FEMA) describing engineering methods and computer codes for predicting the protection provided by various kinds of buildings against initial gamma rays and neutrons from nuclear weapons. This report is the culmination of a 15-year research program that has been a part of a 30-year contract with FEMA and its predecessor agencies concerned with Civil Defense.

Dosimetry (M. J. Berger, S. M. Seltzer, & C. M. Eisenhauer)

- Work has been completed and published on the deposition of energy by electrons and photons in multi-layer targets consisting of several adjacent slabs of different materials. Results were calculated with the NBS transport program ZTRAN for electron beams with energies from 0.4 to

60 MeV, for bremsstrahlung beams with endpoint energies from 2 to 20 MeV, and for ^{60}Co gamma-ray beams. Various comparisons indicate good agreement with experiments.

- An analysis has been carried out of the radiation exposure from ^{125}I seeds used in brachytherapy, this analysis confirmed a suspected 6-8 percent error in the NBS calibration procedure, due to the presence of secondary Ti x rays. An appropriate correction factor has been indicated.

- Monte Carlo calculations were made of silicon detector response functions required by the CRR Dosimetry group in the course of their work on the calibration of beta-particle detectors.

- Monte Carlo calculations have been made of the effect of air scatter on neutron fluence from Cf, moderated Cf, Am-Be and Am-B neutron sources. These results have been applied to the calibration of neutron personnel protection instruments, and a method has been derived for estimating air scatter effects for other neutron sources with different spectra.

- As a contribution to the planning of NASA's Mars Observer Mission, the response function of large high-purity germanium detectors was calculated for gamma rays with energies from 100 keV to 20 MeV, as a function of the direction of incidence of the radiation. Methods for space shielding calculations developed at NBS were presented in an invited talk at a LBL/DOE/NASA Workshop on High-Energy Accelerator and Space Radiation.

Microdosimetry (J. J. Coyne, R. S. Caswell, & H. M. Gerstenberg)

- Microdosimetric event-size distributions have been calculated for four different neutron spectra using the analytical method developed at NBS. The source spectra treated included a ^{252}Cf source, a source with a large component of energetic neutrons (energies up to 16.9 MeV, and sources of neutrons from a pulsed thermal reactor with and without a lead shield. These calculations were carried out in support of the radiobiological research program at the Armed Forces Radiobiology Research Institute.

- Work has been initiated on developing a "standard version" of the analytical code for calculating neutron-induced event-size spectra. This version will be sufficiently documented so that it can easily be used by outside users familiar with the microdosimetry.

- The investigation of alpha-particle event-size spectra resulting from neutron interactions has advanced to the point where the use of the newly-evaluated carbon cross sections, together with the angular distribution of

alpha particles from the $^{12}C(n,n')3\alpha$ reaction gives reasonable agreement between experiment and theory. However, there are still some questions about the results at 19 MeV which remain to be resolved.

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

- Significant improvements have been made in the all-purpose NBS electron-photon Monte Carlo program ETRAN. These include an improved sampling for energy-loss straggling, the incorporation of more accurate stopping powers, bremsstrahlung cross sections and elastic scattering cross sections. Thereby the agreement of calculated electron penetration data with experiments was significantly improved.

- A cross section data base and Monte Carlo model have been developed for calculating the energy-loss straggling of electrons in water, at energies up to 1 MeV. Whereas the conventional theories of Landau, Vavilov and Blunck-Leisegang are applicable only for sufficiently long pathlengths, the new Monte Carlo method is applicable to arbitrarily short pathlengths, and has been developed with a view towards applications in microdosimetry where targets of dimensions of 1 micron or smaller are of interest.

II. Radiation Chemistry and Chemical Dosimetry Group

The program deals with kinetic and mechanistic aspects of radiation effects from model chemical to biological systems and their applications to radiation processing, radiation protection, radiation biology, radiation therapy, and physiology. It is based on the measurement of free radical intermediates and final products. In addition, these measurements are used for the development of chemical dosimeters, dosimetry of damage, and post-irradiation dosimetry (self dosimetry).

A. Radiation Chemistry (M. G. Simic, D. S. Bergtold, L. R. Karam, E. P. L. Hunter, M. Al-Sheikhly, M. F. Desrosiers, & E. A. Thompson)

Radiation effects are studied from the initial physical interaction of radiation and matter to the final biological end points from a kinetic and mechanistic point of view at a molecular level. The properties (spectral, acid-base, redox, reactivity), and reactions of generated free radicals are studied by pulse radiolysis and ESR. Stable products resulting from free radical reactions are studied by various analytical techniques (HPLC, GC/MS, spectroscopy, etc). Bio-effects are investigated by suitable biochemical techniques (ultracentrifugation, electrophoresis, chromatography, etc.).

The emphasis of research is on the mechanisms of radiation damage to bio-systems and the repair of damage. Specifically, DNA, proteins, lipids and their subcomponents are used as model systems for the study of radiation-induced damage. The interactions of sulfhydryls and antioxidants with free radicals on damaged biomolecules are studied in order to understand the mechanisms of chemical repair.

DNA (L. R. Karam, D. S. Bergtold, S. Jovanovic, & M. G. Simic)

The research has been focused predominately on the mechanisms of DNA base damage, crosslinking of DNA with proteins, and measurement of the resulting products. The mechanisms and consequences of crosslinking, however, are not yet understood because of the lack of measurement methodologies. The measurement of products of DNA damage (e.g., thymine glycol, 8-hydroxy-guanine, etc.) is utilized for the development of post-irradiation biochemical and biological dosimetry (e.g., in urine). Irradiation parameters (dose, dose rate, temperature, state, O_2, etc.) are of critical importance since the effects of radiation can be qualitatively and quantitatively altered by them. The effects of quality of radiation (LET) are not investigated at present. However, the study of the effects of low-energy protons and α-particles, as well as high-energy high-Z nuclei (BEVALAC), are in the planning stages.

This research is expected to have an impact in radiation biology, radiation therapy of cancer, cancer etiology, risk assessment, and radiation protection. Specifically, the conducted research is relevant to: assessment of damage from low-LET radiations (γ and x rays, electrons) vs. α-particles (e.g., radon), and development of standards for individual biological sensitivity to radiation. Unique facilities and expertise at NBS, suitable conditions for the development of assays and standards, provide new approaches in the study of the mechanisms of the biological effects of radiation.

Thymine glycol, 8-hydroxyguanine and their nucleosides were separated and identified in urine by GC/MS by using preseparation techniques. The redox potentials of guanine and 8-hydroxyguanine were determined (0.95 and 0.28 V), indicating the charge transfer in a DNA-histone complex takes place from DNA to protein and not the other way around. These measurements are crucial for the understanding of the mechanisms of the direct effect of radiation.

Proteins and Amino Acids (L. R. Karam, M. F. Desrosiers, E. P. L. Hunter, & M. G. Simic)

The research has been focused predominantly on the hydroxylation of aromatic amino acids and dimer formation induced by radiation. The measurement methodologies for hydroxylated products (e.g., o-Tyr) and dimers have to be developed for ppb quantities in the presence of large

numbers of other products, amino acids, and other physiological subcomponents. This research is relevant for safety assessment of irradiated foods and the development of post irradiation dosimetry. The PID of meat is important for quality control and regulatory (imports-exports) procedures.

A differential spectrofluorimetric method was developed for the measurements of radiation induced tyrosine dimers. It was shown that phenoxy radicals do not react with oxygen at a measurable rate ($k < 10^{-3}$ M^{-1} s^{-1}) and that crosslinking can take place in the presence of oxygen as well as via interaction of two phenoxy radicals. The developed mechanisms may serve as a general model for crosslinking of proteins.

Lipids (M. Al-Sheikhly, M. H. Hussmann, & M. G. Simic)

Mechanisms of radiation induced autoxidation of lipids are being studied by pulse radiolysis and oxygen uptake (utilizing oxygen electrode) in aqueous solutions. Since irradiation of aqueous solutions provides a definable number of initial reactive species, it is possible to measure accurately the length of chain reactions. Pulse radiolysis measurements provide kinetic and spectroscopic parameters of the relevant lipid transients, and the reactions which lead to product formation.

Autoxidation of lipids is relevant for cancer promotion, meat irradiation processing, and the storage of foods. Pulse radiolysis measurements in model systems have been conducted in order to provide important kinetic information such as reaction rate constants, for the reaction of oxygen and lipid radicals, which have been lacking until now.

Rod-shaped micelles of linoleic acid have been developed as a model for the studies of autoxidation and antioxidants under simplified membrane conditions.

Antioxidants and Sulfhydryls (E. P. L. Hunter, S. Jovanovic, M. Al-Sheikhly, M. F. Desrosiers, & M. G. Simic)

The kinetic and mechanistic features of natural and man-made antioxidants are not fully understood. Pulse radiolysis measurements provide important features (kinetic parameters, redox potentials) for the selection of the most suitable antioxidants for a particular system. The experiments conducted are geared toward acquisition of such predictability. The emphasis is on phenolic and heterocyclic antioxidants and their reactions with DNA, protein, and lipid radicals.

Antioxidants and sulfhydryls act as radioprotectors and anticarcinogens and in both cases the mechanism of action is not understood. The impact of this work is also of significance in food preservation, and human physiology. NBS is the only institution in the U. S. dealing with

the kinetic aspects of antioxidants. The redox potential of vitamin E was determined ($E = 0.48V$), providing thermokinetic support for restitution of consumed vitamin E molecules by various physiological antioxidants.

Efficiency of bilirubin and vitamin E as antioxidants was compared in model micelles (rod-shaped) and the efficiency of bilirubin was found to exceed that of vitamin E. This raises a question of the actual physiological role of bilirubin.

8-hydroxy-guanine was found to be an excellent antioxidant for processes in aqueous media.

B. Chemical Dosimetry (W. L. McLaughlin, M. Desrosiers, M. Al-Sheikhly, M. Farahani, M. Khan, M. H. Hussmann, W.-Z. Ba, J-H Liang, and H. A. El-Azez)

Research on the mechanistic behavior of both inorganic and organic chemical systems suitable for dosimetry has isolated several promising new systems: (1) An improved and more sensitive dichromate solution; (2) a new form of radiochromic solution having a response over a broad range of absorbed doses; (3) a new fluorescence dosimeter based on substituted phenylcarboxylic acids; (4) several forms of optical waveguide dosimeters; (5) several solid-phase chemical dosimeters (plastics, glasses, and crystalline systems). The first two in this group are being designed as SRM's for various industrial applications of ionizing radiation. The other three are for routine dosimetry and for quality assurance in various applications of current interest: clinical and diagnostic medicine, agriculture, electronics, materials, environmental technology, space and defense, industry, and radiation protection.

Steady-State Dosimetry (W. L. McLaughlin, M. Al-Sheikhly M. Farahani, M. Khan, W.-Z. Ba, J-H. Liang, M. H. Hussmann, & A. El-Azez)

Radiation chemistry studies of the reduction of hexavalent dichromate to the chromic ion in acidic aqueous solution have shown this system to be exceptionally accurate and reproducible for reference dosimetry. Similar to the Fricke dosimeter (dose range 10-400 Gy), it gives an unusually precise and stable system which can be used in a higher dose range (100 to 4000 Gy) for intercomparison studies and for calibration of working dosimeters in industrial and food applications. Another promising reference aqueous dosimeter for doses lower than the Fricke dosimeter range (0.1-10 Gy) for medical and biological applications has been developed in this research effort. It consists of arylcarboxylic acid solutions which are analyzed by a spectrofluorimeter in terms of photostimulated fluorescence signals due to radiation-induced hydroxyl substitutions on the phenyl groups. These systems are also linear, stable, and reproducible for QA purposes and intercomparison studies. In addition to these liquid-phase dosimeters, several new forms of solid dosimeter have been designed, based

on very thin coated films, thicker plastic films, crystalline solid-state systems, and glasses. There is now a family of highly practical and inexpensive dosimeter devices for industrial use, to enable radiation processing industries to measure on a routine basis doses over very broad ranges ($10\text{-}10^9$ Gy). The thin-film devices are also being used for mapping and imaging of dose distribution.

Real-Time Dosimetry (W. L. McLaughlin, M. Al-Sheikhly, & M. H. Hussmann)

Pulse radiolysis studies have revealed the response mechanisms of both dichromate and radiochromic dosimeter systems. The dichromate dosimeter, if properly designed, can be used without dose-rate dependence for both photons and electrons over a wide range of radiation intensities. The same is true for the radiochromic solutions, and in fact, it has been shown recently that, in liquid- or gel-core sensors, these serve as optical waveguide dosimeters for real-time measurements for diagnostic and clinical radiology. They are also being designed and used by DoD for personnel dosimetry of mixed radiation fields. Real-time dosimeters are being investigated for telemetering purpose, in particular, certain solid-state devices whose radiation-induced signals can readily be transmitted remotely.

Chemical Dosimetry Mechanisms (W. L. McLaughlin, M. G. Simic, M. Al-Sheikhly, M. Khan, & M. Desrosiers)

Chemical dosimeters developed at NBS are subjected to rigorous experimental and theoretical investigation, in order to unravel their radiation-chemical response mechanisms. Kinetic studies by pulse radiolysis have recently supplied hidden answers to the behavior of both dichromate and radiochromic radiation dosimetry systems, and have thus offered convenient means of enhancing the performance of these sensors as practical dosimeters. For example, the dichromate dosimeter has been made more sensitive by nearly an order of magnitude; new radiochromic dyes have been designed for greater accuracy, reproducibility, and long-term stability. These efforts are now being extended to other chemical dosimeters, such as photoluminescent solutions and free-radical systems.

High-Dose Calorimeters (W. L. McLaughlin J. C. Humphreys, S. R. Domen, & W-Z Ba)

At present there exists no primary standard for high-dose dosimetry. There are, however, new demands from industry for such a standard, as the use of industrial electron accelerators expands rapidly, and as quality control on assembly lines depends more and more on traceability to such standards. Calorimeters especially suited for standardization and calibration of dosimeters used at large radiation doses and dose rates are being designed and built at NBS for both electron beams and large radionuclide gamma-ray sources. These NBS designs are also being adapted by

other National Laboratories in the UK, Denmark, Canada, and the Federal Republic of Germany. International intercomparisons of these standards are now being carried out on an annual basis, as a means of developing recognized primary standards for the quantities absorbed dose and dose rate delivered at high fluence rates in industrial radiation processing.

C. Post Irradiation Dosimetry (PID). (L. R. Karam, D. S. Bergtold, M. F. Desrosiers, E. A. Thompson, & M. G. Simic)

There are numerous instances when the knowledge of the delivered radiation dose is required either immediately or long after the exposure. For example, proof that suspected foods have or have not been irradiated is required by food processors and wholesalers for purposes of regulation of imports/exports. Reliable measurements which can indicate that irradiated foods have not received radiation dose in excess of the legal limits are needed by regulatory agencies.

Accidental exposure of personnel to radiation has occurred in some cases without an adequate on-line dosimeter being present, accentuating the need for the development of novel concepts in real-time dosimetry and PID for such circumstances.

Measurements of the total energy delivered (J) to a patient in radiation therapy would be useful information to a therapist. So would be the dose received by the NASA personnel exposed to cosmic showers and solar flares in space. The possible presence of unique radiolytic products, URPs, or specific markers, in the urine of irradiated patients or personnel in space (e.g. thymine glycol, 5-hydroxymethyl uracil, etc.) is under investigation.

The discovery of o-Tyr in irradiated chicken meat may be utilized for the development of suitable PID for meats. Analytical procedures and a separation methodology have been developed for determination of o-Tyr in irradiated and nonirradiated chicken-breast meat. No measurable (<0.1 ppm) quantities of o-Tyr were found in nonirradiated meats, while in irradiated samples a linear yield-dose relationship was found. Carbon tetrachloride (fat extraction solvent) was found to induce o-Tyr in irradiated and nonirradiated meat. However, even under those circumstances no o-Tyr was found in the water-insoluble fraction (~75 percent of protein) after water extraction.

Electron spin resonance (ESR) measurements of irradiated bones (pork and chicken) exhibit linear signal-dose relationships. The ESR signal in unirradiated bone was different from the radiation-induced signal. The signal intensity persists for months, making this approach an ideal one for determination whether meat (with bones) has been irradiated.

Thermoluminescence and lyoluminescence methodologies for PID are under development as a counterpart of ESR measurements, since photon-counting could be a much more sensitive technique than electron spin measurements.

III. Neutron Measurements and Research Group

This group is concerned with measurements of neutron interactions which depend strongly on the neutrons' energy. The interactions 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 percent (1 SD) range. Although the group has made significant contributions to this effort, much work remains in selected neutron energy regions to achieve this important goal. This activity, which is jointly supported by the U.S. Department of Energy and NBS, includes both an extensive experimental effort as well as coordination of the evaluation of the neutron cross section standards for the United States. These standards form the basis for nearly all neutron nuclear data since these data are measured relative to the standards. Hence they supply large leverage since an improvement in the accuracy of the standards will improve the accuracy of the entire data base without an extensive remeasurement effort. 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 group possesses the unique combination of highly trained technical staff and research facilities to continue to produce significant leadership in these areas. The NBS facilities used are the 100-MeV linac dedicated pulsed neutron source, 3-MV positive ion electrostatic accelerator, 100 keV neutron generator, and nuclear research reactor. In response to requests from other programs within NBS, a 6-MeV γ-ray radiation facility and a Rutherford Backscattering Analyzer for surface studies have been implemented at the positive-ion accelerator. A technical description of the group's activities and significance of its success in completing projects follows.

$^{235}U(n,f)$ Cross Section from 0.02 to 1000 Electron Volts (R. A. Schrack)

The Neutron Measurements and Research Group has undertaken a measurement of the shape of the neutron induced fission cross section from .02 to 1000 eV where there have been large discrepancies (on the order of 7 percent) in the reported values of these integrals. This measurement is being undertaken to help resolve the current discrepancies in this important cross section standard.

The past year was devoted to diagnostic tests to improve the accelerator operation and data-acquisition electronics. The data obtained after these diagnostic efforts are in good agreement with the most recent work. A final evaluation of these results will produce a cross section which will satisfy the accuracy request in this energy region.

Measurements of the $^{235}U(n,f)$ Cross Section in the MeV Energy Region (A. D. Carlson, O. A. Wasson; P. W. Lisowski, LANL; J. L. Ullmann, LANL; & N. W. Hill, ORNL)

Significant progress has been made in the fission measurement program initiated at the Los Alamos National Laboratory (LANL) facilities. This program was begun in an effort to improve the accuracy and range of the $^{235}U(n,f)$ cross section standard. The neutron flux is being measured with the NBS annular proton telescope. The fission detector is a LANL fission chamber with fission foils prepared at Oak Ridge National Laboratory (ORNL). The multifoil capability of this chamber is being utilized to provide redundancy of measurements and to provide fission cross section measurements of other actinides.

The cross section measurement work began late last year when the new WNR Target 4 facility became operational. This facility is capable of producing the very intense beams of high energy neutrons required for this measurement. The detectors were set up at the 20 m flight path end station. During the brief period before the LAMPF/WNR cycle came to an end, experimental tests, diagnostic studies and some preliminary fission cross section results were obtained in the 3-30 MeV neutron energy range. Measurements have never been made before of this cross section in the higher energy region.

Plans have been made to continue the measurement program at the beginning of the WNR cycle. The longer period of time available for measurements this year should allow comprehensive background investigations, diagnostic tests, and a considerable improvement in the counting statistics.

Absolute Measurements of the $^{235}U(n,f)$ Cross Section for Neutron Energies from 0.3 to 3 MeV (A. D. Carlson, J. W. Behrens, R. G. Johnson, & G. F. Cooper)

The measurements of this cross section have been made at the NBS neutron time-of-flight facility. The neutron flux was measured at the 200 m end station with the NBS Black Neutron Detector. The ^{235}U fission reaction rate was determined with a fission chamber located on the same beam line at 69 m from the neutron producing target. The cross sections from this measurement have been finalized and made available along with extensive correlation and uncertainty information for use in the ENDF/B-VI

standards evaluation. The numerical data are available from the National Nuclear Data Center at Brookhaven National Laboratory. A paper describing this work is being prepared for journal publication.

Application of the Dual Thin Scintillator Neutron Flux Monitor in a $^{235}U(n,f)$ Cross Section Measurement (M. S. Dias, R. G. Johnson, A. D. Carlson, & O. A. Wasson)

The $^{235}U(n,f)$ cross section has been measured over the 1.0 to 6.0 MeV neutron energy range using the dual thin scintillator (DTS) detector as a flux monitor. Final results of the measurement along with a full error analysis have been obtained and are in the process of being submitted for publication.

Characterization of the Moderating Neutron Detector (J. B. Czirr, G. Jensen, R. G. Johnson, A. D. Carlson, & O. A. Wasson)

An innovative series of neutron detectors has been developed at MESA Services International by Dr. J. B. Czirr. In collaboration with Drs. Czirr and Jensen (Brigham Young University), the Neutron Research and Measurement Group are conducting measurements to help characterize this detector.

The detector consists of 2 to 9 sheets of ^{6}Li-enriched glass scintillator. (Each sheet is 10-cm square and 0.5-mm thick.) The ^{6}Li-glass scintillators are surrounded by a neutron-moderating liquid and viewed by two photomultiplier tubes. With five pieces of glass the efficiency drops from 75% to 32% over the 1-eV to 1-MeV range. The timing resolution over this same energy range is 8.1 to 4.0 μs.

At the NBS Neutron Time-of-Flight Facility (NTOFF) a shape measurement of the efficiency for neutron energies from 100 eV to 30 keV has been performed. The measured efficiency will then be compared to the predictions of a Monte Carlo code.

Development of the NBS $^{3}He/Xe$ Gas Scintillation Counter (J. W. Behrens, Hongchang Ma, & O. A. Wasson)

$^{3}He/Xe$ gas scintillation counters have been designed, built, and tested at the NBS for measuring the neutron energy range from 1 keV to 3 MeV. Great effort was concentrated on improving the detector design to optimize ultraviolet-light production in xenon, wavelength shifting in diphenylstilbene, and light collection in the photomultipliers, since the main component affecting energy resolution was photon statistics. The goal was to improve the resolution of the $^{3}He(n,p)T$ pulse-height distribution so that it could be easily separated from most of the ^{3}He recoil events. Two detector designs have been built and tested using a ^{238}Pu

alpha-particle source, thermal-neutron beam from the NBS reactor, and white-neutron spectrum from the NBS dedicated pulsed neutron source. The progress of our work has been reported in recent ANS and APS meetings.

We are pleased to report that our goal has been reached. We now have a detector which can be used in experiments to measure the $^{3}He(n,p)T$ cross section and has great promise as a flux monitor in future standards measurements. We have prepared a paper summarizing our design studies and will be submitting it for publication in Nuclear Instruments and Methods.

Measurement of the $^{3}He(n,p)T$ Cross Section from 1 eV to 750 keV (J. W. Behrens, A. D. Carlson, & H. Ma)

Having designed, built, and tested a $^{3}He/Xe$ gas scintillation counter which has an energy resolution of 17% (FWHM) for the $^{3}He(n,p)T$ reaction and with which we can separate out most of the ^{3}He recoil events, we decided to use the detector to measure the $^{3}He(n,p)T$ cross section. Our first measurements utilized the $^{10}B(n,\alpha)$ reaction as the reference standard. The energy range of interest was from 1 eV to 750 keV and the NBS linac was chosen to produce the neutrons. Data have been taken using our two-detector, two-parameter data taking system. We measured neutron backgrounds with gold, sodium, and aluminum filters. These data are presently being analyzed.

Detectors for Neutron Scattering in the eV Region (R. G. Johnson)

Over the last few years the Neutron Measurements and Research Group has carried out a modest program in detector development for low energy neutron scattering. Neutron scattering is one of the primary tools in condensed-matter studies. With the advent of accelerator-based neutron sources the possibility of extending this technique to higher energies was perceived. However, in moving to higher energies the traditional detectors and instruments used in condensed-matter studies are inappropriate. An opportunity for this group to use its experience in neutron measurements over a very wide range of energies was foreseen.

