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Center for Radiation Research

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Technical Activities

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U.S. Department of Commerce, C. William Verity, Secretary
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ABSTRACT

This report summarizes research projects, measurement method development, calibration and testing, and data evaluation activities that were carried out during Fiscal Year 1988 in the NIST 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 NIST Center for Radiation Research (CRR) for the period October 1, 1987 to September 30, 1988. 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 NIST centers in the interdisciplinary applications of radiation.

This report summarizes the activities that were carried out by the five divisions and one group that comprised the Center for Radiation Research (CRR) for most