Recently the results of this detector development were accepted for publication. In this report two detectors for one of the principal general methods to extend the neutron-scattering technique to the eV region are described and tested. The general method uses low energy neutron resonances to define one energy in the scattering process. The other energy can be measured by time-of-flight. The particular method studied here would be applied to the so-called Resonance Detector Spectrometer (RDS) where the nuclear resonance defines the energy after scattering (indirect geometry).

Multi-Particle Accelerator for Neutron and High-LET Radiation Research (R. G. Johnson)

A final report on a linear induction accelerator for neutron and high-LET radiation has recently been published. This preliminary design study was originally performed as part of the analysis of neutron and high-LET radiation research program at NBS conducted by the Center for Radiation Research staff. The accelerator design study was later updated to include the most recent advances in technology for induction linacs.

Data Acquisition System (R. G. Johnson, G. E. Cooper, & R. A. Schrack)

Funds from the NBS capital-equipment fund were obtained in FY-87 to complete the purchase of computers for replacement of those in our data acquisition systems. Although limited funds were available, the rapid improvement in the price-performance ratio has permitted us to implement our ambitious plan made several years ago. This final purchase did require a change in vendors but virtually no change in computer architecture.

Two MZ9400 computers were obtained from MIZAR, Inc. These computers use the VME bus and the Motorola MC68020 microprocessor. The basic machine contains 1-Mbyte of memory, a 1.2-Mbyte 5-1/4-in floppy disk, and a 20-Mbyte hard disk. The OS-9/68k operating system is being used. The computers were enhanced by a 4-Mbyte memory board and a CAMAC-VME interface board. In addition, two AST Research Inc. Premium/286 computers were purchased to be intelligent terminals for the MIZAR computers. The Premium/286 which is a PC-AT clone will allow us to use the vast pool of software available for personal computers.

The Charles River Data Systems UV2403FT computer (previously purchased) which is also based on a VME and MC68020 architecture will be used for data analysis and storage. This computer with its larger hard-disk capacity (105-Mbyte), better input/output capability (9-track tape drive, laser-jet printer, etc.), and superior multiuser operating system is ideally suited for that role. To fully implement that use we need to acquire a high-speed local area network (LAN).

Continued Development of a 2.5 MeV Neutron Source for Standard Cross Section Measurements (K. C. Duvall)

Development of a 2.5 MeV neutron source using the $D(d,n)^3He$ reaction and the time-correlated associated particle (TCAP) method continues. The 100 kV, 0.5 mA ion generator is in place and operating according to the required specifications. A magnetic quadrupole doublet and a magnetic dipole X-Y steerer have been installed on the beam line. The components are effective in focusing and steering the deuteron beam. A beam spot size of 3 mm diameter has been attained with nearly two hundred microamps

of beam on target. Water cooling is being used to maintain the target heating and outgassing to a reasonable level. In addition to the vac ion main vacuum pump, a turbomolecular pump has been installed near the target to provide increased target pumping. Isolation gate valves are used to separate the target vacuum from the main accelerator vacuum. The nearly 10^7 neutrons/sec D-D source yield is produced from the commercially obtained titanium deuteride targets. The deuteron beam characteristics and the neutron source yield are sufficient for use with TCAP to measure standard neutron cross sections. An article describing the development of the standard 2.5 MeV neutron source has recently been published in Nuclear Instruments and Methods.

Dual Thin Scintillator Development in the Sum Coincidence Mode (K. C. Duvall & R. G. Johnson)

The Dual Thin Scintillator (DTS) is a unique detector that is continually being developed here at the NBS for neutron flux and spectrum measurements in the 1 to 15 MeV energy range. The detector consists of two thin, back to back, plastic scintillators that are optically separated and independently coupled to photomultiplier tubes. Current interest is focused on the development of the detector in the sum coincidence mode of operation which produces a peaked rather than a rectangular spectrum. The peaked energy distribution provides improvement for neutron flux and spectrum measurements.

For absolute neutron flux measurements, the peaked response function will produce more accurate results due to reduced sensitivity to electronic gain instabilities and computational uncertainties. For spectral determinations with spectrum unfolding analyses, the peaked response functions should provide an improvement in unfolded results because of the increased correlation with the initial neutron energy spectrum. As a result of the added effect due to multiple scattering on the detector efficiency at low neutron energies, the DTS detector in the sum coincidence mode fulfills the desired requirements for use with spectrum unfolding analyses.

A Study of Fission Cross-Section Systematics (J. W. Behrens)

A publication has been completed giving the results from a study of fission cross-section systematics. Future studies will examine the thorium and protactinium isotopes and will extend into the transplutonium mass region.

Utilization of the NBS Dual Thin Scintillator Neutron Detector for Activation Cross Section Measurements (K. Zasdny, G. F. Knoll, U. of Michigan; R. G. Johnson, K. C. Duvall, & O. A. Wasson)

The value of the Dual Thin Scintillator Neutron Detector for precise neutron fluence measurements in the 1-15 MeV energy region continues to be recognized by other laboratories. This detector is being used to determine the neutron fluence incident on the samples for new 14 MeV neutron activation cross section measurements at the 125 keV neutron generator facility at the University of Michigan. Previous measurements were compared to a commonly used $^{56}Fe(n,p)$ reference cross section. These new measurements will combine these techniques and further reduce the systematic errors which will produce more accurate cross sections. These cross sections are applied in many areas of neutron dosimetry and spectral measurement.

Development of a Method for the Dosimetry of High Energy Photon Fields by NaI Spectrometry (K. C. Duvall, S. M. Seltzer, C. G. Soares, & B. W. Rust)

A method for the dosimetry of high energy monoenergetic photon fields by analysis of 3-inch x 3-inch NaI pulse height data has been developed. This approach uses calculated NaI detector response functions that have been shown to be reasonably accurate up to 20 MeV. A least-squares fit of the appropriate response functions to a selected region of the data determines the primary high-energy photon fluence. The air kerma delivery at a reference position in the photon field is calculated from the high-energy photon fluence. The primary high-energy photon contribution to the detector response is then removed from the data and the remaining distribution of lower-energy photon contamination is evaluated by spectrum unfolding analyses. The method is applied to NaI measurements at the nearly-monoenergetic 6 to 7 MeV photon source developed at the National Bureau of Standards (NBS) for radiation protection instrument calibration.

The ENDF/B-VI Neutron Cross Section Standards Evaluations (A. D. Carlson, W. P. Poenitz, ANL; G. M. Hale, LANL; & R. W. Peelle, ORNL)

The evaluation cycle has been started for the sixth version of the U.S. Evaluated Nuclear Data File, ENDF/B. The individual evaluations are all critically dependent on the new evaluations of the neutron cross section standards. The standard evaluation process for this new version is more thorough and logically consistent than that used in earlier versions. The primary effort is focused on a simultaneous evaluation using generalized least squares, R-matrix evaluations and a procedure for combining the results of these evaluations. The simultaneous evaluation is important to this process since ratio measurements in addition to shape and absolute determinations are treated properly. Correlations within and

among experimental data sets are also taken into account. Also the output results from the thermal constants evaluation by Axton, including the associated variance-covariance matrix, has been used as input for this evaluation. The R-matrix evaluations provide a method which allows charged-particle measurements involving the same compound nuclei (^{7}Li and ^{11}B) to be included in the evaluation process. These evaluations also provide a smooth meaningful expression for the energy dependence of the cross sections. Independent data bases are used in the simultaneous and R-matrix evaluations. The combining procedure is used to combine the information obtained from these analyses in a proper way to form the final evaluation and its variance-covariance matrix. The standards being evaluated are ^{6}Li(n,t), ^{10}B(n,α_1), ^{10}B(n,α), ^{197}Au(n,γ), and ^{235}U(n,f). Evaluations for the important reactions ^{238}U(n,γ), ^{238}U(n,f), and ^{239}Pu(n,f) are also being performed. The new R-matrix evaluation of the hydrogen scattering cross section by Dodder and Hale has already been accepted as the hydrogen standard for ENDF/B-VI.

The standards evaluation effort required for this project has turned out to be more substantial than we had originally expected. A total of seven cycles of this evaluation process have been performed in order to implement various improvements, changes, and checks into the procedure.

This work is now entering its final phase. The last combining procedure run and the smoothing of the capture and fission data which were performed in July should yield the final cross section values.

Fifty Years with Nuclear Fission, a Conference (J. W. Behrens, A. D. Carlson, & O. A. Wasson)

The NBS will host a topical conference entitled, "Fifty Years with Nuclear Fission" from April 26-28, 1989. Joining the NBS as co-sponsors are the American Chemical Society's Division of Nuclear Chemistry and Technology, the American Nuclear Society, and the American Physical Society's Division of Nuclear Physics. Professors John Archibald Wheeler and Edoardo Amaldi will serve as Honorary Co-Chairman. The conference will be dedicated to the memory of Niels Bohr and Enrico Fermi.

The conference's program committee met on April 22, 1987 to decide on tentative general topics and to nominate members to the advisory committee. The general topics chosen were, 1) The History of Fission, 2) Fission-Theory, 3) Fission-Experiment, 4) Fission-Applied Data, 5) Applications Utilizing Fission, and 6) The Impact on Society of the Discovery of Nuclear Fission. A postcard announcement was distributed to 1600 individuals, worldwide, on the mailing list from the 1985 Santa Fe Conference. A second announcement including a call for contributed papers will be sent out in early 1988. We presently estimate that the conference will be attended by 400-500 participants.

IV. Neutron Dosimetry Group

This group is engaged in the development and the application of well-characterized neutron fields as permanent irradiation facilities for neutron dosimetry standardization, for neutron detector development and calibrations, and for reaction cross section measurements. Strong interactions with outside organizations, both in the federal and private sectors, are important programmatic elements.

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

Activities carried on under this heading include use of the NBS standard neutron fields for routine calibrations of health physics instrumentation, for development and testing of new types of instrumentation, and for quality control of production instruments. In the area of dosimetry, methods research, a tissue equivalent proportional counter system (TEPC) is under development to determine neutron dose as a function of energy deposited.

1. Calibration service. Required documentation for the calibration service has been completed. Approximately 55 health physics instruments were calibrated this year. Most of these were for nuclear power plants and the armed forces. A remotely operated detector positioner has been installed that adds convenience, improves accuracy and speeds up data taking.

2. Performance test of a new type of remmeter. The French Atomic Energy Commission (Commissariat a L'Energie Atomique) have developed a new remmeter, an unusual event, intended to be more accurate and easier to use than current instruments. At their request, definitive performance tests were performed at NBS. Since the instrument is designed to take account of scattered neutrons, it was necessary to correct for room scatter in our calibration facility in order properly to interpret the data. Results indicate that the new remmeter gives accurate results when used as intended.

3. Intercomparisons. Calibration intercomparisons were undertaken with the University of Arkansas Southwest Radiation Calibration Center, and with the Battelle Pacific Northwest Laboratory. Agreement in both cases was within ±5 percent. An intercomparison involving NPL (Great Britain), PTB (Germany), and CEA (France) is in full swing.

4. Purity of the filtered beams. In response to questions concerning the purity of the NBS 2 keV filtered beam, the neutron spectrum was carefully remeasured using a He-3 spectrometer with a new low-noise preamplifier and pile-up rejection circuitry. Newly observed lines between 70 keV and 550 keV amount to only about 2 percent of the primary 2 keV

line. The pulse height spectrum shows that by far the cleanest 2 keV beam at any reactor facility in the world is at NBS. The 144 keV beam also has been improved recently by increasing the amount of Ti in the filter.

5. Quality assurance and type testing. The filtered neutron beams together with the beam at the thermal column, continue to be used for testing radiation protection instrumentation. Included this year were quality control measurements on neutron area monitors for the Naval Surface Weapons Center, dosimeter irradiations as part of the Department of Energy Laboratory Accreditation Program (DOELAP), and testing of a new type of neutron detector developed at the Chalk River Laboratories. The latter testing, done in collaborations with several other laboratories in the United States and England, forms the basis for a paper to be given at the Sixth Symposium on Neutron Dosimetry to be held in Neuherberg, Germany, in October, 1987.

6. Tissue equivalent proportional counter (TEPC) development. New data taking equipment has been tested and computer programs rewritten as appropriate. Work has begun on definitive measurements in NBS reference neutron fields (e.g., bare and moderated californium, filtered beams), which will then be compared with calculation.

7. Figuring out what we're doing. The combination of facility improvements and the coming on-line this year of the MCNP (Monte Carlo) code, made it possible to begin a more detailed study, both experimental and theoretically, of the problem of room scattered neutrons. A clearer understanding of the physics of this aggravating problem is emerging.

Dosimetry for Material Performance Assessment (E. D. McGarry, G. Lamaze, & J. Grundl)

Exposure to neutrons can cause critical performance degradation in materials as different as a silicon wafer and an 8 inch thick plate of steel. Dosimetry methods for assessing the degradation of materials in high-intensity neutron fields are equally diverse. The Neutron Dosimetry Group provides some form of measurement assurance, standardization, methods development, and/or advice for nearly all of the approaches to materials neutron dosimetry pursued in the United States. Because of assorted commercial interests, foreign involvement is also a strong component of this activity.

1. Neptunium neutron fluence standard. For the first time an Np fluence standard was prepared with sufficient activation to allow the 30-year ^{137}Cs activity generated by the Np fission reaction to be calibrated for dosimetry. The Np fission detector is a uniquely effective threshold detector for establishing a neutron exposure component below 1 MeV, and the ^{137}Cs fission product activity is especially useful for monitoring long term exposures.

2. Masses of ultralight fissionable deposits. In many applications solid state track recorders require fissionable deposits of very low mass as for example in the monitoring of 18-month-long power reactor fuel cycles. A cooperation has begun with Westinghouse Corp. to provide mass assay of deposits of three fissionable isotopes in the picogram and sub-picogram range. The accuracy goal is a few percent! The quantity measured is the total number of fissions which take place in the SSTR deposit during a high fluence thermal or fission spectrum irradiation. The final mass is established relative to FIMS, the NBS set of Fissionable Isotope Mass Standards.

3. Development of the SPAD Code Procedure. An NBS procedure for deriving neutron exposure parameters from threshold detector measurements was described in a paper presented in June at the Sixth ASTM/EURATOM Reactor Dosimetry Symposium. The derivation focuses on individual detector results and the option of a coarse group spectrum adjustment when observed detector responses are in modest disagreement with those predicted by an a priori calculation. The procedure is epecially appropriate for threshold detector measurements that have limited information and/or are benchmark referenced.

4. Application of the SPAD procedure. Activation dosimetry experiments have been evaluated with the SPAD Code for the NESSUS reference neutron field at Winfrith, England and for a heavy section steel testing irradiation facility operated by the MEA Corp. at the Univ. of Buffalo. The NESSUS evaluation is part of a more extensive measurement intercomparison of calibration methods in the U. K. and the U. S.

5. Pulsed reactor dosimetry. The Nuclear Effects Laboratory at the White Sands Missile Range has requested help in developing an in-house active fission rate measurement capability connected to NBS standard neutron fields. Plans have been formulated for initial on-site measurements in early FY-88. Fission rate measurements at this laboratory are used to establish neutron dose for electronic components exposed to leakage neutrons from the White Sands fast burst reactor.

Neutron Source Strength Calibration Facility (E. D. McGarry & E. Boswell)

NBS provides routine calibration of neutron source emission rates. Source strengths are calibrated against the National Standard radium-beryllium photoneutron source, NBS-1, to an accuracy of about 1.2 percent by the manganous sulfate bath technique.

1. Calibration service. A total of 15 neutron sources were calibrated for seven U. S. laboratories and installations. This is a threefold increase in source calibrations over last year.

2. Calibration document. The document SP250-18 describing the NBS neutron source calibration facility was completed and published after much unavoidable travail.

Benchmark Neutron Field Facilities and Fission Rate Measurement Capability (E. Boswell, D. Gilliam, J. Grundl, G. Lamaze, & E. D. McGarry)

The foundation of the Neutron Dosimetry Group's service to nuclear technology are the well-specified neutron fields that are maintained as permanent irradiation facilities. Ten separate irradiation sites at NBS provide certified fluences of thermal neutrons (beam or isotropic), of keV neutrons (filtered beams), of sub-MeV distributions (ISNF and the D_2O Moderated Cf Fission Source), or of pure fission spectrum neutrons (Cf or ^{235}U with fluence rates of up to 4×10^{10} n/cm^2 s). Complementing the neutron fields, but with independent applications of its own, is the NBS fission rate measurement capability. At the center of this capability are the NBS set of fissionable isotope mass standard (FIMS) and the double fission chambers in which they are used. Passive and active neutron detectors of all kinds are exposed in these neutron fields for calibration, for measurement assurance projects, for cross section measurements, and for development of new measurement techniques.

1. Facility improvements

- An in-depth review and reworking of the calibration base for the ^{235}U cavity fission source has begun. The complicated path by which the absolute fission neutron fluence rate is established will be set out more explicitly and calculations of irradiation fluences will be handled with computerized spread sheets.

- A new method for monitoring ISNF irradiation fluences has been perfected. It involves neutron fluence transfer from the Cf fission source via fission product activation counting of ^{235}U.

- The calibration documents SP250-13 covering activation foil irradiations at the Cf fission neutron Irradiation Facility and SP250-14 for activation foil irradiations at the ^{235}U Cavity Fission Source were completed and published.

2. Ion chamber testing at 14 MeV. The NBS double fission chamber was used to establish 14 MeV fluence rates for performance test of tissue-equivalent ion chambers. The project is supported by the National Cancer Institute. Early on, an unexpected discrepancy of 15 percent arose between the ion chamber response and that of the fission chamber. Subsequent measurements with a threshold fission reaction (Np) revealed an unsuspected contamination of the 14 MeV fluence by d-D neutrons. Re-analysis with the contamination included resulted in agreement to ±1.1 percent.

Division 536, Technical Activities (cont'd.)

3. Fission chamber monitors. Enlarged versions of the NBS double fission chamber were designed and constructed for use as the primary monitor for exposure rooms at the AFRRI Triga reactor in Bethesda. This new monitoring scheme, which replaces existing ion chambers, will provide an unambiguous response to neutrons in the MeV range for biological specimen irradiations at high fluence rates.

4. Benchmark measurement for criticality safety. The outcome of a series of meetings initiated by managers of the nuclear criticality safety program at DOE is a proposal to create a neutron field at NBS which would benchmark nuclear criticality calculations, especially those which involve fissile materials in water. Initial measurements would establish fission detector responses to the leakage spectrum from various sized water spheres driven by Cf fission sources. As benchmark data for the indefinite future the emphasis will be on accurate definition of geometry and materials in the benchmark, high quality scattering corrections for the fission chamber, and good documentation.

Integral Cross Section Measurements (D. Gilliam, J. Grundl, G. Lamaze & E. D. McGarry)

The standard and reference neutron fields, together with the fission rate measurement capability and the nearby facilities of the Radioactivity Group, conspire to make NBS an excellent place to measure absolute reaction-rate cross sections. As a base program this activity has been pursued for a long time generating influential data for reactor physics as well as neutron dosimetry.

1. Nb(n,n') for high-fluence materials neutron dosimetry. The NBS cavity fission source was the site for a DOE sponsored, multilaboratory cross section measurement that included substantial international participation. Nb is an up and coming dosimetry detector with a 16 year half-life that is attractive for long term sub-MeV neutron exposure monitoring, but not so attractive for differential cross section measurements. Hence, for this detector, a fission-spectrum-averaged cross section is of particular importance. The results of this work were reported at the Sixth ASTM/EURATOM Reactor Dosimetry Symposium in June, 1987.

2. Photofission for correcting fission detector responses. The problem of photofission interference in fission detectors has been around for a long time. To check existing corrections, photofission cross sections in four fissionable isotopes were measured in the new neutron driven gamma ray source designed and constructed by the Neutron Dosimetry Group in cooperation with the SCK/CEN laboratory in Belgium. For these measurements the source was operated first with a cadmium and then with an iron converter. The data obtained will be used to validate and/or adjust calculated correction methods, notable those developed by

C. Eisenhauer at NBS. The measurements were carried out in a cooperation headed by Prof. T. Williamson of the Univ. of Virginia and were reported by him at the ASTM/EURATOM Reactor Dosimetry Symposium in June.

3. Capture reactions in ISNF. Two carefully planned irradiations of 20 activation detectors were carried out in the Intermediate-Energy Neutron Field (ISNF). The purpose was to extend previous capture cross section measurements to include Na, Ag, and Sc, all important reactions for reactor physics applications. Major measurement issues were the perfection of a new method of neutron fluence transfer and corrections for resonance self-absorption. Executing and documenting the irradiations was largely done under contract by a retired group member.

4. Dosimetry reactions in the Cf fission spectrum. Some twelve irradiations have been performed over the last two years at the Cf Fission Neutron Irradiation Facility with the goal of measuring reaction cross sections for nine neutron dosimetry reactions. Absolute neutron fluences were established for each irradiation in analyses completed this year. Preliminary cross sections have been derived for most of the reactions. This activity is carried out with the help of the Radioactivity Section.

Special projects (all group members).

The unique irradiation facilities and measurement capabilities in the Neutron Dosimetry Group coupled with the wide range of institutional involvements characteristic of neutron dosimetry in practice continues to bring on small worthwhile projects and unavoidable responsibilities.

1. Neutron lifetime experiment. In the measurement proposed by the NBS Quantum Metrology Group, the Neutron Dosimetry Group will determine the average linear density of neutron beam downstream from an electromagnetic proton trap. Preliminary experiments carried out this year explored the possibility of using a $^{10}B(n,\alpha,\gamma)$ coincidence technique for absolute thermal neutron counting. More than promising results were obtained and reported in a paper to be published in the Journal of Radioanalytical Chemistry. A visiting scientist from the Univ. of Sussex in England participated in this work.

2. Public knowledge and radiation emergencies. Committee 63 on Radiation Exposure in a Nuclear Emergency, constituted by the NCRP some years ago, recently created a task group to develop guidelines for improving public knowledge about radiation exposure in order to enhance public response during a major radiation emergency. The initial assignment for the Neutron Dosimetry Group appointee to this task group is to identify the pathways by which the public receives information and forms a point of view regarding the hazard of nuclear radiation before and during such an emergency.

3. LiF Chips for megagray gamma dosimetry. The new LiF Chip dosimeter (see Tech. Act.-86) has been tested for neutron sensitivity this year by exposure in the ^{235}U Cavity Fission Source. In the course of this work a new color center was explored and the sensitivity of the dosimeter was extended to the 10 MGy range. In a typical application the correction for neutron response will be 15 to 20 percent. Special LiF-glass encapsulation for the dosimeters are being fabricated prior to shipment to Babcock & Wilcock Co. who have supported this R&D effort. The calibration work has been done in cooperation with the X-ray Physics Group and the results were presented at the ASTM/EURATOM Reactor Dosimetry Symposium in June 1987.

4. Sixth ASTM/EURATOM Reactor Dosimetry Symposium on Reactor Dosimetry. The sixth symposium in this biennial series was held this last June in the U. S. and two group members were strongly involved in preparing and running what has become a rather large international gathering.

5. Nuclear energy exhibit at the National Atomic Museum. The exhibit will focus on the realities of nuclear energy through audio/visual displays and operating devices including the Smithsonian Replica of the Lady Godiva Reactor, a nuclear historic landmark. Our cooperation with the NAM this year concentrated on the preparation of demonstration lectures designed to challenge viewers interests and perception.

V. Radioactivity Group

Introduction

Several long-standing problems were addressed this year. A significant international calibration discrepancy was resolved and methods for assuring the international acceptability of calibration sources were proposed through BIPM and ICRM. A new Research Associate program was established to test measuring abilities in the radiochemistry department of nuclear power plants, and provide a coherent measurement assurance program for commercial suppliers of calibration sources and services. More automated data-processing and certificate-generation programs were developed for calibration services and SRMs. New techniques were investigated and applied. Some of these topics are discussed in the sections that follow. Three significant conferences or workshops were organized.

Program for the Nuclear Power Industry

In response to industry requests, a new program has been organized in cooperation with the U.S. Council for Energy Awareness (CEA). This program, with an additional CEA (formerly AIF) Research Associate now working at NBS, supplies six types of test samples annually to nuclear-power-plant radiochemistry departments as blinds. Activity values measured in the

plants, or by service companies, are compared with the NBS values and a certificate of traceability issued. If measurement results are significantly discrepant, assistance is offered in resolving the difficulty.

Another important aspect of the cooperation is a measurement assurance program for the companies supplying calibration sources to the power plants. In addition to measuring any of the six blind samples supplied each year which are pertinent to calibration sources which they supply, the companies submit a variety of calibrated samples to NBS for verification. The company facilities and procedures will be checked to see if they follow the guidelines being established internationally by the ICRM, with considerable Group input.

At present the program involves 12 utilities (with over 30 existing nuclear power plants), three companies supplying most of the commercial calibration sources, and (directly) one of the major organizations supplying measurement services.

Large-Area Radioactivity Source Measurements (J. M. R. Hutchinson & S. J. Bright)

A counting system for ^{238}Pu and ^{239}Pu x-ray measurements of large area sources was designed and constructed. Its characteristics are being examined and a computer program to be used in the calibration of large-area sources has been developed. This system and the two alpha-particle measurement systems will be used in a traceability program with the central U.S. Air Force calibration laboratory.

After the completion of the planning and investigative phase of the alpha measurements traceability program in FY 1986, two large-area proportional counters, approximately 14-in by 10-in, have been constructed for the purpose of calibrating large-area surface-monitoring standards to be used by the U.S. Air Force in its programs for battlefield monitoring of plutonium. Sources of plutonium on large-area mounts were also constructed and calibrated and issued to the Air Force.

One of the counting systems uses an internal-source proportional counter and the other measures sources external to the counting volume through a thin aluminized mylar window. The "internal" system is used to measure sources in the lower activity ranges. These calibrated sources are then used to establish the efficiency of the "external" counter which is used to measure higher activity sources.

Radon Measurements System (J. M. R. Hutchinson & S. J. Bright)

An updated radon measurements system with four pulse-ionization chambers and two Lucas cells has been designed. Parts have been ordered.

In addition, as a result of reports of a discrepancy in radon calibrations of major laboratories in the U.S., NBS has initiated an intercomparison in a collaboration with these laboratories aimed at resolving this discrepancy.

Comparison of ^{201}Tl Activity Measurements (B. M. Coursey, A. T. Hirshfeld, & D. D. Hoppes)

Until the past year there were significant discrepancies (up to 7%) in international activity calibrations for 73-hour-half-life ^{201}Tl, the radionuclide most used in cardiac imaging. There were consequences for international trade, and for patient dose and image quality for material from different suppliers.

The NBS calibration had been established over 10 years ago, using coincidences between the Auger electrons and x rays from the electron-capture decay detected in a pressurized proportional counter and the subsequent gamma rays selected with a NaI(Tl) spectrometer. The ratio of the coincidence rate to the gamma-ray rate was a measure of the detection efficiency in the proportional counter for a given pulse-height discriminator setting, and this setting was varied to generate points for an extrapolation of the proportional counter rate to 100 percent efficiency.

There are several complications in applying this established technique to ^{201}Tl. The gamma-ray probability is low (about 10 percent), two strong x rays detected simultaneously can sum to about the gamma-ray energy, electron capture in the atomic M shell produces pulses near the detection limit, and corrections must be made for impurities which are always present.

These impurities also make routine measurements with simple instruments such as medical dose calibrators less accurate. For that reason, most radiopharmaceutical manufacturers use gamma-ray spectrometry with efficiency-calibrated systems for analyses. Unfortunately, current tabulations of nuclear data list an old value for the probability of the main gamma-ray which is some six percent different from the present NBS value, although the same authors later published a number in much better agreement.

Concurrent measurements on samples from a common solution at NBS, NPL, and PTB in 1986 showed excellent agreement (<1% difference) with the original NBS activity calibration, as preserved on our reference ionization chambers. A measurement of the gamma-ray probability per decay was also made at NBS, with a careful consideration of uncertainties. The value of 0.0988 ± 0.008 (combined uncertainty as an approximation to one standard deviation) was submitted to the comparison organizer at NPL for publication in a joint report.

SRM 4354 (K. G. W. Inn & F. J. Schima)

A new natural-matrix environmental-level radioactivity Standard Reference Material (SRM 4354) was issued. The freshwater-lake sediment (Gyttja), very rich in organic matter (≃ 50% wt), was certified for ten radionuclides. The SRM is intended for use in tests of measurements of environmental radioactivity contained in similar matrices or evaluating analytical methods, or as a generally available calibrated "real" sample matrix in interlaboratory comparisons.

Tritium Measurements (F. J. Schima and M. P. Unterweger)

The Group internal gas counters were used to calibrate several submitted samples of tritium. Activity levels ranged from 1 pCi mL^{-1} to 5 μCi mL^{-1}.

Uranium in Human Bone Ash (K. G. W. Inn)

NBS participated in an interlaboratory comparison for the determination of low levels of uranium in ashed human bone. The intercomparison was organized by the Environmental Measurements Laboratory (DoE). The results of the intercomparison indicated some serious differences between the laboratories and may indicate a need for future development of an SRM.

Xenon-Isomer Spectrometer (A. T. Hirshfeld, D. D. Hoppes, & F. J. Schima)

The xenon-isomer detector system, using conversion-electron spectrometry of low-activity samples condensed on cooled silicon detectors, is being redesigned with experimental large-area implanted detectors in direct contact with a thermal conductor. This arrangement should avoid thermal contact problems that arose with previous low-background ring-mounted detectors, while increasing the transmission of gamma rays used to assay other xenon radionuclides.

Low-level Radioactivity Study of Calcium Fluoride Dosimetry Materials (B. M. Coursey, K. G. W. Inn, & F. J. Schima)

NBS studied the low-level radioactivity content in calcium fluoride dosimetry materials for the U.S. Naval Sea Systems Command. The purpose of the study was to help them determine if there was excessive radionuclide content in dosimetry materials which may have caused high blank values. The measurements indicated that the radioactivity content did not account for the high blanks for the calcium fluoride materials.

Multilevel Anticoincidence System Design (L. L. Lucas)

The relevance of the new IEEE 488.2 standard to the design of laboratory instrumentation was investigated, with a survey of present commercial use of the 488 bus. It was suggested that experience gained in the application to anticoincidence and control-system design be used to produce an engineers' guide to aid others in the applying of the standard.

Closed-vessel Microwave Dissolution of Environmental Samples (K. G. W. Inn & S. J. Bright)

Because previous studies indicated open-vessel acid dissolutions of environmental samples were unreliable, an investigation was initiated to investigate closed-vessel microwave dissolution techniques. The development of a reliable dissolution method is critical for all future environmental-level radioactivity SRM efforts. Preliminary results are very encouraging.

Comprehensive Data Management (M. P. Unterweger)

A dBase III program was developed to enable final calibration reports and SRM certificates to be generated from initial data with a minimum of operator manipulation and hand entry. The program will also lead to real-time updating of SRM inventories, with eventual interfacing to the Health Physics inventory data base.

Calibration of Germanium Spectrometry Systems (D. D. Hoppes, P. A. Hodge & F. J. Schima)

In order to prepare for the reissue of SRMs 4275 and 4276, the long-lived mixture of ^{125}Sb, ^{154}Eu, and ^{155}Eu popular for the calibration of germanium spectrometry systems, three Group spectrometers are being recalibrated with radionuclides for which gamma-ray emission rates can be established independent of past spectrometry measurements. Many of these radionuclides are short-lived but are available with activity calibrations through the NBS-CEA nuclear medicine program once a year.

Propagation of NBS Radioactivity Calibrations (J. M. Calhoun, B. M. Coursey, & P. A. Hodge)

Traditionally, the basic calibration established at NBS for each radionuclide is supplied to U.S. users through Standard Reference Materials, with a variety of forms and activity levels available to suit particular needs. Calibration services and special measurements are a useful supplement for cases where demand does not warrant SRM production.

However, programs developed in recent years have increased confidence in the calibrations of commercial suppliers; accurate data have been developed which allow good activity measurements with gamma-ray spectrometers for which efficiency-energy relations have been established with unique long-lived mixed-radionuclide SRMs; and techniques have been developed for sufficiently accurate measurement of many radionuclides with commercial liquid- scintillation counters and NBS tritium SRMs.

These factors, coupled with SRM prices that have been increased in an effort to support a greater fraction of the cost of the variety of basic calibration and analysis techniques required, have led to gradual small reductions in SRM sales and less general use of the calibration services. However, there has been a corresponding increase in the traceability tests, especially through the new nuclear-power-plant program.

In the period August 1, 1986 to July 31, 1987, the following actions supplied NBS calibrations to users:

Total radioactivity SRMs distributed	792
Short-lived SRMs supplied under the USCEA(AIF) program for nuclear medicine	202
Scheduled calibrations	24
Special measurements	36
Traceability tests for FDA, NRC, and commercial firms	145

VI. X-Ray Physics Group

Performance Evaluations of DoD Radiological Inspection Systems (20 KeV to 16 MeV) (Julian H. Sparrow)

At the request of the Navy Department, this program carries out the following tasks:

1) Measure and calibrate, every 12 to 18 months, the x-ray outputs of approximately ten 16 MeV Linear Accelerators used for radiological inspection systems by DoD and their contractors;

2) Propose radiological procedures to determine image quality achieved during production and refitting inspection of missiles; approximately every 6 to 12 months, perform an on-site audit of the radiological image quality achieved at the various DoD facilities and product manufacturers; participate in the development of radiological

penetrameters which are used as image quality indicators; and participate in new design of a test specimen used to evaluate both image quality and system performance for high energy CT radiological inspection systems;

3) Assist in the integration of old and new radiological methods, (film, real-time, and tomography), so that image quality is adequate for routine inspections; and

4) Propose radiographic equipment which can be used at the DoD facilities and vendors to monitor the x-ray beam energy fluence and beam position; and assist in the implementation of that equipment.

4-MeV Electron Van de Graaff Accelerator (C. E. Dick)

Use of the 4 MeV electron Van de Graaff accelerator has increased with the applications of the pulsed beams to studies in pulsed radiolysis and chemical kinetics. At the present, experiments are underway to determine the radiation chemistry associated with acid rain. In addition, the dc electron beams are being used to examine the response of beta particle detectors in standardized electron fields. Improvements to the facility are continuing with the construction of a double sector non-dispersive bending magnet system. This system will provide additional beam ports for experimental programs while preserving the pulse shape and beam position for the pulsed electron beams. At present, the final components of this system are under construction and installation will begin shortly.

Digital Energy Subtraction for Biomaterials (C. E. Dick)

The program to investigate the efficacy of digital subtraction imaging is well underway. With the definition of the x-ray beams to be used and the implementation of a new PC based image storage and retrieval system, images of a digital subtraction angiography (DSA) phantom are being recorded. This phantom which contains material that emulates soft tissue, bone, and arterial blood vessels will be imaged with various energy x-ray beams and the resulting video images from a 9-inch image intensifier system will be analyzed using various image analysis and manipulation algorithms.

Photostimulable Phosphors (C. E. Dick)

A program is being implemented to investigate the properties of a new class of x-ray imaging medium, photostimulable phosphors. These phosphors have the property of storing the x-ray image information in deep traps in the phosphor material and then releasing the trapped charge when stimulated with infrared radiation. Experiments are currently in the formative stages to investigate the physical properties of these materials, including the x-ray interaction efficiency, the prompt energy release, the

delayed fluorescence, and the resolution of the systems. In addition, Monte Carlo calculations are underway to investigate some of these phenomena.

Portable Dental X-Ray Imaging Systems (J. H. Sparrow, M. R. McClelland, J. W. Motz)

The X-Ray Physics Group has completed prototypes of portable, dental x-ray imaging systems for field use by the U.S. Army. The smallest prototype, which weighs approximately 16 pounds, is an analog imaging system consisting of a carrying case with a six pound, 55 kilovolt x-ray source, batteries, and self-developing dental x-ray films. A second prototype, which weights approximately 45 pounds, is a non-film system consisting of a carrying case with a real-time intra-oral x-ray image sensor, a frame-grabber, a monitor, and the x-ray source described above. This second system may be used either in an analog or digital format, and images may be instantly displayed on the monitor or stored on tape, floppy disks, or different types of solid-state memories. Future efforts in the program will be directed toward improvements in the x-ray intra-oral image sensor, in the portable x-ray source, and in the image storage and display equipment.

Dosimetry of High-Energy Electron Beams (J. C. Humphreys)

A new project was initiated to explore various techniques for measuring absorbed dose, dose rate, and electron energy in a 25-40 MeV high-intensity electron beam at the White Sands Missile Range (NM) linac. This accelerator facility is utilized essentially 24 hours a day for hardness testing of electronic semiconductor devices by DoD contractors. Because of discrepancies of dosimetry results from internal White Sands measurements, NBS was asked to develop new methods for the measurement of the linac electron beam characteristics. One possible design approach is the use of a multiple foil-array calorimeter with a total thickness greater than the electron range. The temperatures of all foils would be measured as a function of time after irradiation by a single pulse of electrons by means of a fast scan multiplex data acquisition system. Thus, the entire electron depth-dose profile would be determined by dynamically, yielding both total absorbed dose and dose rate. The extrapolated range could then be used to calculate the maximum electron energy. Development of such portable calorimeter systems will enable NBS to provide routine on-site calibration of industrial electron beam facilities. They will eventually enable NBS to provide routine calibration irradiations of customer's dosimeters with electron beams when such facilities become available at NBS.

High-Dose Radiation Calibration Services (J. C. Humphreys)

Documentation of these services has been developed which describes in detail the various services available for the standardization of high absorbed dose measurements of ionizing radiation (photons and electrons only). The first internal report was published in October, 1986, and described the irradiation facilities employed, the dosimeter handling and analysis procedures and the assignment of uncertainties to all aspects of the services. Final revisions of this documentation are nearly complete and the published SP250 document should be available for public distribution shortly.

Industrial Radiology (R. C. Placious)

There is an ongoing program in the X-Ray Physics Group in standards and methods for industrial radiology. These programs include (e.g.) Standards for Quantitative Evaluation of X-Ray Image Quality at Very Low and Very High Energies, Characterization of X-Ray Sources - Kilovoltage and Unsharpness and Standards for Radiographic Film Processing and Storage Of Radiographic Film. Some of this work is collaborative with industrial laboratory based investigators.

Another effort relates to developing a long range program plan for meeting some of the measurement needs of industrial users of real time radiological systems engaged in the inspection of a large variety of industrial materials and components. To this end, a workshop was organized and convened in April 1987 to discuss the NBS role.

VII. 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 in dosimetry of ionizing radiation, principally in medicine and radiation protection. 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 in 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 Gamma-ray Calibration and Measurement-Assurance Services (J. T. Weaver, P. J. Lamperti, & E. L. Bright)

Calibration services for x-ray and gamma-ray measuring instruments continues at approximately the same rate as last year. The number of TLD badge irradiations has increased by a factor of two this fiscal year.

Measurement-assurance tests have been carried out with the five AAPM therapy-level accredited calibration laboratories, with Battelle Pacific Northwest Laboratories, Richland, WA and with the Department of Energy Laboratory, Idaho Falls, ID. Satisfactory agreement was obtained with these laboratories, although a small systematic difference was uncovered with the AAPM laboratories, which has not yet been satisfactorily explained. In these measurement-assurance tests, the test equipment is shipped to the participating laboratory, calibrated by the participant, then returned to NBS for final calibration. Traceability to NBS is maintained by such a measurement test, without the necessity of returning the local standard to NBS, unless the results of the measurement-assurance test show it to be necessary.

The Navy thermoluminescence dosimetry (TLD) measurement-assurance program, sponsored by the Naval Sea Systems Command, continues. NBS receives boxes of 15 TLDs from the Naval Surface Weapons Center and irradiates 12 of them to known exposures with ^{137}Cs gamma rays. The boxes are dispatched to designated Naval units for readout, the results of which are returned to NBS for data reduction and comparison to NBS exposures. The results are sent to the sponsoring agency, who schedules a retest or recalibration for any TLD readout instruments that indicate exposures that differ from the NBS exposure by more than 13 percent. About 285 such boxes, containing 3420 exposed dosimeters, were dispatched during FY87.

It is estimated at the time of writing that 14 brachytherapy sources (small-size gamma-ray sources used in medicine and industry) will have been calibrated during FY87.

The documentation of the NBS calibration procedures for x-ray and gamma-ray measuring instruments, and also the documentation of the NBS calibration procedures, equipment, standards and history for the brachytherapy sources, have been through the appropriate review and are in the final stages of revision. About 100 copies of the above two documents were made available for internal (NBS) use. Final publication will be in the NBS Special Publication 250 series.

The Hewlett-Packard data-acquisition system used with the x-ray and gamma-ray instrument calibration ranges is obsolete and no longer supported, and a breakdown would interrupt the calibration services. As a result, work is underway to interface the DEC 1123 minicomputer with a current-model HP 3497A data-acquisition system using an IEEE-488 bus

connection instead of a serial input. The DEC 1123 would then be used to control essentially all aspects of the instrument calibration.

Another round of in-house capacitor comparisons has taken place, utilizing four capacitors recently calibrated by the capacitance group at NBS. These in-house comparisons have been improved by the interfacing of a computer with a precision power supply and a precision digital voltmeter. The new technique provides superior statistical results and to a large degree eliminates human bias. Recalibration of the laboratory working standard barometer, and comparison of that with other laboratory barometers, has been completed.

Assistance in use of the ^{60}Co and ^{137}Cs gamma-ray ranges was provided to the Environmental Measurement Laboratory of the Department of Energy, New York, NY for their special international intercomparison of TLDs. Assistance was also provided to the X-Ray Physics Group and a guest scientist from Israel for their study of the intensifying effects of metallic screens in industrial radiography. Increased heavy use for radiation chemistry by other NBS groups continues on the vertical gamma-ray ranges.

High-Energy Electron and Photon Measurement-Assurance Services (C. G. Soares & E. L. Bright)

Users of medical linear accelerators for cancer teletherapy need assurance that their machines are delivering the required radiation dosage. To meet this need, NBS offers a measurement-assurance service that involves mailing to the users passive dosimeters to be irradiated in a prescribed geometry and returned to NBS for evaluation of the absorbed dose delivered. For this service, ferrous-ferric (Fricke) dosimeters are used at present. There were four mailings of Fricke dosimeters in FY87, involving 62 sets of participants. Two batches of dosimeters were prepared. In principle, each dosimeter can be used as many times as it takes to accumulate 200 to 300 Gy (20 to 30 krad). In order to conserve time, and thus cost to the participants, the tests are administered simultaneously to as many participants as the batch size permits. To help in preparing summary reports and identifying trends, the test results from the entire 20-year history of the service have been entered into a data base.

Documentation of the NBS procedures for the Fricke measurement-assurance service is complete and in the process of being published.

Standard Monoenergetic Electron Beams (C. G. Soares)

NBS has been requested by the radiation protection community to establish standards for and assist in the development of methods of measuring the beta-particle radiation fields that are found in nuclear

power installations. Beta-particle detection instrumentation is currently being calibrated at NBS using only broad-spectrum radionuclide sources. In order to determine, in detail, instrument response as a function of energy NBS has developed a set of accelerator-produced nearly monoenergetic electron beams. The beam monitoring and control system described in the previous year's annual report has been completed. Test results indicate that its use has reduced the random uncertainties in instrument-response measurements from the previously unacceptable 10-15 percent to an acceptable level of less than 5 percent. The system's flexibility was demonstrated when a need for radiation-processing dose levels (10 kGy, 1 Mrad) was expressed. By moving the monitors away from the beam axis, it was possible to monitor dose rates of 10 Gy/s, showing that a seven-decade dynamic range in dose-rate monitoring is possible with the system. Using this modified arrangement, high-dose irradiations were performed for Humphreys and McLaughlin of the X-Ray Physics and Radiation Chemistry Groups as well as for an outside user who paid for the service.

Beta-particle Source Calibration and Associated Measurement-Assurance Services (J. S. Pruitt)

The NBS extrapolation chamber has been used to calibrate four ophthalmic applicators for absorbed dose to water at the applicator surface. Each calibration was accompanied by quality-assurance measurements with the NBS applicator SN0258. The quality-assurance parameter is the position of the high-voltage electrode obtained by extrapolating to zero air gap the measurements made at air gaps between 0.5 mm and 2.5 mm. Since February of 1986, when quality-assurance measurements were begun, that position has varied by no more than 0.02 mm. In June of 1987, the source alignment mechanism was improved so that the variation of the high-voltage electrode position is expected to be even smaller in the future.

The PTW extrapolation chambers have been used for a variety of purposes, including calibration-at-a-distance of sources owned by several different customers. The first of these was a physically large source (44 cm x 44 cm x 7 cm) made from the dried coolant of a reactor at the Palo Verde Nuclear Generating Station in Arizona. Preliminary investigations in Arizona had shown that the principal beta-particle-emitting radionuclide was ^{124}Sb, which has a half-life of about 60 hours. Measurements of dose rate were made over a period of about two weeks at several positions near the source and at several absorber depths.

A plaque source of ^{99}Tc was calibrated at distances of 0.5 cm, 4 cm, and 10 cm. More recently, calibration of a complete set of Amersham-Buchler beta-particle sources has been undertaken. This set of four sources consists of the same radionuclides as the NBS set, two of $^{90}Sr + ^{90}Y$, and one each of ^{204}Tl and ^{147}Pm. These were calibrated at the normal distances, the first three at a distance of 30 cm and the ^{147}Pm source at 20 cm.

All of the source calibrations-at-a-distance consist of current measurements with a PTW extrapolation chamber, and are corrected for perturbations caused by the presence of the chamber, as well as for variations from reference conditions of time, altitude, and humidity. Most of the eight chamber corrections have been well documented for the Amersham-Buchler set of sources at the standard source distances, but considerable time was spent determining the proper corrections for ^{99}Tc at the distances used. (For the ^{124}Sb source, the dose rates were never larger than 10 μGy/h (1 mrad/h) and the standard deviations ranged from 4% to 30%, too large to warrant investigating the exact size of corrections that are normally no larger than 1%.).

The PTW extrapolation chambers have been used in a program to determine chamber side-scatter corrections for the three Amersham-Buchler radionuclides at nonstandard distances. For ^{204}Tl and ^{147}Pm, the result to date is verification of the published data at the standard distances, but for $^{90}Sr + ^{90}Y$, measurements have been completed for five distances between 20 cm and 40 cm, showing that the correction varies from 0.45 to 0.29% per mm of air gap over that range.

When the Amersham-Buchler sources were delivered to NBS in January 1983, they had been calibrated in terms of absorbed dose to tissue at the tissue surface, by the Physikalish Technische Bundesanstalt (PTB) of Braunschweig, W. Germany. The fully corrected NBS surface calibrations of these sources agree with the PTB calibrations within 4% for ^{147}Pm, 2% for ^{204}Tl, and 1% for $^{90}Sr + ^{90}Y$.

Measurements with the ^{147}Pm source have shown that, during normal operation, the retracted shutter intercepts part of the beta-particle beam during irradiation, even though it lies about 1 cm outside of the truncated cone connecting source and chamber. This is caused by excessive, air scatter, which makes the beam barrel-shaped rather than conical. When the shutter is completely removed, the field is flat over an 8-cm diameter at a distance of 20 cm. When the shutter is in place, but retracted to one side, the dose rate varies by 5% across that central 8-cm area.

Absorbed dose calorimetry (S. R. Domen)

Medical and industrial applications of ionizing radiation are quantified in terms of the physical quantity absorbed dose, which is the energy absorbed per unit mass in the material of interest. The calorimeter, which measures absorbed energy in terms of the temperature rise, is the logical standard of absorbed dose. NBS has developed a series of calorimeters as part of a program to develop reliable national measurement standards for absorbed dose. One of these NBS calorimeters, the water calorimeter, which measures the temperature rise due to radiation directly in water, has aroused much interest, and has been studied in a number of

standards laboratories and universities. One of the persistent problems, which has not received adequate attention, is the effect of convection on the accuracy of temperature readings by the tiny thermistors. An experiment was devised to study this phenomenon using controlled flow past thermistors operated at various power levels. The results of this experiment will allow operation of water calorimeters under efficient conditions and without loss of accuracy, when convection is present. A report of the work is in preparation.

Preliminary tests of a calorimeter made of A-150 plastic (a tissue substitute) have shown adequate behavior except for thermal drifts apparently caused by contact potentials at the connectors. Connectors with gold-plated contacts are being prepared. The completed calorimeter will be tested in the NBS ^{60}Co beam for comparison of calorimeter and ionization-chamber measurements. A similar comparison will be made at another institution using a beam of 15-MeV neutrons.

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

It is important to test the adequacy of current clinical protocols to provide accurate photon and electron dosimetry for applications to high-energy cancer therapy. These tests would compare measurements made with ionization chambers calibrated according to prescribed protocols to measurements performed with an absorbed-dose calorimeter. We propose to use the electron beam of the NBS racetrack microtron to produce collimated beams of high-energy protons and electrons, which will simulate those applied clinically to treat cancer.

A separate beam line will be used to transport the electron beam to a transmission window from which it will enter a target, filter, and collimator assembly. The electron beam current and energy required will range from about 180 μA at 5 MeV to about 1 μA at 35 MeV. The apparatus which has thus far been designed and constructed includes the target, filter, and collimator assembly, a special alignment and support table for this assembly, and a rolling table with a remote-controlled translation platform for positioning the phantoms and dosimeters. Several of the beam-line components have been ordered. Funding is being sought to purchase a water phantom with a three-dimension, remote-controlled translation system and its computer for control and data analysis, to purchase the remaining beam-line apparatus, and to install the equipment in a shielded room adjacent to the accelerator.

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

Neutron radiation therapy is being clinically tested at several cancer treatment centers in the United States and at other centers worldwide. To facilitate the exchange of clinical information between treatment centers, it is essential that the U.S. neutron dosimetry standards be accurate and consistent with the international standards system. The dosimetry program, sponsored by the National Cancer Institute, aims at improving the accuracy and consistency of absorbed-dose measurements for neutron therapy by developing national dosimetry standards and providing improved data on neutron interactions in tissue and tissue-like materials. NBS will provide these standards as it has provided and continues to provide similar standards for photons and electrons.

Tissue-equivalent ionization chambers, in combination with low-neutron-sensitivity gamma-ray dosimeters, are accepted as the most reliable instruments for clinical neutron dosimetry. We have under study such a system of instrumentation. Its accuracy will be assessed by comparing it to other instruments of the same type and of different types. Thus far, the NBS ionization chambers have been compared to a similar set of dosimeters from the Bureau International des Poids et Mesures and to instruments of other national standards laboratories. At NBS we have also favorably compared the ionization chamber dosimetry method of measuring neutron kerma to a determination of this quantity made from measurements of neutron fluence combined with calculated kerma factors. This latter comparison will be repeated using monoenergetic 15-MeV neutrons, an energy more appropriate for developing a neutron standard. A comparison between the ionization chamber method and a tissue-equivalent calorimeter is also planned using the intense 15-MeV neutron beam available at a remote site. Agreement between the three independent methods and with the measurements of other standards laboratories will assure the accuracy and consistency of the U.S. dosimetry standards for neutron therapy.

Theoretical support for the experimental standards program is aimed at improving the physical data and correction factors needed to interpret the physical measurements. These data and factors include the mean energy required to produce an ion pair, kerma factors, and mass stopping powers.

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

Work performed under this contract with the Armed Forces Radiobiology Research Institute (AFRRI) aims to improve the accuracy and long-term consistency of neutron and gamma-ray dosimetry at the AFRRI research reactor by consultations with a group of NBS scientists and by providing specific dosimetry services. This effort is needed to support the radiobiological studies at AFRRI because of the relatively frequent (approxi-

mately 2-year) turnover of scientific military personnel at AFRRI. It is essential that accurate dosimetry methods support the radiobiological experiments in order to relate this research to similar work at other laboratories.

During the past year we have designed and installed a ^{252}Cf radiation source housed in a special shield for use in checking the large variety of ionization chambers at AFRRI for proper operation. This source, which emits neutrons by spontaneous fission, is necessary to test the neutron response of the dosimeters used at the AFRRI reactor. Benchmark measurements of the AFRRI ionization chambers have begun and will be continued after needed modifications to the check-source cask have been completed.

An improved monitoring system for the radiation fields produced in the reactor exposure rooms has been designed. The fission chambers needed to implement this system were designed, constructed, and installed. Testing and calibration of these chambers is in progress.

To verify the accuracy of the AFRRI reactor dosimetry, and as a training exercise for new military dosimetrists at AFRRI, a comparison of neutron and gamma-ray dosimetry in free air and in two sizes of monkey phantoms was carried out. This work compared the instruments, measurement techniques, and calculation procedures of the NBS and AFRRI scientists.

VIII. Office of Radiation Measurement

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. The Office assists the technical organizational components of the Ionizing Radiation Division 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, through a national system of secondary standards laboratories. 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, Health Physics Society, and the Conference of Radiation Control Program Directors. The Office participates in collaborative programs with these organizations to satisfy specific measurement quality assurance requirements.

Radon (R. Collé & J. M. R. Hutchinson)

The Office continued to collaborate with members of the Radioactivity Group on projects that include upgrading and replacement of the primary radon measurement system; continuing work on developing a transfer standard for radon flux density measurements; new calibrations of a NaI(Tℓ) detector system for direct assay of radon samples contained in spherical glass ampoules; and measurement intercomparisons with laboratories that maintain an independent radon calibration capability.

Work on replacing the old primary radon measurement system has started. Based on our specifications, four new pulse ionization chambers are being custom-built by Reuter-Stokes. All ancillary electronics for power and signal processing and a computer for the system are being assembled. The extensive gas handling and purification manifold was designed, and construction will begin shortly. The construction and initial calibrations of the system will be completed in 12 to 18 months.

The Office provides oversight for the project to develop a large surface area flux density standard. A 40-cm prototype is fully operational. Preliminary calibrations for the constrained flux density have been completed; and the efficacy of performing a direct calibration for the unconstrained flux density was demonstrated. The latter is an unexpected significant technical achievement since it will allow use of the standard without having to rely on the adequacy of a diffusion model for the standard. Confirmatory calibrations under both constrained and unconstrained conditions continue.

A NaI(Tℓ) well counter was cross calibrated against the primary radon measurement system. This detector used in conjunction with spherical glass ampoules was shown to be very reproducible and fairly independent of geometry. It has a wide dynamic range and can be used for radon samples from the picocurie level to a 100 nCi level. This system was used for a recent measurement intercomparison of all laboratories within the U.S. that maintain an independent calibration capability.

Measurement Uncertainties (R. Collé)

Significant progress on developing an international guidance document for the treatment and reporting of measurement uncertainties was made in the past year under the leadership of a member of the Office. The document is being developed by a joint international working group which represents the International Standardization Organization, the International Electrotechnical Commission, the International Bureau of Weights and Measures, and the International Organization of Legal Metrology. A first draft was completed in June, and presently is under revision. The next version will be completed in the next few months and then distributed to a larger audience for comment.

Input and views of the US industrial metrology community are being sought through an ad hoc advisory group of nearly 70 members. An all-day meeting of this group was held at NBS to keep the US industry aware of the international activities, as well as to encourage their participation in the development and dissemination of the final guidance document.

Private-Sector Calibration Laboratories (E. H. Eisenhower, C. G. Jones, & H. T. Heaton)

In July 1987 the Executive Board of the Health Physics Society (HPS) gave final approval to the policy, procedures, and criteria that will be used in a program for accreditation of laboratories that calibrate ionizing radiation survey instruments. This program is an outgrowth of a workshop held by NBS in 1984. Since then the Office and the HPS collaboratively developed the criteria to be used for evaluation of candidate laboratories. NBS is represented on the HPS Operations Group that is responsible for carrying out the policies and procedures of the program, including a review of quality assurance procedures used by candidate laboratories and an on-site assessment of each laboratory. The Office will conduct periodic proficiency tests of candidate and accredited laboratories, beginning in early 1988. The entire program will be self-supporting through fees paid by accredited laboratories. It will initially be limited to x and gamma radiations, but is expected to expand to other radiations in the future.

With the increasing number of secondary laboratories, it will be necessary to use the same instrument for testing the proficiency of several laboratories without recalibration by NBS. Thus the Office is developing procedures to monitor continued proper operation of the test instrument before sending it to the next participant. This includes developing quality control procedures for all NBS equipment used to monitor the test instrument.

The Office in cooperation with the Radiation Measurements Committee of the CRCPD is revising the "Directory of Commercial Calibration Services for Ionizing Radiation Survey Instruments". As part of the revision, the results from a questionnaire were entered into data base files suitable for analysis with DBASE. This allows specific searches of the services offered by the calibration companies. The proposed final draft is awaiting any editorial changes by the Radiation Measurements Committee.

Federally-Owned Calibration Laboratories (E. H. Eisenhower & C. G. Jones)

In December 1986 representatives of various federal departments and agencies met at NBS to discuss the possibility of developing a program that would lead to formal recognition of the competence of federally-owned calibration laboratories. It was unanimously agreed that development

should proceed, and that performance criteria should be prepared for a broad range of calibrations (i.e., survey instruments, x-ray diagnostic instruments, dosimeter irradiations, and source calibrations). A first draft of those criteria was subsequently developed for secondary laboratories, and is now being refined. It is planned that criteria for tertiary laboratories will be developed in the near future. Various possibilities for formal recognition have been considered, including accreditation under the NBS National Voluntary Laboratory Accreditation Program (NVLAP). The Office is coordinating program development, leading the preparation of criteria, will conduct proficiency tests, and will participate in on-site evaluation of candidate secondary laboratories. Departments and agencies actively involved are DOE, DOD, FDA, and FEMA, represented by a total of 21 individuals from 18 laboratories.

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

The Office is continuing to provide technical assistance to five state-operated calibration labs (IL, SC, WA, CA, and AR). These labs provide calibrations of instruments used for diagnostic x-ray machine compliance measurements and for x-ray and gamma-ray radiation protection measurements. The lab in Springfield, IL continues to be accredited by the Conference of Radiation Control Program Directors (CRCPD) for both x-ray and gamma-ray calibrations. The lab in Seattle, WA is accredited by the CRCPD for gamma-ray calibrations. Their x-ray machine and gamma sources have been installed on a turntable mechanism to allow any of the radiation sources to be used with the calibration bench. They are presently making the preliminary measurements necessary to characterize the x-ray equipment. The lab in Columbia, SC has completed their protocol for x-ray calibrations and is awaiting an on-site visit from the CRCPD as the last step before accreditation. The lab in Sacramento, CA has been simultaneously developing their x-ray and gamma-ray facilities. Emphasis is now being placed on the x-ray facility. The measurements necessary to characterize this equipment are nearly complete and the first draft of the lab protocol for x rays has been written. The lab in Fayetteville, AR continues to place major emphasis on neutron calibrations. Both bare and moderated Cf sources are available at both high- and low-level calibration facilities. This lab recently participated in a performance test using an instrument as the transfer standard. The results of the test showed an unexpectedly large deviation at the high-level facility. Further investigations attribute this deviation to a scatter problem. The results show the importance of performance tests to help a lab discover unsuspected problems in their calibration procedures.

Instrument Calibration Computer Code (H. T. Heaton)

The computer code used to assist the state-sector labs in their instrument calibrations and routine in-house QC programs has been field tested for the past year by the CA lab. Their suggested changes are being incorporated into the code. At the same time the code is being rewritten from an interactive BASIC to a compiled BASIC. Also additional subroutines are being written to include more QC programs for the equipment used in the calibration and for calibrating more types of instruments. The code is specifically geared to the equipment common to the state-sector labs and, in fact, the CA lab is developing their protocol around the computer code. Once all the state labs are using this code, it will be much easier to monitor the problems in lab performance by having them transmit the files containing their QC data for evaluation by Office personnel. Finally, the code is being extended to include the procedures necessary for the Office to monitor the instrument used to test the secondary level laboratories.

Fixed-Geometry Radiation Source-Detector System (C. G. Jones)

To allow laboratories that calibrate portable ionizing radiation detection instruments to conduct proficiency tests, routine quality control, and calibrations with greater efficiency, a prototype of a source/detector system is being designed and developed. This type of system will ultimately be used in secondary laboratories for routine testing of the laboratory's demonstrated proficiency in calibrating radiation protection instrumentation. This device, or jig, will be used to maintain mechanically the correct position between the survey instrument being calibrated and the radiation source being used for such calibrations. One type of source/detector system that has been designed would enable the interchange of radioactive sources within the jig to allow the user to calibrate and test survey instruments for different radiation types, energies, and intensities. This system is being designed to assure that it will have the broadest potential range of uses and therefore maximum utility.

Environmental Dosimetry (H. T. Heaton, J. T. Weaver, & C. G. Soares)

This is a joint program between NBS and personnel from the DOE Environmental Measurements Laboratory (EML) to determine potential effects of the type of radiation used to calibrate environmental dosimeters. In the past EML has conducted 8 international intercomparisons of environmental dosimeters in which the participants sent in dosimeters to be exposed to a known amount of radiation in a laboratory setting. EML has consistently found that those participants who use Cs to calibrate their readout unit have a systematically lower result than those who use Co for their calibration. This difference is independent of the type of radiation used

in the EML lab to irradiate the dosimeters (Co, Cs, and Ra). This difference is just statistically significant and, if it really exists, there are potential implications for all dosimetry applications. To investigate this effect, a special intercomparison was arranged in which the dosimeters will be irradiated to known amounts of radiation in Cs and Co beams. The irradiations at NBS and EML have been completed and the dosimeters returned to the participants for their readout. In addition to the irradiations done at NBS, and to act as a control, NBS submitted dosimeters as a participant. These will be read out by our Dosimetry Group.

SPONSORED WORKSHOPS, CONFERENCES AND SYMPOSIA

Division 536, Ionizing Radiation

P. Cerutti, Chairman, M. G. Simic, O. F. Nygaard, Co-Chairmen, Second Conference on Anticarcinogenesis and Radiation Protection, Gaithersburg, MD, March 9-12, 1987.

J. F. Weiss, Chairman, M. G. Simic, Co-Chairman, Perspective in Radioprotection, Bethesda, MD, March 13-14, 1987.

M. G. Simic, Chairman, C. von Sonntag, and J. F. Ward, Co-chairmen, 4th International Congress on Oxygen Radicals, La Jolla, CA, June 27-July 4, 1987.

J. M. Calhoun and B. M. Coursey planned and conducted a workshop on "Design and Calibration of Ionization Chambers for use in Nuclear Medicine" which was sponsored by the NBS Radioactivity Group, the International Committee for Radionuclide Metrology, and the Center for Devices, U.S. Food and Drug Administration, on November 19-20, 1986. This workshop provided a forum for the designers of these chambers, pharmaceutical suppliers, commercial source manufacturers, and representatives from national standards laboratories, to discuss methods of improving the accuracy of assays made in hospitals.

J. M. R. Hutchinson and the Low-level Techniques Group of the International Committee for Radionuclide Metrology (ICRM) organized a two and one-half day symposium, with Hutchinson as chairman, in Wurenlingen, Switzerland on June 10 to 12, 1987. The symposium provided a forum for the exchange of information regarding the current status of five areas of concern to scientists in the field of low-level radionuclide metrology: standards, quality control, regulatory concern, applications, and techniques. The meeting was hosted by the Swiss Federal Institute for Reactor Safety. Thirty-nine papers were presented. The proceedings will be published in Environment International.

K. G. W. Inn organized and conducted the 32nd Annual Conference on Bioassay, Analytical and Environmental Radiochemistry, at NBS, October 21-23, 1986. The purpose of this conference was to bring together researchers and analysts from government, the private-sector, the nuclear power industry, contractors, and academia to openly and frankly discuss new, improved, or even problem analytical methods, and to interpret subsequent data and evaluate health and environmental implications. The scope of the conference included in-vivo and in-vitro bioassay, analytical method development, distribution and partition of radionuclides in the environment, and modeling and health significance of radionuclide pathways to humans.

INVITED TALKS

Division 536, Ionizing Radiation

Berger, M. J. and Seltzer, S. M., A series of lectures for the course "Monte Carlo Transport of Electrons and Photons Below 50 MeV," International School of Radiation Damage and Protection at the Ettore Majorana Center for Scientific Culture, Erice, Sicily, September 24 - October 3, 1987.

Bergtold, D. S., Alessio, H., Cutler, R. G., and Simic, M. G., "Measurement of Biomarkers for DNA Damage by GC/MS," Fourth International Congress on Oxygen Radicals, LaJolla, CA, June 27-July 4, 1987.

Bergtold, D. S., "The Oxygen Effect in Radiation Biology," Fourth International Congress on Oxygen Radicals, LaJolla, CA, June 27-July 4, 1987.

Calhoun, J. M., "NBS Measurements of Sample Geometry Effects on Ionization Chamber Calibrations," ANS Winter Meeting, Washington, DC, November 18, 1986.

Caswell, R. S., "Neutron Dosimetry and Microdosimetry, Theory and Experiment," Institute of Atomic Energy, Beijing, China, June 6, 1987.

Caswell, R. S., "Neutron Energy Deposition in Biological Materials," Institute of Atomic Energy, Beijing, China, June 9, 1987.

Caswell, R. S., "Research and Standards Program of the Ionizing Radiation Division of the National Bureau of Standards," Institute of Atomic Energy, Beijing, China, June 9, 1987.

Caswell, R. S., "Neutron Dosimetry and Microdosimetry, Theory and Experiment," National Institute of Metrology, Beijing, China, June 10, 1987.

Caswell, R. S., "Research and Standards Program of the Ionizing Radiation Division of the National Bureau of Standards," National Institute of Metrology, Beijing, China, June 10, 1987.

Caswell, R. S., "Research and Standards Program of the Ionizing Radiation Division of the National Bureau of Standards," Beijing University, Beijing, China, June 11, 1987.

Caswell, R. S., "Neutron Energy Deposition in Biological Materials," Research Institute of Xian Petroleum Exploration Instrument Complex, Xian, China, June 16, 1987.

Division 536, Invited Talks (cont'd.)

Caswell, R. S., "Research and Standards Program of the Ionizing Radiation Division of the National Bureau of Standards," Research Institute of Xian Petroleum Exploration Instrument Complex, Xian, China, June 16, 1987.

Caswell, R. S., "Research and Standards Program of the Ionizing Radiation Division of the National Bureau of Standards," Fudan University, Shanghai, China, June 18, 1987.

Caswell, R. S., "Neutron Dosimetry and Microdosimetry, Theory and Experiment," Fudan University, Shanghai, China, June 18, 1987.

Collé, R., "Measurement Uncertainties," Analytical Chemistry Seminar, NBS, April 21, 1987.

Collé, R., "Measurement Uncertainties: Converging on an International Consensus," Measurement Science Conference, Irvine, CA, January 29, 1987.

Domen, S. R., "Development, Investigation, and Status of an Absorbed Dose Water Calorimeter," Conference on Application of Accelerators in Research and Industry, Denton, TX, November 10-12, 1986.

Eisenhower, E. H. (with R. Collé and H. T. Heaton), "National Measurement Quality Assurance Programs," 32nd Annual Conference on Bioassay, Analytical, and Environmental Radiochemistry, NBS, October 21, 1986.

Eisenhower, E. H., "Measurement Quality Assurance," 25th Hanford Life Sciences Symposium, Richland, WA, October 21, 1986.

Eisenhower, E. H., "Status and Plans for a National System of Secondary Calibration Laboratories," Department of Energy Workshop on Instrument and Dosimeter Calibrations, Richland, WA, October 24, 1986.

Eisenhower, E. H., "Measurement Quality Assurance and Laboratory Accreditation for Ionizing Radiation," Region 3 Meeting of the National Conference of Standards Laboratories, Lexington Park, MD, January 21, 1987.

Eisenhower, E. H., "Measurement Quality Assurance through a National System of Secondary Laboratories," Workshop and Symposium of the National Conference of Standards Laboratories, Denver, CO, July 14, 1987.

Eisenhower, E. H., "The Role of Traceability in Measurement Quality Assurance," Health Physics Society Summer School, Pocatello, ID, July 16, 1987.

Heaton, II, H. T., "Controlling the Calibration Process at Secondary Level Laboratories," HPS Summer School at Idaho State University, Pocatello, ID, July 14, 1987.

Division 536, Invited Talks (cont'd.)

Hoppes, D. D., "Ionizing Radiation Measurement Services at NBS," National Conference of Standards Laboratories Workshop and Symposium, Denver, CO, July 16, 1987.

Hubbell, J. H., "Industrial, Agricultural, and Medical Applications of Radiation Metrology: Current Status and Prospects for the 1990's," 6th Pacific Basin Nuclear Conference, Beijing, PRC, September 9, 1987.

Hubbell, J. H., "Survey of Photon Attenuation Coefficient Data 10 eV to 100 GeV and the Major Individual Processes for Interaction of Photon with Atoms," Institute of Applied Physics and Computational Mathematics, Beijing, PRC, September 10, 1987.

Humphreys, J. C., "ASTM Dosimetry Activities: A Progress Report," 6th International Meeting on Radiation Processing, Ottawa, Canada, May 31 - June 5, 1987.

Jovanovic, S. V., and Simic, M. G., "Redox Properties of Oxy and Antioxidant Radicals," 4th International Congress on Oxygen Radicals, LaJolla, CA, June 27-July 4, 1987.

Karam, L. R., "Radiation-Induced Cross-links in Biological Model Systems (DNA and proteins)," 8th International Congress of Radiation Research, Edinburgh, UK, July 15-19, 1987.

Karam, L. R., "Alcohol and Free Radicals," 1st Congress of the European Society for Biomedical Research on Alcoholism, Paris, France, September 18-19, 1987.

Lucas, L. L., "Uncertainties Associated With the Calibration and Use of NBS Pressurized $4\pi\gamma$ Ionization Chamber A," American Nuclear Society Winter Meeting, Washington Sheraton, Washington, DC, November 18, 1986.

McLaughlin, W. L., "Radiation Dosimetry," International Conference on Sterility Assurance, Travenol Laboratories, Round Lake, IL, September 17, 1986.

McLaughlin, W. L., "Radiation Sterility Assurance," International Conference on Sterility Assurance, Travenol Laboratories, Round Lake, IL, September 18, 1986.

McLaughlin, W. L., "NBS Reference Standards and Traceability of High-Dose Measurements in Electron Beams," IAEA Consultants Meeting on Electron High-Dose Intercomparison, International Atomic Energy Agency, Vienna, Austria, October 30, 1986.

Division 536, Invited Talks (cont'd.)

McLaughlin, W. L., "Dosimetry in the Radiation Treatment of Foods," World Health Organization Working Group on Health Impact and Control Methods of Irradiated Foods, Gesellschaft für Strahlen-und Umweltforschung, Neuherberg, München, Federal Republic of Germany, November 18, 1986.

McLaughlin, W. L., "Electron Beam Dosimetry," 3M Seminar, 3M ECC Products Laboratory, Burlington, MA, November 20, 1986.

McLaughlin, W. L., "Electron Beam Dosimetry With Thin Films," Seminar, GAF Chemicals Corporation, Wayne, NJ, December 9, 1986.

McLaughlin, W. L., "Calibration of Thin-Film Dosimeters in Electron Beams by Calorimetry," Accelerator Department Seminar, Risø National Laboratory, Roskilde, Denmark, November 11, 1987.

McLaughlin, W. L., "Dosimetry System," Irradiation Sterilization Seminar, IOTECH, Inc., Thornton, CO, January 27, 1987.

McLaughlin, W. L., "Optical Waveguide Dosimetry," FEMA Special Facility Seminar, February 23, 1987.

McLaughlin, W. L., "Chemical Dosimetry," Committee on Interagency Radiation Research and Policy Coordination, Gaithersburg, MD, April 28, 1987.

McLaughlin, W. L., "Radiation Dosimetry for Sterility Control of Pharmaceuticals," National Cancer Institute Seminar, Ft. Detrick, MD, May 7, 1987.

McLaughlin, W. L., "Radiation Effects on Microbes and Natural Products," NIH, National Cancer Institute, Bethesda, MD, May 11, 1987.

McLaughlin, W. L., "A Thin-Film Recording Medium for Use in Food Irradiation," 6th International Meeting on Radiation Processing, Ottawa, Canada, June 2, 1987.

McLaughlin, W. L., "Cellulose Diacetate Film Dosimeter," 6th International Meeting on Radiation Processing, Ottawa, Canada, June 3, 1987.

McLaughlin, W. L., "Radiochromic Dosimetry for Validation and Commissioning of Industrial Radiation Processes," 6th International Meeting on Radiation Processing, Ottawa, Canada, June 4, 1987.

Placious, R. C., "A Look at the Long Term Role for the National Bureau of Standards in Real Time Radiology Standards," ASNT Topical Conference Automating and Advancing Radiographic NDG, Wilmington, DE, August 11, 1987.

Division 536, Invited Talks (cont'd.)

Seltzer, S. M., "Electron-Bremsstrahlung Space Shielding Calculations," LBL/DOE/NASA Workshop on High Energy Accelerator and Space Radiation, Berkeley, CA (February 17-19, 1987).

Schrack, Roald A., "NBS Research on Resonance Neutron Radiography," Workshop on Neutron Resonance Radiography, Los Alamos, NM, July 27-29, 1987.

Simic, M. G., "Autoxidation of Linoleic Acid and Its Prevention by Antioxidants," University of California, Berkeley, CA, November 12, 1986.

Simic, M. G., "Mechanisms of Free Radical Damage to DNA Bases," Stanford University, Stanford, CA, November 13, 1986.

Simic, M. G., "Mechanisms of Repair of Free Radicals by Sulfhydryls and Implications for Radiation Protection," University of California, San Francisco, CA, November 14, 1986.

Simic, M. G., "Chemistry of Irradiated Foods," CIRRPC, Washington, DC, December 1, 1986.

Simic, M. G., "Free Radical Mechanisms of DNA Damage," Center for Devices and Radiobiological Health, FDA, Rockville, MD, January 9, 1987.

Simic, M. G., "Repair Mechanisms of DNA Damaged by Free Radicals," Pharmacology Dept., University of Southern California, Los Angeles, CA, February 19, 1987.

Simic, M. G., "Electron vs. H-atom Transfer in Chemical Repair," 2nd International Conference on Anticarcinogenesis & Radiation Protection, Gaithersburg, MD, March 8-12, 1987.

Simic, M. G., "Mechanisms of Anticarcinogenesis," American Industrial Health Council, Washington, DC, March 25, 1987.

Simic, M. G., "Chemistry of Irradiated Food," American Institute of Physics Annual Meeting, April 21, 1987.

Simic, M. G., "Post-irradiation Dosimetry," CIRRPC, Gaithersburg, MD, April 28, 1987.

Simic, M. G. and Jovanovic, S. V., "Interaction of Vitamin E and Physiological Antioxidants," 4th International Congress on Oxygen Radicals, La Jolla, Ca, June 27-July 4, 1987.

Unterweger, M., "Ionization Chambers in the National Bureau of Standards Radioactivity Group," ANS Winter Meeting, Washington, DC, November 11, 1986.

PUBLICATIONS

Division 536, Ionizing Radiation

Abdel-Rahim, F., Eid, S. A., Souka, N., and McLaughlin, W. L., The Radiolysis of Bromophenol Blue In Aqueous Solutions, Radiat. Phys. Chem. 27, 211-217 (1986).

Barnea, G. and Dick, C. E., Coupled Electron/Photon Monte Carlo Calculations of X-Ray Scattering with Applications in Industrial Radiography, NDT International 20, 111 (1987).

Barnea, G., Berger, M. J., and Seltzer, S. M., Optimization Study of Electron Bremsstrahlung Shielding for Manned Spacecraft, J. Spacecraft 24, 158-161 (1987).

Behrens, James W., Ma, Hongchang, and Wasson, Oren A., Advances in the Use of ^{3}He in a Gas Scintillation Counter, Trans. Am. Nucl. Soc. 53, 163 (1986).

Berger, M. J. and Hubbell, J. H., XCOM: Photon Cross Sections on a Personal Computer, NBSIR 87-3597 (1987).

Calhoun, J. M., Paras, P., Comer, F. D., Coursey, B. M., and Golas, D. B., Evaluation of Radionuclide Dose-Calibrator Measurements, Trans. Am. Nucl. Soc. 53, 18 (1986).

Calhoun, J. M., Radioactivity Calibrations with the NBS "4π" Gamma Ionization Chamber and other NBS Radioactivity Calibrations Capabilities, NBS SP250-10 (1987).

Calhoun, M., Golas, D. B., and Harris, S., Effects of Varying Geometry on Dose Calibrator Response: Cobalt-57 Technetium-99m, J. Nucl. Med. 28, No. 9, 1478 (1987).

Calhoun, J. M., NBS Measurements of Sample Geometry Effects on Ionization Chamber Calibrations, Trans. Am. Nucl. Soc. 53, 21 (1986).

Carlson, A. D., Wasson, O. A., Lisowski, P. W., Ullmann, J. L., and Hill, N. W., Measurements of the $^{235}U(n,f)$ Cross Section in the MeV Energy Region, Bull. Am. Phys. Soc. 32, 1035 (1987).

Caswell, R. S., Coyne, J. J., Gerstenberg, H. H., and Schwartz, R. B., Refinement of Neutron Energy Deposition and Microdosimetry Calculations, Proceedings of the International Conference on Fast Neutron Physics, Dubrovnik, Yugoslavia, 122-134 (1986).

Division 536, Publications (cont'd.)

Chang, C., Seltzer, S. M., and Wilson, J. W., Effects of Backing Plates on the Electron Exposure of Thin Polymer Films, NASA Technical Memorandum 88995 (1986).

Collé, R., and Karp, P., Measurement Uncertainties: Report of an International Working Group Meeting, NBS J. Res. 92, 243-244 (1987).

Coursey, B. M., Hoppes, D. D., Schima, F. J., and Unterweger, M. P., The Standardization of Samarium-153, Int. J. Appl. Radiat. Isot. 38, No. 1, 31-34 (1987).

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TECHNICAL AND PROFESSIONAL COMMITTEE PARTICIPATION AND LEADERSHIP

Division 536, Ionizing Radiation

James W. Behrens

Chairman, Nuclear Data Committee, Isotopes and Radiation Division, American Nuclear Society.

Chairman, Transuranic Task Force, Isotopes and Radiation Division, American Nuclear Society.

Member, Program Committee for the American Nuclear Society/European Nuclear Society Meeting to be held in Washington, D.C. (Nov. 1988).

Chairman, Organizing Committee for conference entitled "Fifty Years with Nuclear Fission" to be held at the NBS (April 1989).

Member, Cross Section Evaluation Working Group Subcommittee on Nuclear Data Review.

Martin J. Berger

Member International Atomic Energy Agency Advisory Group on Nuclear and Atomic Data for Radiotherapy and Radiobiology.

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 on Dosimetry.

Member, NCRP Committee #55 (inactive) on Experimental Verification of Internal Dosimetry.

Jacqueline M. Calhoun

EEO Counselor, NBS, two-year re-appointment, January 7, 1987 through January 7, 1989.

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

Allan D. Carlson

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

Division 536, Technical and Professional Committee Participation and Leadership (cont'd.)

Allan D. Carlson (cont'd.)

Member, Evaluation Committee of CSEWG.

Member, Data Status and Requests Subcommittee of CSEWG.

Chairman, Program Committee for conference entitled "Fifty Years with Nuclear Fission" to be held at the NBS (April 1989).

Randall S. Caswell

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

Alternate Member, CIRRPC, Office of Science and Technology Policy.

Member, 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).

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 Material Equivalent and Tissue Substitutes.

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

Sponsor, ICRU Report Committee on Characterization of Irradiation for Materials Effect Studies.

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

Division 536, Technical and Professional Committee Participation and Leadership (cont'd.)

Randall S. Caswell (cont'd.)

Member, Organizing Committee, Second International Conference on Anticarcinogenesis and Radiation Protection, March 8-12, 1987.

Member, Program Committee for the Sixth Symposium on Neutron Dosimetry, Munich (Neuherberg), October 12-16, 1987.

Ronald Collé

Staff Assistant to Chairman, Radon Policy Subpanel, CIRRPC.

Member, Radon Working Group, Interagency Committee on Indoor Air Quality.

Chairman, International Standards Organization, Working Group on Measurement Uncertainties.

Bert M. Coursey

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

Member, ANSI Committee N42.02 on Nuclear Instruments, Procedural Standards for Calibration of Detectors for Radioactive Measurements.

J. Joseph Coyne

Member, CIRRPC Subcommittee on High-LET Radiation.

Member, European Community Dosimetry Group (EURADOS) Committee 1: Tissue-Equivalent Proportional Counters as an Instrument for Radiation Protection.

Member, EURADOS Committee 4: Computational Methods and Benchmark Calculations in Radiation Protection.

Member, International Atomic Energy Agency Advisory Group on Nuclear and Atomic Data for Radiotherapy and Radiobiology.

Charles E. Dick

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

Division 536, Technical and Professional Committee Participation and Leadership (cont'd.)

Charles M. Eisenhauer

Member, CIRRPC Science Panel.

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

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

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

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

Elmer H. Eisenhower

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

Representative, 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.

Member, ASTM Subcommittee E10.04 on Radiation Protection Methodology.

Chairman, ASTM Task Group E10.07.05 on Performance of Calibration Laboratories for Radiation Dosimetry in Industrial Testing and Processing.

Member, ASTM Committee E10 on Nuclear Technology and Applications.

Member, CIRRPC Science Subpanel on Scientific Basis for Radiation Protection Standards.

Division 536, Technical and Professional Committee Participation and Leadership (cont'd.)

Elmer H. Eisenhower (cont'd.)

Member, Operations Group for the Accreditation of Instrument Calibration Laboratories, Health Physics Society.

Leon J. Goodman

Member, ICRU Report Committee on Clinical Neutron Dosimetry--Part I: Determination of Absorbed Dose in a Patient Treated by External Beams of Fast Neutrons.

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

Consultant, AAPM Task Group 18, Fast Neutron Beam Dosimetry.

James A. Grundl

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

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

Secretary, Steering Committee for Lady Godiva Display at the National Atomic Museum.

H. Thompson Heaton, II

Alternate Representative, ANSI N43, Equipment for Non-Medical Radiation Applications.

Member, ANSI N43-3, Subcommittee for Gamma Irradiators.

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

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

Dale D. Hoppes

Secretary, International Committee for Radionuclide Metrology (ICRM).

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

Member, Atomic Industrial Forum (AIF)-NBS Standards Program Committee.

Division 536, Technical and Professional Committee Participation and Leadership (cont'd.)

Dale D. Hoppes (cont'd.)

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

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

John H. Hubbell

Chairman, General Radiation Protection Section, Health Physics Society Standards Committee.

Organizer and Overseer, Task Groups: ANSI Standard N-319 on Personnel Neutron Dosimeters; and ASTM-E-10.04 PlanCo 56 on Radiation Protection Survey Documentation, PlanCo 57 on Airborne Radioactive Particulates, and PlanCo 58 on Low-level Radwaste.

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

Member, ANS Isotopes and Radiation Division Nuclear, Atomic, and Radiation Data Committee; Organizer and Chairman of sponsored session: "Atomic and Radiation Data and Applications", for November 1987 ANS Meeting.

Member, ANS Isotopes and Radiation Division Industrial Radiation Measurement Applications Committee.

Member, ANS Technical Program Committee for Sponsored Topical Meeting, "Industrial Radiation and Radioisotope Measurement Applications", September 1988.

Executive Councilor, International Radiation Physics Society; Member Nominating Committee for 1988 elections.

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

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

Division 536, Technical and Professional Committee Participation and Leadership (cont'd.)

Jimmy C. Humphreys

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

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

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

J. M. Robin Hutchinson

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

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

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

Kenneth G. W. Inn

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

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

George P. Lamaze

Vice-Chairman, ASTM Subcommittee E10.05, Nuclear Radiation Metrology.

Chairman, Membership Subcommittee, ASTM Committee E10, Nuclear Technology and Applications.

Secretary, Planning Committees for the 6th and 7th ASTM-EURATOM Symposia on Reactor Dosimetry.

Robert Loevinger

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

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

Division 536, Technical and Professional Committee Participation and Leadership (cont'd.)

Robert Loevinger (cont'd.)

Consultant, American Association of Physicists in Medicine (AAPM) Radiation Therapy Committee.

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

Consultant, ICRU Report Group on Determination of Dose Rate at a Point in the Vicinity of a Brachytherapy Source.

Wilfrid B. Mann

Consultant, ICRU.

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

Honorary Council Member, NCRP.

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

Life Member, ICRM.

Emmert D. McGarry

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

Chairman, Awards Committee of ASTM Subcommittee E10.05.

Member, Planning Committee for the 7th ASTM-EURATOM Symposum on Reactor Dosimetry.

William L. McLaughlin

Chairman, ICRU Report Committee on Absolute and Relative Measurements of High Doses.

Technical Advisor, ICRU Report Committee on Chemical Dosimetry.

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

Division 536, Technical and Professional Committee Participation and Leadership (cont'd.)

William L. McLaughlin (cont'd.)

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

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

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

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

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

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

Science and Technology Consultant, CIRRPC.

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

Member, Organizing and Program Committees, 7th International Conference on Radiation Processing, Amsterdam 1989.

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

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

Robert C. Placious

NBS Representative, Advisory Board, Center for NDE, Iowa State University.

Session Chairperson: ASNT Topical Conference Automating and Advancing Radiographic NDT.

Division 536, Technical and Professional Committee Participation and Leadership (cont'd.)

Francis J. Schima

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

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

Scientific and Technical Consultant, CIRRPC.

Robert B. Schwartz

Member, International Standards Organization (ISO) Technical Committee 85 (Nuclear Energy), Subcommittee 2 (Radiation Protection), Working Group 2 (Reference Radiations). Chairman, Neutron Sub-Group.

Member, ICRU Report Committee on Measurements of Dose Equivalent.

Member, Health Physics Society Standards Committee, Working Group on Neutron Radiation Instrumentation.

Member, European Radiation Dosimetry Group, (EURADOS), Working Committee 4 (Numerical Dosimetry).

Stephen M. Seltzer

Member, Program Advisory Board, Conference on High Energy Radiation Background in Space, November 3-5, 1987.

Member, ICRU Committee on Stopping Power.

Member, ANS Nuclear Data Committee.

Member, ANS Radiation Effects Committee.

Christopher G. Soares

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

Michael P. Unterwerger

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

Division 536, Technical and Professional Committee Participation and Leadership (cont'd.)

Oren A. Wasson

Member, Department of Energy Nuclear Data Committee.

General Chairman, for conference entitled "Fifty Years with Nuclear Fission" to be held at the NBS (April 1989).

MAJOR CONSULTING AND ADVISORY SERVICES

Division 536, Ionizing Radiation

1. J. W. Behrens consulted with Lawrence Livermore National Laboratory on neutron measurements.

2. R. Collé assisted and advised the Radon Policy Subpanel of the Committee on Interagency Radiation Research and Policy Coordination in developing a report on the extent and adequacy of federal radon programs.

3. C. E. Dick consulted with Mr. Richard Von Metter of Eastman Kodak Corp. on the applications of single photon counting for measuring the Swank noise of medical x-ray intensifying screens.

4. C. E. Dick consulted with Mr. Peter Soltani of Quantex Corp. on the electron irradiation of photostimulable phosphors.

5. C. E. Dick consulted with Mr. Peter Soltani of Quantex Corp. on the method of single photon counting for the evaluation of x-ray sensitive phosphors.

6. C. E. Dick consulted with Mr. Robert Kissel of the U.S. Navy EOD Tech Center, NAVEODTECHCEN, on the use of PIN x-ray imaging detectors for ordnance inspection.

7. C. E. Dick consulted with Mr. Donald Snyder, Eglin Air Force Base, on the use of real time high resolution x-ray imaging in the development of aircraft ordnance.

8. S. R. Domen consulted with members of the Radiological Sciences Department at the University of Lowell, to help them establish a research program in absorbed-dose calorimetry.

9. S. R. Domen visited the Radiology Department of the Yale Medical School to provide consultation on theoretical problems in measurement of radiation absorbed dose using a water calorimeter, and the consultation has been continued by correspondence.

10. S. R. Domen provided extensive consultation on the absorbed-dose water calorimeter during a two-day visit to NBS by the head of the Dosimetry Laboratory of Ghent University (Belgium), and the consultation has continued by correspondence.

11. E. H. Eisenhower advised the International Committee for Radionuclide Metrology regarding the distinction between traceability and measurement quality assurance.

Division 536, Major Consulting and Advisory Services (cont'd.)

12. E. H. Eisenhower advised the Federal Emergency Management Agency regarding negotiations with the manufacturer of leaking sealed sources procured by FEMA.

13. David M. Gilliam advised and assisted Babcock and Wilcox (B&W) in preparation of high-level dosimeters for measurements in mixed gamma and neutron radiation fields at commercial nuclear reactors. These measurements are being made for assessing the integrity of reactor pressure vessels and understanding radiation shielding for reducing personnel exposures.

14. David M. Gilliam developed an automatic data acquisition and processing system for new exposure room neutron monitors at the Armed Forces Radiobiological Research Institute reactor.

15. H. T. Heaton, II consulted with the U.S. Air Force calibration lab at Newark Air Force Station on models of exposure rate from gamma sources and methods for comparing model parameters to observed ion chamber measurements.

16. H. T. Heaton, II consulted with Radcal Corporation on ion chamber correction factors.

17. H. T. Heaton, II consulted with Battelle Northwest Laboratories on making HVL measurements with energy-dependent ion chambers.

18. J. H. Hubbell responded to 310 inquiries (technical advice, data, bibliographic search, publication requests, referencing of journal manuscripts, etc.) to the Photon and Charged Particle Data Center during the reporting period, 7/1/86 to 6/30/87.

19. J. C. Humphreys, along with W. L. McLaughlin and D. Hocken, provided an in-depth on-site review (lasting approximately 3 or 4 days) of dosimetry measurement procedures for Geraldine Barrett at Neutron Products Inc., Dickerson, MD.

20. J. C. Humphreys provided advice about six times over a period of several months to Arnold Fero of Westinghouse Electric Corp., Pittsburgh, PA, on the LiF chips as dosimeters for "in-situ" measurements in a power reactor core. Advice was needed on how to determine the gamma/neutron sensitivity of these dosimeters in the mixed radiation field and the appropriate analysis methods.

21. J. C. Humphreys provided advice to David Bigbee of the FBI on appropriate methods for the use of the FBI Laboratory 320 kV x-ray machine to sterilize blood specimens containing the AIDS virus to make these specimens safe to handle.

Division 536, Major Consulting and Advisory Services (cont'd.)

22. R. G. Johnson and R. A. Schrack consulted with Princeton Plasma Fusion Laboratory on 14 MeV neutron measurements.

23. R. G. Johnson and K. C. Duvall consulted with MESA Services International on neutron detectors.

24. R. Loevinger served as consultant to the Dosimetry Section of the International Atomic Energy Agency at a meeting of the Scientific Committee of the Secondary Standard Dosimetry Laboratory Network, in Vienna, Austria, June 1 - 5, 1987.

25. E. D. McGarry provided consultation, and ^{235}U Standard Neutron Irradiations on a (successful) try-and-see basis, to Westinghouse Electric Corporation's Research Division (Monroeville, PA), to establish mass scales for ultralight fissionable deposits whose masses are in the fractional nanogram/cmr range.

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

27. W. L. McLaughlin, Northern California Transplant Bank, San Francisco, CA (Dr. James Forsell). Consultation on dosimetry for QA in the sterilization of prosthetic tissues (for biocompatible transplants).

28. W. L. McLaughlin, Children's Hospital, National Medical Center, ENT Department (Dr. Colin Barber). Assisted in irradiation of transplant tissue (trachea) as a means of sterilization biocompatibility prior to surgery.

29. W. L. McLaughlin, Rensallear Polytechnical Institute, Physics Department (Dr. Brian Methe). High-dose measurement and irradiation of thermoluminescent powders in order to extend useful range of conventional TLD materials to higher doses than usual.

30. W. L. McLaughlin, PPG Industries, Oak Creek, WI (Dr. Roy Modjewski). Provide means for calibrating response of thin radiochromic films irradiated to very low energy electron beams (100 kev).

31. W. L. McLaughlin and J. C. Humphreys, Becton-Dickinsen Research Laboratory, Research Triangle Park, NC (Dr. Lois Jones). Assisted in the design of BD dosimeter calibration laboratory and calorimetry systems for high-dose measurements.

32. W. L. McLaughlin, Acme United Corporation., Fairfield CN (Dr. Louise Wheeler). Provided consultation on ferrous-cupric chemical dosimetry as a means of calibrating red Perspex dosimeters for sterilization of gauze dressings.

Division 536, Major Consulting and Advisory Services (cont'd.)

33. W. L. McLaughlin, Kendall-McGaw, Irvine, CA (Dr's Steven Smith and Roger Morrison). Devised a novel experimental means of mapping dose distribution in polypropylene tubes and sleeves irradiated with 12-MeV electrons.

34. W. L. McLaughlin, Merck, Sharpe and Dome (Dr. Brenda Staehlee). Provided means for calibrating medical supplies using radiochromic thin-film dosimeters.

35. W. L. McLaughlin, IRT Corporation, San Diego, CA (Dr. Elaine Bondos). Supplied a new type of radiochromic film prototype for large-scale mapping in semi-conductors being processed by electron beams at very high beam powers (300kW).

36. W. L. McLaughlin, Radiation Sterilizers, Inc., Atlanta GA (Dr. Thomas Fisher). Consultation on standardizing spectrophotometers in their applications with chemical dosimeters use for QA in radiation sterilization of disposable medical devices.

37. W. L. McLaughlin, Surgikos (Johnson & Johnson), Arlington, TX (Dr. Kathy Harris). Supplied temperature and rate dependence data for the response of thin-film radiochromic films to electron beams (4-MeV).

38. W. L. McLaughlin, McDonnell Douglas, Vitak Systems, Hazleton, MI (Dr. William J. Bakich). Consultation on the use of radiochromic dosimeters as a mean of QA in the radiation sterilization of bone grafts.

39. W. L. McLaughlin, US Department of Energy, Environmental Branch (Dr. David Balletine). Consultation on radioactivity induced in the irradiation of foods by 5-10 MeV x-rays and 10-12 MeV electron beams.

40. W. L. McLaughlin, IBM, San Jose, CA (Dr. Hans Coufal). Consultation on the radiation effects on plastics (e.g. polyvinylidene fluoride) used for piezoelectric devices and new possibilities for high-dose dosimetry.

41. W. L. McLaughlin, State of California Department of Food and Agriculture Sacramento, CA (Joseph Rothleder). Devised a detailed testing procedure and evaluation protocol for optical waveguide dosimeters to be used for standardizing the irradiation of foods.

42. W. L. McLaughlin, Abbott Labs, Austin, TX (Carlos Parra). Design of validation dosimetry procedures for setting sterilization dose levels, using radiochromic dosimetry.

Division 536, Major Consulting and Advisory Services (cont'd.)

43. W. L. McLaughlin, North American Science Associates, Northwood, OH (Jacqueline Breno). Designed a radiation experiment for testing and validating the appropriate sterilization doses for standardized microbiological spore strips.

44. W. L. McLaughlin, Westinghouse, Nuclear Technology Systems Division, Pittsburgh, PA (Dr. Arnold Fero). Designed high-dose calibration methods using optical-quality lithium fluoride crystals and color-center formation.

45. W. L. McLaughlin, Monsanto, O'Fallen, IL (Dr. Donald Hines). Consultation on high-dose dosimetry methods in the radiation synthesis of macromolecular specialty chemicals.

46. W. L. McLaughlin, Monsanto, St. Louis, MO (Dr. Daniel Steinmeyer). Supplied details of the radiation chemistry in the radiolysis of nitrous oxide (products, yields, etc.).

47. W. L. McLaughlin, R. S. Landauer, Inc., Chicago, IL (Steven Scharf) Supplied details of food irradiation dosimetry requirements, as well as samples of typical dosimetry systems for quality assurance.

48. W. L. McLaughlin and J. C. Humphreys, Convertors-Travenol, El Paso, TX (Dr. Harry Shaffer). Consultation on energy dependence and temperature dependence of radiochromic response to ionizing photons (x-and gamma rays).

49. W. L. McLaughlin, Franrica Company, Stockton, CA (Dr. Steven Rechtsteiner). Provided details of differences in response of anaerobic and aerobic bacteriological spores to electrons and photons, as well as radiation-resistant microbes (e.g. clostridium botulinum type E and viruses).

50. W. L. McLaughlin, Thermon Manufacturing Co., San Marcos, TX (Dr. Fred Weber). Devised a method for dosimetry at very high doses (200-500 kGy) for polymers irradiated with 3-MeV electron beams.

51. W. L. McLaughlin, USDA, Entomology Department, Yakima, WA (Dr. Arthur Burditt). Supplied dosimetry for low-dose irradiation as a means of quarantine control of fruits and vegetables.

52. W. L. McLaughlin, Drug and Device Associate, Inc. (Dr. Donald J. Cattaneo). Provided validation and sterility-control data and procedures in the sterilization of pharmaceutical and medical devices.

Division 536, Major Consulting and Advisory Services (cont'd.)

53. W. L. McLaughlin, Kimberly-Clark, Roswell, GA (Dr. Elizabeth Jackson). Consultation on the use of radiochromic film dosimetry as a means of evaluating the safety of sterilization of medical devices by ionizing radiation.

54. W. L. McLaughlin, Boeing Aerospace, Seattle, WA (Dr. William Vartholep). Supplied means and procedures for dosimetry of 20-ns pulsed beams at 10^{13} Gy s^{-1}, 2kHz, at very high electron beam powers (elevated temperatures).

55. W. L. McLaughlin, Insultab Corp., Woburn, MA (Dr. Clement Bourgault) Assisted in the dosimetry as a means of QA in the curing of wires, cables, tubing and laminated plastic films.

56. W. L. McLaughlin, Michigan Tissue Bank, Lansing, MI (Dr. Nancy Webb). Supplied special radiochromic dosimeters and procedures for monitoring radiation sterilization of prosthetic devices.

57. W. L. McLaughlin, Food and Drug Administration (Dr. H. Herman). Consultation on monitory of radioisotope labeled proteins in the testing of latex barriers to AIDS virus; testing of mechanical properties following sterilization.

58. W. L. McLaughlin, Abbott Laboratories, Abbott Park, IL (Dr. Richard A. Domanik). Consultation on in-vivo dosimeters for diagnostic and clinical radiology, utilizing optical waveguide sensors.

59. W. L. McLaughlin, IBM Corp., Yorktown Heights, NY (Dr. Ronald Dellaguardia). Provided means of standardizing low-energy x-ray exposures at high doses, in the fabrication of lithographic masks for sub-micron semi-conductor architectures.

60. W. L. McLaughlin, SAIC Corp., San Diego, CA (Dr. Michael Hyman; Dr. David Delesdernier). Supplied technology in the fabrication of optical waveguide systems under contract with DOD for use as radiation dosimeters for military personnel.

61. W. L. McLaughlin, Physics Department, University of California, Berkeley, CA (Dr. Buford Price). Consultation on sensitive glasses for use in the dosimetry of heavy charged particles and the registration of nuclear tracks.

62. W. L. McLaughlin and J. C. Humphreys, 3M Company, St. Paul, MN (Dr. Nate Postma). Consultation on the production of magnetic tapes, discs etc. for use of electron beams scanned over wide-webbings and supplying dosimetry for quality control.

Division 536, Major Consulting and Advisory Services (cont'd.)

63. W. L. McLaughlin, Allied Corporation, Morristown, NJ (Dr. Theodore Prusik). Consultation on the development of new dosimeters for food irradiation. NBS supplied tests and standards for assisting Allied in meeting regulatory requirements and product specifications.

64. W. L. McLaughlin, Atomic Energy of Canada Ltd., Ottawa, Canada (Dr. Joseph McKoewn). Provided measurement systems and expertise as means of QA for industry producing large radionuclide sources and accelerator technology.

65. W. L. McLaughlin, Bichron Corporation, Newbury, OH (Dr. Joseph Bellian, President). Consultation on development for DOE and industry of new dosimeters for environment radiation and for radiation protection measurements.

66. W. L. McLaughlin, DOD, ERADCOM Ft. Monmouth, NJ (Dr. Stanley Kronenbery). Designed and tested practical field radiation dosimeters for military personnel.

67. W. L. McLaughlin and J. C. Humphreys, Energy Sciences Inc., Woburn, MS (Dr. Samuel V. Nablo). Supplied quality control assistance for low-energy (0.1-0.5 MeV) electron accelerators being used for curing coatings and laminates at high assembly-line speeds.

68. W. L. McLaughlin, European Organization for Nuclear Research, Geneva, Switzerland (Dr. H. Schonbacher). Designed dosimetry as a convenient and inexpensive means of monitoring large doses of high -energy charged particles and chronic radiation-induced damage in steering magnets.

69. W. L. McLaughlin and J. C. Humphreys, Far West Technology, Inc. (K. C. Humphreys). Supplied innovations and new chemical dosimetry formulations and film fabrication methods, as well as optical waveguide materials and designs for new dosimetry applications in radiation processing, radiology, and protection.

70. W. L. McLaughlin and J. C. Humphreys, FMC Corporation, Central Engineering Laboratories, Santa Clara, CA (Dr. George Hsieh). Supplied measurement systems and means for measurement quality assurance (including training course to FMC personnel) for applications in radiation processing food preservation.

71. W. L. McLaughlin, GAF Corporation, Wayne, NJ (Dr. David Lewis). Provided testing and applications in the development of a new family of dosimeter materials which are expected to have an impact on radiation measurement technology.

Division 536, Major Consulting and Advisory Services (cont'd.)

72. W. L. McLaughlin, Gesellschaft fur Strahlen-und Umweltforschung, Neuherberg/Munich, Federal Republic of Germany, (Dr. Dieter Regulla). Supplied primary standards and dosimetry intercomparisons for the development of reference standard dosimeters (alanine) used in the IAEA International Dose Assurance Service.

73. W. L. McLaughlin, W. R. Grace & Company, Duncan, SC (Dr. James Pike) Collaboration on the development of polyolefin films and dyed cellulose films for the measurement of very large doses delivered by industrial electron accelerators at relatively high temperatures.

74. W. L. McLaughlin, Harwell Laboratory, Oxfordshire, UK (Dr. Brian Whittaker). Supplied dosimetry intercomparisons and standards for industrial radiation processing applications and international dose assurance services.

75. W. L. McLaughlin, IOTECH, Inc., Northglenn, CO (Dr. Gary Pageau and Dr. Steven Kruger). Established quality control procedures and measurement methods for industrial sterilization of medical devices.

76. W. L. McLaughlin and J. C. Humphreys, ISOMEDIX, Inc., Whippany, NJ (Michael Saylor). Provided calibrations and consultation on the use of optichromic dosimeters for quality assurance in the radiation processing of tropical fruits for quarantine control.

77. W. L. McLaughlin and J. C. Humphreys, Radiation Dynamics, Inc., Melville, NY (Laura Tampanick and Marion Stelchnk). Assisted with beam diagnostics and characterization of processing efficiencies of high-power industrial electron accelerators.

78. W. L. McLaughlin and J. C. Humphreys, Radiation Sterilizers, Inc. Westerville, OH (Dr. Barry Fairand). Designed MQA procedures and training courses for industrial plant personnel performing sterilization of medical devices.

79. W. L. McLaughlin and J. C. Humphreys, Johnson & Johnson, Somerville, NJ (Dr. Jeffrey Beck). Assisted with radiation dosimetry used as MQA for safe release of radiation sterilized sutures for surgical use.

80. W. L. McLaughlin, Medical Sterilization, Inc., Syosset, NY (Dr. Kennard H. Morgenstern and Dr. Michael Fogerty). Supplied specialized dosimetry for measuring accurately radiation doses in highly heterogeneous materials used in recyclable medical supplies.

81. W. L. McLaughlin, National Cancer Institute (NIH), Bethesda, MD (Dr. Gordon Cragg). Consultant on QA and dosimetry for sterilization of natural products as chemotherapy agents.

Division 536, Major Consulting and Advisory Services (cont'd.)

82. W. L. McLaughlin, Naval Surface Weapons Center (DOD), White Oak, MD (Dr. Stanley H. Stern). Provided dosimetry and calibrations for detailed emergency dose mapping in the vicinity of strategic weapons and simulators.

83. W. L. McLaughlin, RPC Industries, Hayward, CA (Dr. Anthony Rodriguez (VP) and Dr. Sherman Farrell). Assisted with beam diagnostics and QA dosimetry control for processing with large accelerators and ultraviolet sources used for radiation curing and processing.

84. W. L. McLaughlin, Travenol Laboratories Inc., Round Lake, IL (Dr. William Fitzgerald). Supplied contracted QA expertise and radiation processing training courses for radiation sterilization of hospital and medical disposable materials.

85. Robert B. Schwartz participated in the following intercomparisons: a) neutron dosimeters with Battelle Pacific Northwest Laboratory; b) neutron remmeters with University of Arkansas; and c) neutron remmeters with National Physical Laboratory (U.K.); Commissariat a L'Energie Atomique (France); and Physikalisch - Technische Budesanstalt (FRG).

86. Robert B. Schwartz assisted the U. S. Navy in evaluating a new type of neutron personnel dosimetry.

87. Robert B. Schwartz worked with a representative of the French Atomic Energy Commission to evaluate a new type of neutron remmeter.

88. Julian Sparrow has performed major advisory services on radiographic inspection of rocket motors for the following groups: Jerry Lyman and Richard O'Brien at the Strategic Weapons Facility Pacific, Bremerton, WA; Martin Johnson, Polaris Missile Facility Atlantic, Charleston, SC; Dick Shafer and Gary Barrett, Hercules Bacchus Division, Magna, UT; and Kent Robertson, Morton-Thiokol Inc., Brigham City, UT.

89. Julian Sparrow has consulted with Lockheed and Atlantic Research Corporation personnel on radiographic procedures to be used to inspect missile motor components.

90. Julian Sparrow has consulted with personnel from the University of West Virginia, Morgantown, on the construction of an x-ray phantom to standardize the x-ray geometry in medical radiography.

91. Julian Sparrow demonstrated the Hand-Held, Dental X-Ray Unit in film mode and real-time mode for General Chandler of the U.S. Army Medical Research and Development Center, at Ft. Detrick, MD.

Division 536, Major Consulting and Advisory Services (cont'd.)

92. Julian Sparrow has hosted an NBS and NDT meeting for the Navy Special Programs Office and served as the recording secretary. The meeting was attended by Navy field representatives, consultants and the program officer of the prime contractor to discuss the status of nondestructive testing techniques being used in the D-5 missile program.

93. Julian Sparrow consulted with Frank Ameduri, Los Alamos National Laboratory on the use of compact parallel-plate ionization chambers with Ross filter-pairs for absolute fluence measurements of high intensity pulsed 1 to 10 KeV x-rays.

94. Julian Sparrow consulted with Lynn Spence, Lockheed Missile and Space Corp., and Maynard Grove, Atlantic Research Corp., on the thickness of polystyrene equilibrium build-up cap required for small volume ionization chamber used to measure x-ray fluence from an 8 MeV linear accelerator.

JOURNAL EDITORSHIPS

Division 536, Ionizing Radiation

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

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

J. H. Hubbell, Editorial Board, Journal of the Nigerian Association of Medical Physicists.

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

W. B. Mann, Editor-in-Chief for North America, International Journal of Radiation Applications and Instrumentation, Part B. Nuclear Medicine and Biology.

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

W. L. McLaughlin, Editor, International Journal of Radiation Applications and Instrumentation, Part C. Radiation Physics and Chemistry.

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

J. W. Motz, Editor, Computerized Radiology.

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

TRIPS SPONSORED BY OTHERS

Division 536, Ionizing Radiation

M. J. Berger and S. M. Seltzer attended meeting of the ICRU Committee on Stopping Powers, Argonne, IL. All expenses paid by the ICRU (October 22-24, 1986).

M. J. Berger and S. M. Seltzer lectured at the Ettore Majorana Center for Scientific Culture, International School of Radiation Damage and Protection, Erice, Sicily. Expenses were paid by the Ettore Majorana Center for Scientific Culture (September 24 - October 3, 1987).

Randall S. Caswell traveled to Beijing, Xian, Shanghai, and Hangzhou, China to give a series of lectures on ionizing radiation measurement and neutron interactions with biological tissue. All expenses while in China were paid for by the Institute of Atomic Energy, Beijing, China (June 1986).

Randall S. Caswell traveled to New York City, NY to participate in the National Cancer Institute review of the Radiological Research Program at Columbia University. All expenses were paid for by the National Cancer Institute (August 1986).

Randall S. Caswell traveled to Brussels, Belgium to attend the Annual Meeting of the International Commission on Radiation Units and Measurements (ICRU). All expenses were paid for by the ICRU (September 1986).

B. M. Coursey attended the Rome, Italy meeting of the ICRM for the purpose of editing the proceedings of a Seminar for the International Journal of Radiation Applications and Instrumentation. Pergamon Press paid for air transportation and partial per diem (June 15-24, 1987).

B. M. Coursey provided consulting services, audit source certification, and QA procedures under the framework of the AIF/NBS MAP for the Nuclear Power Industry, Analytics, Inc., Atlanta, GA. Travel expenses paid by Analytics, Inc. (April 20, 1987).

E. H. Eisenhower lectured at the Health Physics Society Summer School on Practical Statistics for Operational Health Physics, in Pocatello, ID. All expenses were paid by Idaho State University (July 1987).

H. T. Heaton, II traveled to Pocatello, ID to present a talk at the Health Physics Society Summer School. All expenses were paid by Idaho State University (July 1987).

Division 536, Trips Sponsored by Others (cont'd.)

J. H. Hubbell lectured and held laboratory discussions in the People's Republic of China at the Institute of Applied Physics, and Computational Mathematics and at the Institute of Atomic Energy, In Beijing. The host organizations covered all living expenses (September 10-12, 1987).

J. H. Hubbell, under the terms of the Protocol and Cooperation between the U.S. Department of Commerce and the PRC State Bureau of Metrology (SBM), lectured and held laboratory discussions at the SBM in Beijing and in other SBM-affiliated institutions in the People's Republic of China. The SBM covered all living expenses (September 13-30, 1987).

J. M. R. Hutchinson attended the "First International Summer School on Low-Level Measurements and Their Applications to Environmental Radioactivity," and presented three lectures at the Department of Atomic and Nuclear Physics of the University of Seville, Spain. The University of Seville provided all expenses (September 27 - October 10, 1987).

R. Loevinger traveled to the People's Republic of China and gave lectures at institutions in Beijing, Taiyuan, Xian, and Shanghai. His expenses within the PRC were paid by the Chinese government (October 15 - November 5, 1986).

R. Loevinger traveled to San Francisco, CA to take part in a meeting of the MIRD Committee of the Society of Nuclear Medicine. The trip was paid for by the Society of Nuclear Medicine (March 12 & 13, 1987).

R. Loevinger traveled to Vienna, Austria as a member of an Advisory Group on Procedures and Data for the Calibration of Radiation Protection Monitoring Instruments at the International Atomic Energy Agency. The trip was paid for by the IAEA (May 18 - 22, 1987).

R. Loevinger traveled to Vienna, Austria to serve as consultant to the Dosimetry Group of the International Atomic Energy Agency at a meeting of the Scientific Committee of the Secondary Standard Dosimetry Laboratory Network. The trip was paid for by the IAEA (June 1 - 5, 1987).

William L. McLaughlin taught a training course at Travenol Laboratories, Round Lake, IL. All expenses paid by Travenol Laboratories (October 1986).

F. J. Schima attended the International Atomic Energy Agency research associate's meeting, Rome, Italy. As part of the Research Agreement with the IAEA, per diem and airfare were provided by IAEA (June 11-13, 1987).

Division 536, Trips Sponsored by Others (cont'd.)

R. A. Schrack attended the Workshop on Neutron Resonance Radiography held at Los Alamos National Laboratory, NM. They paid travel expenses (July 1987).

Michael G. Simic gave a talk and discussed research of mutual interest at the University of California, Berkeley, CA. The University of California paid all expenses (November 1986).

Michael G. Simic was invited to give a talk and discuss research of mutual interest at Stanford University, Stanford, CA. Stanford University paid subsistence (November 1986).

Michael G. Simic gave an invited talk and discussed research of mutual interest at the University of California, San Francisco, CA. The University of California paid subsistence (November 1986).

Michael G. Simic was invited to give a talk and discuss collaborative research at the University of Southern California, Los Angeles, CA. The University of California paid subsistence (February 1987).

Michael G. Simic was invited to give a Symposium talk at the annual meeting of the American Institute of Physics at Crystal City, VA. The American Institute of Physics paid subsistence (April 1986).

Michael G. Simic traveled to LaJolla, CA to serve as chairman of 4th International Congress on Oxygen Radicals. Conference paid for all expenses (June-July 1987).

Division 536, Ionizing Radiation

Radioactivity Group Standards Issued - 1 August 1986 through 31 July 1987

SRM	Radionuclide	Principal Use
4417L-F	Indium-111	Calibration of instruments for activity measurements of radiopharmaceuticals
4410H-K	Technetium-99m	"
4419C	Ytterbium-169	"
4407L	Iodine-25	"
4401L-M	Iodine-131	"
4412L-L	Molybdenum-99	"
4415L-K	Xenon-133	"
4416-H	Gallium-67	"
4404L-J	Thallium-201	"
4400L-I	Chromium-51	"
4321 4322 4323	Natural Uranium Solution) Americum-241 Solution) Plutonium-234 solution)	Environmental monitoring in the nuclear fuel cycle
4354	Cobalt-60, Strontium-90, Cesium-137, Thorium-228, 232 Uranium-235, 238 Plutonium-238, 239+240 Americum-241	Fresh water lake sediment Natural Matrix
4361B	Low-level Tritium in water	International Standard for ground-water dating
4906C	Plutonium-238 point source	Calibration of alpha counting equipment in environmental monitoring
4945F	Strontium-89 solution	Calibration of beta-counting equipment in the Nuclear Power Industry
4207B	Cesium-137 point source	Calibrating Ge(Li) semi-conductors used for monitoring radionuclide levels under operation and accident conditions in nuclear power facilities

CALIBRATION SERVICES PERFORMED

Division 536, Ionizing Radiation

I. Neutron Dosimetry Group

Type of Service	Customer	Sp 250	No. of Tests
Certified Fluence Standards	Univ. of Arizona	8.1R	1
	AFRRI	8.1R	6
	AFRRI	8.1Q	1
		Total	8
Neutron Personnel Protection Instrumentation	AFRRI	44060C	2
	Georgia Power	44060C	4
	Rochester Gas & Electric	44060C	3
	Virginia Power	44060C	5
	Calvert Cliffs	44060C	12
	Caroline P&L	8.1J	7
	Omaha Public Power	8.1J	3
	U. S. Army	8.1J	10
	Illinois Power	8.1J	2
	WPPSS	8.1J	2
	Barlett Nuclear Corp.	8.1J	2
	Eberline Inste. Corp.	8.1J	2
	Penn. Power & Light	8.1J	1
		Total	55
Neutron Source Calibration	Oak Ridge National Lab	44010C	2
	Sandia National Lab	44010C	4
	Naval Research Lab	44010C	2
	Westinghouse/Bettis	44010C	1
	Lawrence Livermore National Lab	44010C	1
	U. S. Air Force, Newark	44010C	1
		Sub Total	11
	In-house (NBS) Sources	N/A	4
		Total	15

Division 536, Calibration Services Performed (cont'd)

II. Radioactivity Group

August 1, 1986 to August 1, 1987

Category	Scheduled Calibrations		Non-scheduled Tests	
	Number of Sources	Total Fee $k	Number of Sources	Total Fee $k
Alpha-particle Sources 8.2 H, I, J	21	17.1	4	4.6
Beta-Particle Solutions and Gases (^{85}Kr) 8.2 P, Q, R	--	--	5	6.8
Gamma-ray Solutions, Point Sources, and Xe Isotopes	3	2.9	19	9.2
Mixed Radionuclide Sources, Solutions and Gases	--	--	8	4.1
Other Services	--	--	--	2.8
	24	20.0	36	27.5

Division 536, Calibration Services Performed (cont'd.)

III. X-Ray Physics Group

Customer Classification	Type of Service	No. of Customers	No. of Tests Performed	Service Fee Income
Industrial:	A	26	148	$34,508
medical product	B	4	11	5,237
sterilization	C	7	40	2,742
Industrial:	A	11	27	6,618
electronic hardness	B	3	43	11,221
testing	C	0	0	0
Industrial:	A	0	0	0
polymer	B	0	0	0
modification	C	0	0	0
National Laboratory:	A	0	0	0
electronic hardness	B	1	34	8,807
testing	C	0	0	0
Dept. of Defense:	A	0	0	0
electronic hardness	B	0	0	0
testing	C	0	0	0
Secondary	A	0	0	0
Calibration	B	1	2	1,222
Laboratory	C	0	0	0
University:	A	1	1	200
Research	B	0	0	0
	C	0	0	0
Subtotals:	A	38	176	$41,326
	B	9	91	26,487
	C	7	40	2,742
Grand Totals:	XXX	54	307	$70,555

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

Division 536, Calibration Services Performed (cont'd.)

IV. Dosimetry Group and X-Ray Physics Group

Type of Service	Customer Type*	SP 250 Item No.	Number of Tests	Income
Calibration of x-ray and γ-ray measuring instruments, and irradiation of TL dosimeters	1-7	46010-50	316	$141 k
Calibration of γ-ray and β-particle sources	2-6	47010-40	17	$ 11 k
Chemical dosimetry measurement assurance service for electron beam	2	48010-20	146	$ 29 k
High-dose irradiation and interpretation	3-7	49010-50	383	$ 74 k
Irradiat. of TLDs and prep. of units for shipboard measurement	Navy	N.A.	285	$100 k
Instrument calibration and evaluation	5	N.A.	10	$ 10 k
Totals			1160	$330 k

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

SPONSORED SEMINARS AND COLLOQUIA

Division 536, Ionizing Radiation

Elfinn Larsen, Risø National Laboratory, Denmark, "Mass Spectrometry at Risø," January 20, 1987.

Thomas Werge, Institute of Microbiology, University of Copenhagen, "In-Vitro Regulation of Cellular and Viral Oncogenes by Antisense RNA," February 17, 1987.

Sigmund Guldbakke, Physikalisch-Technische Bundesandtalt, Braunschweig, West Germany, "High Energy Photon Fields: Production, Dose Calibration, and Contamination," April 9, 1987.

Gunther Dietze, Physikalisch-Technische Bundesanstalt, Braunschweig, West Germany, "Determination of Neutron Cross Sections and Kerma Factors on Carbon," April 14, 1987.

Marc F. Desrosiers, Argonne National Laboratory, Agronne, IL, "Detection of Transient Organic Radical Cations Produced in Pulse Radiolysis. Time-Resolved Fluorescence Detected Magnetic Resonance," April 28, 1987.

Krzysztof Morstin, Brookhaven National Laboratory, Upton, NY, "Nuclear Model Calculations for High-Energy Neutron Dosimetry," May 26, 1987.

John T. Lett, Colorado State University, "Towards a General Theory of Cellular Radiosensitivity: Recent Experimental Results," May 27, 1987.

Wolf Mannhart, Physikalisch-Technische Bundesanstalt, Braunschweig, West Germany, "Introduction to Generating Covariances of Experimental Data," July 14, 1987.

Wolf Mannhart, Physikalisch-Technische Bundesanstalt, Braunschweig, West Germany, "Evaluation of the Californium Neutron Spectrum," July 16, 1987.

Gideon Barnea, Raphael Laboratory, Haifa, Israel, "Electron/Photon Transport Calculations with Application to Radiography, Dosimetry and Radiation Shielding," August 21, 1987.

Elizabeth K. Balcer-Kubiczek, University of Maryland School of Medicine, "Effects of Neutron Dose Rate on Carcinogenesis in Vitro," August 27, 1987.

Melvin Siedband, Department of Radiology, "Digital Radiography," University of Wisconsin, September 10, 1987.

Tony Berejka, Radtech International, Huntington, NY, "International Industrial Markets for Electron Beam Accelerators," September 16, 1987.

TECHNICAL ACTIVITIES

Division 530.1 - Nuclear Physics Group

The Center for Radiation Research conducts a fundamental research program in nuclear and high energy physics. This program includes both theoretical and experimental projects that address priority questions in these areas. The personnel in this group are strongly coupled to related research efforts around the world through active collaborations with leading scientist at several major facilities or institutions. This program maintains a window for the Bureau into forefront research on the fundamental structure of matter and provides a source of expert advice and skills to other NBS scientists engaged in nuclear radiation measurements or studies of radiation interactions at the nuclear level.

The CRR experimental program in this area is now being carried out at world-class facilities operating or being constructed in the US and Canada for fundamental nuclear and particle physics. This user mode of operation has become necessary with the curtailment of operation of the NBS Linac and the shift in commitment of the RTM to that of injector for the free electron laser being constructed at NBS.

Theory activities are carried out by M. Danos, L.C. Maximon, S. Meshkov, and J.S. O'Connell, while experimental work is carried out by W.R. Dodge, E. Hayward, J.W. Lightbody Jr., and until recently, X.K. Maruyama. Dr. Maruyama resigned in July and accepted a faculty position at the Naval Postgraduate School in Monterey, California. The experimental effort currently involves measurements at several major nuclear facilities, including: the MIT/Bates laboratory, the SLAC/NPAS facility, the Berkeley 88" Cyclotron, the Triangle Universities Nuclear Laboratory (TUNL), the Saskatchewan linac/pulse stretcher CW electron facility, the Indiana University Cyclotron Facility (IUCF), and other laboratories. The NBS Nuclear Group is also heavily involved in user activities and planning for CEBAF, the DoE funded flagship facility dedicated to nuclear research. This facility will be the center of nuclear research in the US for the rest of this century. Theoretical efforts include studies of coincidence electron scattering processes, few-nucleon physics, Coulomb distortion and dispersive effects in electron scattering, neutrino reaction rates, muon catalyzed fusion, quark gluon plasmas and related phenomena, and the spectroscopy of elementary particles using QCD. Approximately two-thirds of our theory effort is related to intermediate energy nuclear physics, the balance in high energy physics. Both the theoretical and experimental members of the group continue to work at the forefront of particle and nuclear physics.

The NBS research program profits greatly from the participation of guest scientists and collaborators (university faculty and graduate students), who extend our resources and bring in new ideas. This year many visitors and guest scientists contributed to our basic and applied

research programs. The list of scientific colleagues who have participated in collaborative research with the Nuclear Physics Group includes: Everett Fuller, retired NBS Nuclear Physics Group employee; Miles McCord, Hall Crannell, Dan Sober, and Larry Fagg from the Catholic University of America; Dennis Skopik from the University of Saskatchewan, Canada; Bent Schroder and co-workers from the University of Lund, Sweden; Haaken Olsen from the University of Trondheim, Norway; Johann Rafelski, University of Arizona; George Chang and Chul Park, University of Maryland; Ralph Fiorito and Don Rule from the Naval Surface Weapons Center. We encourage these involvements and, additionally, have a seminar program which brings outside speakers to NBS.

In addition to guest scientists visiting NBS, a few members of the Nuclear Physics Group have had extensive stays at other nuclear laboratories: M. Danos, Centre d'Etudes Nucléaires de Saclay, France; Institute for Theoretical Physics, University of Frankfurt, West Germany; Institute of Theoretical Physics and Astrophysics, University of Cape Town, South Africa; L. Maximon, Centre d'Etudes Nucléaires de Saclay, France; S. Meshkov, Aspen Center for Physics (Aspen, CO); Institute for Theoretical Physics of the University of California at Santa Barbara; and E. Hayward, Duke University. During this year, E. Hayward began a three month leave to teach a graduate physics course at Duke University, and J. Lightbody began a one year leave to become Program Director for Intermediate Energy Nuclear Physics at the National Science Foundation. These visits provide valuable new insights to our current research and often provide the perspective to plan and direct our future research activities.

This year the experimental part of the Nuclear Physics Group underwent several changes. The most important of these is the concentration on outside user activities. In support of our research, we have been highly successful in competing for beam time at various major facilities, including MIT/Bates linac, Saskatchewan linac/pulse stretcher ring, SLAC/NPAS, Berkeley 88" cyclotron, IUCF (detector tests), and the Groningen (Holland) cyclotron. Although Xavier Maruyama, of our staff, has left NBS to take a position as Professor of Physics at the Naval Postgraduate School, we expect to have a continued involvement with him in both our nuclear experiments and in our applied studies of transition radiation and other sources of coherent radiation.

In the following sections we outline the groups primary research activities during FY87. This list includes experimental activities at other laboratories, electromagnetic nuclear physics theory, nuclear theory, elementary particle physics, and miscellaneous activities.

External Activities. Last year we presented a proposal to study the $^3He(\gamma,2p)$ reaction using a CW bremsstrahlung beam at the Saskatchewan linac/pulse stretcher ring facility in Saskatoon. This work will be carried out using the 10 μa beam expected late calendar year 1987. The goal of the experiment is to look for evidence of three-body effects in

nuclear photodisintegration. Laget has estimated the cross section including three-body effects. The (γ,2p) process should be down by two orders of magnitude from the (γ,pn) process. By selecting kinematics that suppress the dominant one- and two-body dipole and quadrupole breakup amplitudes, we hope to get an estimate of the magnitude of three-body effects. By choosing photon energies below pion threshold we have a kinematically complete experiment when the proton energies and angles are measured, even when a bremsstrahlung beam is used. Our plan is to use two plastic scintillator DE-E telescopes for this measurement, which should provide sufficient particle identification to separate 2-body and 3-body breakup processes. We feel that the additional use of polarized gammas from off-axis bremsstrahlung may provide an extra handle on the nature of any background processes related to the dominant quasideuteron absorption process. Collaborating in this experiment with the NBS group are researchers from the University of Saskatchewan, the University of Regina, and the University of Maryland. Detectors and target cells have been constructed. Detector tests have been performed at the parasite proton beam facility at IUCF. This experiment will be the PhD thesis of C. Park of the University of Maryland. (W.R. Dodge, J.W. Lightbody, and J.S. O'Connell)

In a continuing effort, members of our group are collaborating with H. Weller and M. Whitton of Duke University in an experiment to study the D-state in ^{4}He. This experiment uses beams of vector and tensor polarized deuterons provided by the 88" Berkeley cyclotron and by the University of Groningen (Holland) cyclotron. Polarized deuterons are captured by the deuterons in a CD_2 target and the ground-state capture gamma rays are detected over an angular range extending from 45 to 135 degrees. Tensor and vector analyzing powers have been measured. New data have been taken in which alpha/gamma coincidence techniques were employed to reduce backgrounds. Further measurements are planned using a spin precession solenoid, in order to access other components of the analyzing power. A number of interesting questions have arisen as a result of these data. Our group provided one of the two detector systems used in this experiment. (W.R. Dodge and E. Hayward)

This year our group, in collaboration with groups from CEBAF, University of Virginia, William and Mary College, and Stanford, has made a proposal to make an (e,e'p) measurement on ^{4}He at the SLAC/NPAS facility. This is a forefront experiment to search for medium modifications to nucleon electromagnetic structure functions when nucleons are bound in nuclei. The experiment (NE16) was approved by the SLAC Program Advisory Committee in a very strong competition for beam time. We have been given the go-ahead for a month long run next year. The existing detection systems for the SLAC 1.6 and 8 GeV spectrometers will have to be modified to enhance the fast rejection of events not originating in the target. This is a problem arising from the low duty factor of the SLAC accelerator. Our group has assumed the responsibility for upgrading the 8 GeV detector package. This involves constructing two large plastic

scintillator hodoscopes with x-y position sensitivity. This experiment is a predecessor for experiments to come when CEBAF comes on-line. It addresses questions about the quark substructure of nucleons and their possible deconfinement in nuclei. (W.R. Dodge, J.W. Lightbody, and J.S. O'Connell)

Our work at the MIT/Bates laboratory this year includes the following list of currently active experiments in which we are involved, or those in final stages of analysis:

(1) ^{238}U(e,e'f) in the delta resonance region,
(2) ^{52}Cr(e,e') 180 degree scattering,
(3) ^{3}H,^{3}He(e,e'),
(4) (e,e'p) quasielastic studies using polarized electrons,
(5) (e,e'p),(e,e'alpha) giant resonance decay,
(6) (e,e'p) quasielastic studies of attenuation lengths,
(7) (e,e'p) quasielastic studies of current operators,
(8) transition radiation studies.

The ^{238}U(e,e'f) work is in collaboration with the University of Lund and University of New Hampshire nuclear physics groups. Preliminary data were taken two years ago. When the fission data are integrated to give the partial contribution to the inclusive results we obtain a rather flat spectrum in energy loss. This is in contrast to the result expected on the basis of arguments that all knockout and delta processes at this energy loss should lead to fission. Apparently in the quasielastic scattering process at this momentum transfer there is insufficient residual interaction to induce fission. However, in the delta region we appear to arrive at the full inclusive cross section, consistent with the delta damping strongly into many-body channels, and thus providing the residual energy required to induce fission. During June 1987 new data for ^{238}U and ^{233}U were taken with the Bates 800 MeV electron beam, using improved parallel plate avalanche detectors for the fission fragments. These data are currently undergoing analysis. (W.R. Dodge, J.W. Lightbody, J.S. O'Connell, and X.K. Maruyama)

The ^{52}Cr(e,e') 180 degree scattering experiment to study properties of the first 2+ state transverse form factor is in final stages of analysis. These data have been taken in collaboration with J. Flanz of MIT and R. Lindgren of the University of Virginia. Data have been taken at momentum transfers between 0.5 and 1.2 fm^{-1}. The preliminary results have been compared with shell model calculations by R. Mooy of Drexel University, and also with a result obtained from the measured longitudinal form factor using the continuity equation to relate the transverse and longitudinal form factors. The shell model results use effective charges of 2.16e for protons and 1.16e for neutrons. Both the shell model and phenomenological model fail to predict sufficient transverse strength. DWBA calculations are planned during the coming year. (J.W. Lightbody and X.K. Maruyama)

The $^{3}H,^{3}He(e,e')$ experiment is a collaboration involving many of the Bates users, too numerous to mention here. The target was a cooled gas system developed at Bates, and was operated near 45 K. at a pressure of approximately 220 psia. Data were taken at electron beam energies between 100 and 815 MeV, and for scattering angles between 54 and 134 degrees. The data are being analyzed at Bates and at UVA. The primary results will be improved radii determinations, threshold measurements to compare with breakup calculations, quasielastic measurements, and measurement of the delta production cross section. Together with earlier measurements on the deuteron and recent Saclay data on ^{3}H, these data should provide a data base with which stringent tests of few-body calculations can be made. The elastic scattering results will be published in Physical Review Letters shortly. All inelastic data are in the final stages of analysis, and will be the basis for further publications. (W.R. Dodge, J.W. Lightbody, and X.K. Maruyama)

A proposed (e,e'p) experiment to measure the polarization- related, fifth structure function in the quasielastic region was deferred until detector development could be made and a reliable polarized electron beam was available. Work is continuing to develop large area, high-purity Ge detectors, and to see if such detectors can be made to operate in the Bates beam environment. Directors reserve beam time at Bates will be used in the fall for this effort. Protons of 135 MeV kinetic energy will be detected t backwards angles in the Ge detectors, and electron coincidences will be sought in the ELSSY spectrometer. Recirculator energies will be required. Calculations in support of this experiment have been performed by VanOrden of the University of Maryland using a relativistic potential model. We are currently examining several options for measuring the beam polarization including (1) polarization of synchrotron radiation, (2) Møller scattering from a magnetized iron foil, and (3) Compton scattering of laser light by the electron beam. In addition to this work we are conducting background tests this fall to determine operating characteristics of our out-of-plane spectrometer required in this measurement. (W.R. Dodge, J.W. Lightbody, and J.S. O'Connell)

In collaboration with the University of Maryland, the University of New Hampshire, Stanford, and MIT we are determining the feasibility of measuring the (e,e'p) and (e,e'α) cross sections for ^{12}C and ^{16}O in the GDR excitation region. Initial studies made two years ago seemed encouraging, but runs made in May 1985 indicated severe beam halo problems. Progress in reducing the beam halo has been made recently by observing the beam on a series of ZnS screens with holes in the center through which the most intense part of the beam could pass. The most recent tests indicate that the proposed experiments may indeed be possible at Bates. (W.R. Dodge)

The A-dependence of the ratio of (e,e'p) coincidence to (e,e') events was measured during this past year to determine the macroscopic attenuation of 140 MeV nucleons. This was a collaborative study involving Argonne National Laboratory, Northwestern University, MIT, the University

of Maryland, Mount Holyoke College, and NBS. The OHIPS spectrometer was used to detect 600 MeV/c electrons in coincidence with 400 to 600 MeV/c protons detected in the BIGBITE spectrometer. The data from this experiment is presently under analysis and should provide information on proton propagation in nuclei which is essential for the analysis of many processes, including pion absorption and inclusive proton induced reactions. (X.K. Maruyama)

The use of transition radiation as a source of hard x-rays for applications is being investigated in collaboration with M.A. Piestrup of Adelphi Technology, M.J. Moran of LLNL, and B.L. Berman of George Washington University. A Bates experiment was run during this past year to demonstrate that high fluxes of x-rays can be obtained from high average current electron beams at moderate energies. The goal of the preliminary experiment was to (1) to measure the absolute flux of x-rays from foil stacks of transition radiators, and (2) to destructively test these stacks over long periods of time. Potential applications for transition radiation include uses for angiography, x-ray lithography, beam diagnostics, and particle detection. This work is continuing. (X.K. Maruyama)

In addition to the above active areas of investigation, we published an expanded paper describing our earlier work (in collaboration with the University of Lund, MIT, and UNH) on the excitation of the delta resonance by forward angle electron scattering (J.S. O'Connell et al., Phys. Rev. Lett. 53, 1984.) The expanded work contains the complete data set including data taken at 537 MeV as well as the 730 MeV data. Details of the data analysis and comparison to δ-hole model calculations by Koch and Ohtsuka were presented. The δ-hole calculations were found to underestimate the measured cross sections in the resonance region by about 20 percent, but describe the shape rather well. (W.R. Dodge, J.W. Lightbody, X.K. Maruyama, and J.S. O'Connell)

In order to analyze data tapes generated by off-site collaborations, a Digital MicroVAX II computer was acquired this year. A MicroVAX II is directly compatible with the computers used in all of the laboratories with which we now have collaborations. Installation of hardware and software has begun. We will be installing the Los Alamos MP Group's Q system in order to replay data taken at the MIT/Bates and Saskatchewan labs. A link to the NBS CYBER computer will be established so that network facilities of the NBS CYBER can be employed. This addition is a very important resource for our group's user activities. (W.R. Dodge, J.W. Lightbody, and J.S. O'Connell)

Finally, this year we participated in an evaluation of synthetic diamonds as radiation damage insensitive, radiation detectors. These detectors have very poor resolution but are indeed very radiation resistant. This study was undertaken at the request of the U.S. Army standardization group stationed in London. The small size of these detectors suggests their possible use as beam halo monitors in electron scattering experiments. (W.R. Dodge)

Electromagnetic Nuclear Theory Activities. In connection with the design of tagged photon systems, a detailed analysis of the fully differential cross section and polarization for bremsstrahlung is being carried out for small angles and high energies of the final electron and photon. In addition, simple, analytic closed form expressions have been developed for the angular distribution of the scattered electron (integrated over photon angles) including the effects of atomic screening. A study of wide angle bremsstrahlung has been initiated in order to estimate the cross section for low energy photon production, extending down to 10's of keV. This fundamental work is being undertaken because of the importance of this process to the successful operation of the 10-20 M$ large acceptance detector being built at CEBAF for an extensive program of coincidence measurements. In addition to studies of bremsstrahlung, analysis of electron and positron scattering from nuclei is continuing in collaboration with experimentalists at the University of Illinois and at the Division of High Energy Nuclear Physics, Saclay, France. Investigation has continued into the photo and pionic disintegration of few body systems (^{2}H,^{3}H,^{3}He), particularly in the region dominated by the isobar (200-400 MeV). The aim is the formulation of a relatively simple model for these reactions, for comparison with currently existing data, in particular, the recent experimental data on the radiative capture of polarized protons by deuterons. Finally, work is beginning on a calculation of continuum 3-body final states, including rescattering to all orders. This work is a collaboration between NBS, George Washington University, and several universities in Europe and Japan, and will be very important in the analysis of data for a ^{3}He(γ,2p) measurement which the NBS experimental group has undertaken. (L.C. Maximon)

In addition to the above investigations, work is continuing in connection with the momentum transfer dependence of the quasi-elastic peak position observed in electron scattering. This effect, observed for ^{4}He and ^{12}C, can be related to the concept of effective mass and in turn to momentum dependence in the mean field experienced by the knock-out nucleon. This work is being carried out in collaboration with the University of Lund photo-nuclear group. In a collaboration with E. Dressler of Penn State, a calculation of the (e,e'Nπ) cross section is being carried out within the context of the Fermi gas model. This type of calculation will be useful for estimating counting rates for experiments planned for CEBAF and other CW electron beam facilities. The delta resonance is a composite πN system and dominates pion and photon reactions at intermediate energies. Its production, propagation, and subsequent decay into the pion-nucleon channel is therefore of great importance. In collaboration with T. Gaiser of the Bartol Research Foundation, work has continued on calculating the spectra of leptons generated by cosmic ray neutrinos. (J.S. O'Connell)

Finally, in connection with CEBAF planning, we are continuing to examine the prospects for studying the two-nucleon knockout reaction with the high energy beams planned for CEBAF. We are looking at the various known processes that contribute to this reaction, including final state

effects, meson exchange currents, as well as initial state two-body correlations. We are also examining the processes that will form the experimental backgrounds to the two-nucleon knockout reaction. We have modeled the proton electro-production process including quasi-free knock-out, delta production and decay, and quasi-deuteron breakup. We have also modeled the single arm electron scattering process in the quasi-free, delta production, higher resonance, and x-scaling regions. Through these efforts we hope to find the sensitivity of the various measurable structure functions to the processes of interest, using this as a guide to plan measurements at CEBAF. We have produced a FORTRAN program for these purposes. Many university nuclear groups around the country have utilized this program for planning their experiments at the future CEBAF laboratory. A published version of this effort will soon be available. (J.W. Lightbody and J.S. O'Connell)

During this year we have continued to address the problem of the polarizability of the nucleon. This quantity is of fundamental importance relating to basic predictions of QCD, and plans are being drawn for the experimental study of both the electric and magnetic polarizability using the new generation CW electron machines. The photonuclear absorption cross section of the proton is dominated by the delta-resonance, a magnetic dipole state. This resonance overlaps an electric dipole continuum and is followed at higher energies by other pion-nucleon resonances of electric dipole and quadrupole character. It is difficult to reconcile what we know about the total photo-absorption cross section with the results of earlier and somewhat imprecise photon scattering experiments, which conclude that the electric polarizability is ten times the magnetic polarizability. The theoretical answer to this problem might lay in a proper treatment of retardation effects. Experimentally, the magnetic polarizability should be better determined. One possiblility is to use a linearly polarized photon beam and measure the scattering intensity along the polarization direction. (E. Hayward)

Nuclear Theory. The activities described in this section were carried out by M. Danos and co-workers. In the past, nuclear forces have been treated by computing a nucleon-nucleon 2-body force in terms of meson exchanges between point nucleons treated n second order perturbation, 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. There are two aspects to this problem. First, the short range part of the interaction must be re-done in terms of explicit quark degrees of freedom. 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 anti-quark. There are many-body correlations among the quarks. A program to investigate these forces has been started.

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. In fact, it is nuclear physics which will have to yield information on the confinement effect. As a first step one must achieve an understanding, i.e., a description, of the vacuum itself before considering the interface. 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 gap, which exhibits a Meissner-Ochsenfeld effect, and which can not be described by perturbative quantum field theory. More particularly, it is believed that these characteristics of the physical vacuum result from the infrared properties of QCD. Utilizing these considerations, an attempt is underway to construct a model of the QCD vacuum with the techniques developed in the context of superconductivity theory.

The other aspect concerns the long-range part of the interaction, i.e., that part where the microscopic structure of the vertex is unimportant. There the many-body aspects of the system nucleon-plus-mesons have to be accounted for, which are neglected in the presently employed perturbation treatment of the nuclear force. This proper description requires that the nucleus be treated as a relativistic many-body system. A program of such a treatment is underway.

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 high energy collision of two heavy nuclei. Diverse aspects of this subject are being explored.

An example of the importance of quarks in the nucleus is a recent study in which experiments at SLAC and CERN have been used to show that between 2 and 10 percent of the quark wave function occupies the nucleus as a whole rather than being correlated into individual nucleons.

In a more applied direction, work is continuing on the study of muon catalyzed fusion. New experimental developments on the effectiveness of muons to catalyze d-t fusion have been impressive, with as many as 150 fusions per muon being produced. If this rate can be increased 2- or 3-fold, we will be on the verge of breakeven in raw energy production. Atomic, molecular, and nuclear theorists are actively examining the theory of this process to see where theoretical limits set in. This is a large cross disciplinary effort. Our work was cited in a recent Scientific American article examining this important and exciting field. (M. Danos.)

Elementary Particle Theory. The elementary particle theory program under S. Meshkov is varied, with activity on several fronts. QCD: Two comprehensive reviews of Glueballs and Meson Spectroscopy were presented at the Division of Particles and Fields meeting of the American Physical Society, Salt Lake City, January 1987, and at the Recontre de Moriond, Les

Arcs, France, March 1987. These reviews presented by S. Meshkov and done in collaboration with W. Palmer and S. Pinsky of Ohio State University, examined the most recent data on the ι/E systems to elucidate the quark/glue nature of these particles. Recent data implies that the system is comprised of two or more states: a high mass state, the ι(1460-1500 MeV), has JPC=0^{-+} and has a considerable amount of glue in its wave function. The low mass state (or states) around 1420 MeV, has JPC=0^{-+} and /or 1^{++}. The latter states are of interest in understanding hadron spectroscopy. t-quark mass: Recent experiments on B^0-$\overline{B}^0$ mixing imply a mass for the t (top) quark of greater than 100 GeV. This is far higher than previously anticipated. A new area of research by S. Meshkov, in collaboration with P. Kaus (U.C.- Riverside), has been to find mass matrices that explain the quark spectroscopy for the u(up), d(down), s(strange), c(charm), b(bottom), and t(top) quark masses. Carrying out this program involves research on CP violation as manifested by KO-KO and B^0-$\overline{B}^0$ mixing. This study also involves predicting the spectrum of heavy $t\overline{t}$ states, meson states, which provides the first spectroscopic test of the running of the strong coupling constant as predicted by asymptotic freedom.

Miscellaneous Activities. During the past year members of our staff have participated extensively in outside activities. S. Meshkov has been heavily involved in the administration of the Aspen Center for Physics as head of the Summer Program Committee and as Chairman of the 1988 Aspen Elementary Particle Physics Winter Conference. J.S. O'Connell continues his activities on the Physical Review C Editorial Board. He delivered lectures at the NSF sponsored National Summer School on Intermediate Energy Nuclear Physics, held at Georgetown University. E. Hayward continues as a member of the American Physical Society's DNP Executive Board, and the Southeastern Universities Research Association (SURA) Board of Directors. She is Chairperson of the 1988 Spring Meeting of the American Physical Society to be held in Baltimore. X.K. Maruyama was responsible for the successful FEL proposal and 5 M$ construction award made to NBS early in 1987. This facility will be one of the major new NBS research facilities during the coming decade. M. Danos was responsible for running a DoE sponsored workshop on muon catalyzed fusion, which is becoming an important and promising new direction for long range planning of energy production in the U.S. J.W. Lightbody chaired the multi-hadron working group at CEBAF, is Chairman of the CEBAF Users Group, and served on the CEBAF National Advisory Board (NAB) and Program Advisory Committee (PAC). He serves on the Saskatchewan Accelerator Laboratory PAC, lectured at the Summer School for Intermediate Energy Nuclear Physics held at the International Center for Theoretical Physics in Trieste (Italy), and is now on temporary assignment to the NSF as Program Director for Intermediate Energy Nuclear Physics. Every member of the group has given lectures at other institutions and participated heavily in user

activities. The theorists of the group have, in addition to carrying out their own research, provided guidance and advice to the experimental members of the group whenever needed.

We feel that the Nuclear Physics program represents the long range NBS goals in nuclear research, and there is a growing vitality and enthusiasm from strong involvement with the larger nuclear research community. The theoretical efforts cover the full spectrum of current interest in nuclear research. The experimental effort represents a strong fundamental research program which makes full use of world class facilities.

SPONSORED WORKSHOPS, CONFERENCES AND SYMPOSIA

Division 530.01, Nuclear Physics Group

Danos, Michael, Workshop On Muon Catalyzed Fusion, Department of Energy, April 29-30, 1987.

INVITED TALKS

Division 530.01, Nuclear Physics Group

Danos, Michael, "Anomalies In Quantum Field Theories", Physics Seminar, University of Bonn, Germany, February 26, 1987.

Danos, Michael, "Recent Developments In D-T Muon Catalyzed Fusion; Outlook For The Future", Physics Seminar, University Of Maryland, Baltimore, Maryland, April 6, 1987.

Danos, Michael, "Sticking In Muon Catalyzed Fusion", International Symposium Muon Catalyzed Fusion - 87, Gatchina, Leningrad, May 26-29, 1987.

Danos, Michael, "Interplay Of Molecular And Nuclear Degrees Of Freedom In Muon Catalyzed D-T Fusion", Physics Seminar, Rutgers University, New Brunswick, New Jersey, September 14-15, 1987.

Dodge, William R., "Differential Virtual Photon Spectra For All Electric Multipoles In The Long Wavelength Approximation", APS Meeting, Denton, Texas, November 10-12, 1986.

Hayward, Evans V., "The Polarizability Of The Nucleon", Physics Seminar, Duke University, Durham, North Carolina, October 2, 1986.

Hayward, Evans V., "The Polarizability Of The Nucleon", Physics Seminar, Center For Radiation Research, National Bureau Of Standards, Gaithersburg, Maryland, December 4, 1987.

Hayward, Evans V., "The Polarizability Of The Nucleon", Physics Seminar, University Of Maryland, College Park, Maryland, April 6, 1987.

Hayward, Evans V., "The Polarizability Of The Nucleon", Kernfysisch Versneller Instituut der Rijksuniversiteit, Gronigon, The Netherlands, September 8, 1987.

Lightbody, John W., "A Program Of (e,e'2N) Reaction Studies At CEBAF", CEBAF, Newport News Virginia, February 13, 1987.

Lightbody, John W., "(e,e'2N) Reactions AT CEBAF", International Summer School On Intermediate Energy Nuclear Physics, Trieste, Italy, May 21, 1987.

Lightbody, John W., "(e,e'2N) Knockout Reactions", CEBAF Summer Workshop, Christopher Newport College, Newport News, Virginia, June 24, 1987.

Division 530.01, Invited Talks (cont'd)

Lightbody, John W., Summary: "Working Group On Multihadron Knockout Reactions", CEBAF Summer Workshop, Christopher College Newport College, Newport News, Virginia, June 26, 1987.

Lightbody, John W., "The $^3He(\gamma,2p)$ Reaction And The Three-Body Force", Saskatchewan Accelerator Laboratory, University Of Saskatchewan, Saskatchewan, Canada, August 11, 1987.

Lightbody, John W., "A Study Of Three-Body Forces Using The $^3He(\gamma,2p)$ Reaction", University Of Maryland, September 28, 1987.

Maruyama, Xavier K., "Microwave Cerenkov Radiation As A Diffraction Phenomenon", 9th Conference On The Application Of Accelerators In Research And Industry, North Texas State University, Denton, Texas, November 12, 1986.

Maruyama, Xavier K., "Cerenkov Radiation As a Diffraction Phenomenon", Plasma Fusion Center Seminar, Massachusetts Institute Of Technology, Cambridge, Massachusetts, March 13, 1987.

Maruyama, Xavier K., "Threshold Cerenkov Radiation And Beam Diagnostics", 1987 Particle Accelerator Conference, Omni-Shoreham Hotel, Washington, D.C., March 16-19, 1987.

Maximon, Leonard C., "Tagged Photons", Saskatchewan Accelerator Laboratory, University of Saskatchewan, Saskatchewan, Canada, October 16, 1986.

Meshkov, Sydney, "Glueballs And Meson Spectroscopy", Physics Department, University of Washington, Seattle, Washington, October 12, 1986.

Meshkov, Sydney, "Glueballs And Meson Spectroscopy", Nuclear, Radiological And Accelerator Physics Seminar, Center For Radiation Research, National Bureau Of Standards, Gaithersburg, Maryland, November 7, 1986.

Meshkov, Sydney, "ι/E System", DPF Meeting of American Physical Society, Salt Lake City, Utah, January 11-17, 1987.

Meshkov, Sydney, "Glueballs and the ι/E System", Theoretical Seminar, University of Florida, Gainesville, Florida, February 3, 1987.

Meshkov, Sydney, "Glueballs and Meson Spectroscopy", Colloquim, University of Miami, Coral Gables, Florida, February 10, 1987.

O'Connell, James S., "Electromagnetic Excitation Of The Delta Resonance In Nuclei", Brookhaven National Laboratory, Upton, New York, November 18, 1986.

PUBLICATIONS

Division 530.01, Nuclear Physics Group

Beck, D., J. W. Lightbody, Jr., et al, Elastic Electron Scattering from ^{3}H ^{3}He at Low Q, Proceedings, PANIC Conference, Sendai, Japan, (1987).

Danos, M., B. Muller, and J. Rafelski, Detuning Reduction of Muon Sticking in Resonant Muon-Catalyzed d-t Fusion, Phys. Rev. A34, 3642 (1986).

Danos, M., B. Muller, and J. Rafelski, Comment on Muon-Alpha-Particle Sticking Probability in Muon Catalyzed Fusion, PHys. Rev. A35, 2741 (1987).

Danos, M., The QCD Vacuum, Maratea Summer School, W. Greiner, ed., Plenum Pres (1987).

Lightbody, J. W., Jr., Possible (e,e'2N) Experiments at CEBAF, Proceedings, International Summer School on Intermediate Energy Nuclear Physics, Trieste, Italy, (1987).

Maximon, L.C., A. de Miniac, T. Aniel, and E. Ganz, Tagged Photons, An Analysis of The Bremsstrahlung Cross Section, Physics Reports, 147, No. 4 (1987).

Maximon, L.C. and S. E. Williamson, Piece-Wise Analytic Evaluation of the Radiative Tail from Elastic and Inelastic Electron Scattering, Nucl. Instr. Methods in Physics Research A258, 95 (1987).

Meshkov, S., Glueballs and Meson Spectroscopy, Proceedings of Aspen Winter Conference 1986 (1987).

O'Connell, J. S., et al, Electromagnetic Excitation of the Delta Resonance in Nuclei Conference on Pion Nucleus Physics, Los Alamos, New Mexico, (1987).

Rafelski, J., B. Muller, and M. Danos, Muon Sticking in Catalyzed d-t Fusion: Nuclear Resonance Effects, Proceedings, 4th International Conference on Emerging Nuclear Energy Systems, 1986, Madrid, G. Velarde and E. Minguez eds., World Scientific Publishing Co., Singapore (1987).

Rafelski, H., B. Muller, J. Rafelski, D. Trautman, R. D. Viollier and M. Danos, Muon Sticking in Muon-Catalyzed d-t, Fusion, Mu. Cat. Fus. 1, 315 (1987).

Rafelski, J., and M. Danos, Possible Signature for and Early Hadronization Mechanisms of Quark-Gluon Plasma, Phys. Lett. B192, 432 (1987).

Tupper, G., M. Danos, B. Muller, and J. Rafelski, On the Detection of Cosmic-Background Neutrinos by Acoustic Phonon Scattering, Phys. Rev. D35, 394 (1987).

Whitney, R., J. W. Lightbody, Jr., et al, Inelastic Electron Scattering from ^{3}H and ^{3}He, Proceedings, Particle and Nuclear Physics Interface Conference (PANIC), Sendai, Japan, (1987).

PUBLICATIONS IN PREPARATION

Division 530.01, Nuclear Physics Group

Cardman, L. (Univ. Illinois), W. P. Trower (VPISU), Lightbody, J. W., Jr., Elastic Electron Scattering from ^{12}C.

Danos, M., L. C. Biedenharn, A. Stahlhofen, J. Rafelski, and B. Muller, Theory of the Muon-Catalyzed d-t Fusion.

Danos, M. and L. C. Biedenharn, Anomalies in Lagrangian Field Theory, Phys. Rev. D (in press).

Flanz, J. and J. W. Lightbody, Jr., 180° Electron Scattering from the Low-lying States in ^{52}Cr (MIT).

Maximon, L. C., D. R. Lehman, and J. L. Friar, Conlomb Effects in Asymptotic Normalization Constants: A Soluble Model, (submitted to Phys. Rev. C).

Meshkov, S., ι/E System, Proceedings of DPF Meeting of American Physical Society, Salt Lake City, Utah.

Meshkov, S., Current View of ι/E System, Proceedings of XXII Rencontre de Moriond, Les Arcs, Savoie, France.

O'Connell, J. S., and J. W. Lightbody, Jr., Modeling Single Arm Electron Scattering and Nucleon Production from Nuclei by GeV Electrons.

TECHNICAL AND PROFESSIONAL COMMITTEE PARTICIPATION AND LEADERSHIP

Division 530.01, Nuclear Physics

Hayward, E. V.

Member, Program Committee for the Conference on Fifty Years of Fission.

Member, SURA Board of Trustees.

Member, Subcommittee on Science and Technology of SURA.

Chairman, Program Committee for the Spring meeting of the APS.

Member, Real Photon Collaboration (Mainz).

Lightbody, J. W., Jr.

Chairman, CEBAF User Group.

Member, CEBAF National Advisory Board.

Member, CEBAF Program Advisory Committee.

Member, University of Saskatchwan Accelerator Laboratory Program Advisory Committee.

Director, NSF Intermediate Energy Nuclear Physics Program (as of September 14, 1987).

Chairman, CEBAF (e,e'2N) Working Group.

Co-Chairman, CEBAF Multihadron Knockout Working Group, CEBAF 1987 Summer Workshop.

Meshkov, S.

Member, Organizing Committee 1987 Aspen Winter Elementary Particle Physics Conference.

Chairman, Organizing Committee 1988 Aspen Winter Elementry Particle Physics Conference.

Member, Advisory Board, Aspen Center for Physics.

Division 530.01, Technical and Professional Committee Participation and Leadership (cont'd)

Meshkov, S.

Member, Interagency Seminar Series (Wash).

Member, Keystone Committee on Future Funding of American Science.

Chairman, Program Committee for Summer 1988 Aspen Center for Physics.

O'Connell, J. S.

Member, Editorial Advisory Board for Physical Review C.

President, Users Group, Bates Linear Accelereator Center.

MAJOR CONSULTING AND ADVISORY SERVICES

Division 530.01, Nuclear Physics

J. W. Lightbody, Jr. consulted with The Physical Review C.

J. W. Lightbody, Jr. consulted with DoE Intermediate Energy Nuclear Pysics Grants Program.

J. W. Lightbody Jr., consulted with Program Advisory Boards of CEBAF and the University of Saskatchewan Accelerator Laboratory.

J. W. Lightbody, Jr., participated on National Advisory Board, CEBAF, Newport News, Virginia.

L. C. Maximon consulted by invitation, with experimentalists at Brookhaven National Laboratory and planned experiments on photon scattering.

L. C. Maximon consulted by invitation, with experimentalists at the Saskatchewan Accelerator Laboratory, University of Saskatchewan, Saskatoon, Saskatchewan, Canada, on the design of a tagged photon system for the accelerator laboratory.

L. C. Maximon consulted by invitation, with experimentalists at the Linear Accelerator of the Center for Nuclear Studies, Saclay, France, on the design of photon tagging systems.

L. C. Maximon consulted by invitation, with experimentalists at the Nuclear Physics Laboratory of the University of Illinois at Urbana, Champaign, on the analysis of position scattering experiments.

L. C. Maximon consulted by invitation, with experimentalists at CEBAF, Newport News, Virginia, on the analysis of background radiation in conjunction with large angle spectrometers.

S. Meshkov helped organize QCD - Glueball session for Moriond; also advised Moriond organizers on future relationship between Aspen and Moriond.

S. Meshkov participated in SSC meeting of states.

TRIPS SPONSORED BY OTHERS

Division 530.01, Nuclear Physics Group

Danos, M., Centre d'Etudes Nucleaire de Saclay, France, January 15-30, 1987; CERN, Switzerland, February 1-14, 1987; University of Bonn, West Germany, February 15-March 4, 1987.

Dodge, W. R., Consultation with members of the Nuclear Physics Laboratory of the City University of Sao Paulo, Brasil, February 1-18, 1987.

Hayward, E. V., Participation in an experiment, and seminar at Duke University, Durham, North Carolina, September 27-Ocotber 3, 1986.

Hayward, E.V., Participated in an experiment at TUNL, North Carolina, March 26-April 3, 1987.

Hayward, E.V., Worked on experiment in Berkeley, CA May 28-June 13. This trip was also jointly sponsored by TUNL, The Lawrence Berkeley Lab, and The Hayward Foundation.

Hayward, E.V., Traveled to Europe, August 24-September 15 and attended a workshop and a conference on capture gamma-rays. Also participated in an experiment on D-D Capture in Gronigen. This trip was jointly supported by NBS, Kernfysisch Versneller Institut, and The Hayward Foundation.

Lightbody, J. W., Jr., University of Virginia, Consultation, December, 1986.

Lightbody, J. W., Jr., CEBAF Program Advisory Committee Meeting, February 19-21, 1987, sponsored by CEBAF.

Lightbody, J. W., Jr., Trieste International Summer School on Intermediate Energy Nuclear Physics; Trieste, Italy, May 18-22, 1987 sponsored by the International Center for Theoretical Physics.

Lightbody, J. W., Jr., CEBAF Summer Workshop, Christopher Newport College, Newport News, Virginia, June 22-26, 1987 sponsored by CEBAF.

Lightbody, J. W., Jr., University of Saskatchewan Accelerator Laboratory Miniworkshop, August 10-13, 1987, sponsored by University of Saskatchewan.

Maximon, L. C., Saskatchewan Accelerator Laboratory, University of Saskatchewan, Saskatoon, Saskatchewan, Canada, October 15-19, 1986.

Division 530.01, Trips Sponsored by Others (cont'd)

Maximon, L. C., Center for Nuclear Studies, Saclay, France, December 20-January 12, 1987.

Maximon, L. C., Beijing, PRC International Symposium on Medium Energy Physics, June 23-27, 1987.

O'Connell, J. S., Brookhaven National Laboratory November, 1986.

O'Connell, J. S., University of Virginia, January 1987.

O'Connell, J.S., Los Alamos National Laboratory, Los Alamos New Mexico, August 1987.

CALIBRATION SERVICES PERFORMED

Division 530.01, Nuclear Physics

Pennsylvania State University, high energy physics detector calibration using the NBS Linac.

University of Indiana, calibration using a hadron detector system.

SPONSORED SEMINARS

Division 530.01, Nuclear Physics

J. M. Laget, Center for Nuclear Studies, Saclay, France, Studies of Correlations Using Electron Scattering, July 9, 1987.

LIST OF ACRONYMS

AAMI	Association for the Advancement fo Medical Instrumentation
AAPM	American Association of Physicists in Medicine
AEC	Atomic Energy Commission
AERE	Atomic Energy Research Establishment (U.K.)
AFRRI	Armed Forces Radiobiology Research Institute
AIF	Atomic Industrial Forum
ANL	Argonne National Laboratory
ANS	American Nuclear Society
ANSI	American National Standards Institute
APRES	Angle Resolved Photoelectron Spectroscopy
APS	American Physical Society
ASNT	American Society for Nondestructive Testing
ASTM	American Society for Testing and Materials
Bevalac	Name of a heavy ion accelerator at Berkeley
BGO	Bismuth germanate
BIPM	Bureau International des Poids et Mesures (International Bureau of Weights and Measures)
BPNL	Battelle-Pacific Northwest Laboratory
BSDF	Bidirectional Scattering Distribution Function
CAC	Center for Analytical Chemistry
CAD	Computer-aided Design
CAE	Computer-aided Engineering
CEA	(French) Atomic Energy
CEA	(U.S.) Council for Energy Awareness
CAMAC	Computer Automated Measurement and Control
CCEMRI	Consultative Committee for Ionizing Radiations (to CIPM)
CCPR	Consultative Committee on Photometry and Radiometry
CEBAF	Continuous Electron Beam Accelerator Facility
CERN	European Center for Nuclear Research (Switzerland)
CIE	International Commission on Illumination (French)
CIPM	Comité International des Poids et Mesures
CIRRPC	Committee on Interagency Radiation Research and Policy Coordination, OSTP
CRCPD	Conference of Radiation Control Program Directors
CRDS	Charles River Data System
CRR	Center for Radiation Research
CSEWG	Cross Section Evaluation Working Group
CW	Continuous Wave
DNA	Deoxyribose nucleic acid
DoC	Department of Commerce
DOD	Department of Defense
DOE	Department of Energy
DOELAP	Department of Energy Laboratory Accreditation Program
DRIP	Detector Response Intercomparison Package
DSA	Digital Subtraction Angiography
DTS	Dual thin scintillator
DWBA	Distorted Wave Born Approximation

EC	Electron Capture
EEO	Equal Employment Opportunity
ELSSY	Energy Loss Spectrometer System
EMA	Ellipsoidal Mirror Analyzer
ENDF	Evaluated Nuclear Data File
EPA	Environmental Protection Agency
ESONE	European Standards on Nuclear Electronics
ESR	Electron spin resonance
ETL	Electro-Technical Laboratory (Japan)
EURADOS	European Community Dosimetry Committee
FASCAL	Facility for Automatic Spectroradiometric Calibrations
FDA	Food and Drug Administration
FEMA	Federal Emergency Management Agency
FEL	Free Electron Laser
FERDoR	(computer code)
FGR	Federal Republic of Germany
FIMS	Fissionable Isotope Mass Standards
FOS	Faint Object Spectrograph
FT	Fourier Transform
FTIR	Fourier Transfor Infrared
FWHM	Full Width at Half Maximum
FY	Fiscal Year
GC/MS	Gas chromatography/mass spectrometry
GDR	Giant Dipole Resonance
GPIB	General Purpose Instrumentation Bus
HAFM	Helium Accumulation Fluence Monitor
HPGe	High-purity germanium detector
HPLC	High performance liquid chromatography
HP	Hewlett Packard
HPS	High Pressure Sodium
HPS	Health Physics Society
HVL	Half-value layer
IAEA	International Atomic Energy Agency (Vienna)
IAU	International Union
IBM	International Business Machine Corporation
ICIAQ	Interagency Committee on Indoor Air Quality
ICRM	International Committee for Radionuclide Metrology
ICRU	International Commission on Radiation Units and Measurements
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IMFP	Inelastic Mean Free Path
INEL	Idaho National Engineering Laboratory
INMM	Institute for Nuclear Materials Management

ACRONYMS (Continued)

IPNS	Intense Pulsed Neutron Source
IR	Infrared
ISCC	Inter-Society Color Council
ISNF	Intermediate Energy Standard Neutron Field
ISO	International Organization for Standards
ITP-UCSB	Institute for Theoretical Physics - University of California, Santa Barbara
IUCF	Indiana University Cyclotron Facility
JAERI	Japan Atomic Energy Research Institute
JEN	Junta de Energia Nuclear (Spain)
JET	Joint European Torus
KEK	National Laboratory for High Energy Physics (Japan)
KENS	High Energy Neutron Source (Japan)
KRI	Khlopin Radium Institute (USSR)
LANL	Los Alamos National Laboratory
LBIR	Low Background Infrared
LEED	Low Energy Electron Diffraction
LET	Linear Energy Transfer
LINAC	Linear Accelerator
LLNL	Lawrence Livermore National Laboratory
LTEC	Lamp Testing Engineer's Conference
MCNP	(computer code)
MEA	Materials Engineering Associates
MIRD	Medical Internal Radiation Dose (committee)
MIT	Massachusetts Institute of Technology
MQA	Measurement quality assurance
MRG	Materials Research Group
NAB	National Advisory Board
NAM	National Atomic Museum
NASA	National Aeronautical and Space Administration
NAS-NRC	National Academy of Sciences-National Research Council
NBS	National Bureau of Standards
NCAR	National Center for Atmospheric Research
NCRP	National Council on Radiation Protection and Measurements
NCSL	National Conference of Standards Laboratories
NDE	Nondestructive evaluation
NDT	Nondestructive testing
NESSUS	Reactor pressure vessel irradiation mockup facility
NIM	Nuclear Instrumentation Module
NIR	Near Infrared
nm	Nanometer
NPL	National Physical Laboratory (U.K.)

NRL	Naval Research Laboratory
NRRS	Near resonance Rayleigh scattering
NSF	National Science Foundation
NSLS	National Synchrotron Light Source
NTOFF	Neutron Time-of-Flight Facility
NVLAP	National Voluntary Laboratory Accreditation Program
ONR	Office of Naval Research
ORNL	Oak Ridge National Laboratory
OSA	Optical Society of America
OMEGA	24 Beam Laser Facility at Rochester
P	Polarization parallel to plane of incidence
PAC	Program Advisory Committee
PAC	Particle Accelerator Conference
PC	Personal Computer
PID	Post irradiation dosimetry
PNL	Battelle Pacific Northwest Laboratories
PRC	People's Republic of China
PRT	Proton recoil telescope
PSD	Photon Stimulated Desorption
PTB	Physikalisch-Technische Bundesanstalt (West Germany)
PTFE	Polytetrafluoroethylene
PTW	Physikalisch-Technische Werkstätten
QA	Quality assurance
QCD	Quantum Chromodyanimcs
QED	Quantum electrodynamics
RARAF	Radiological Research Accelerator Facility (Columbia University)
RF	Radio Frequency
RFP	Request for Proposals
RIMS	Resonance Ionization Mass Spectrometry
RIS	Resonance Ionization Spectroscopy
RTM	Racetrack Microton
S	Polarization perpendicular to plane of incidence
SCK-CEN	Studiecentrum voor Kernenergie-Centre d'Etude de l'Energie Nucleaire (Belgium)
SDIO	Strategic Defense Initiative Office
SEM	Scanning Electron Microscope
SEMPA	Scanning Electron Microscopy with Polarization Analysis
SIRIS	Sputter Initiated Resonance Ionization Mass Spectrometry
SLAC	Stanford Linear Accelerator Center
SLAC/NPAS	Stanford Linear Accelerator Center/Nuclear Physics At Stanford Linear Accelerator Center

ACRONYMS (Continued)

SNS	Spallation Neutron Source
SPAD	Neutron exposure estimating code
SPIPES	Spin Polarized Inverse Photoemission
SRM	Standard Reference Material
SSTR	Solid State Track Recorder
STM	Scanning Tunneling Microscope
STOS	Space Telescope Optical Simulator
SURA	Southeastern Universities Research Association
SURF	Synchrotron Ultraviolet Radiation Facility
TAMS	Tandum Accelerator Mass Spectrometry
TC	Technical Committee
TEPC	Tissue Equivalent Proportional Counter
TEXT	Texas Experimental Tokamak
TLD	Thermoluminescent Detector
TRIGA	(research reactor design made by General Atomic)
TUD	Technical University of Dresden (East Germany)
TUNL	Triangle Universities Nuclear Laboratory
TUO	TEXT Users Organization
UK	United Kingdom
UNH	University of New Hampshire
UPS	Ultraviolet Photoemission Spectroscopy
URPs	Unique radiolytic products
USSR	Union of Socialist Soviet Republic
USUHS	Uniformed Services University of Health Sciences
UV	Ultraviolet
UVA	University of Virginia
VIAS	(computer code)
VIS	Visible
VME	(computer bus system)
VUV	Vacuum Ultraviolet
WNR-PSR	Weapons Neutron Source-Proton Storage Ring (Los Alamos)
XUV	Soft X-Ray and Ultraviolet Wavelength Range, 4-50 nm

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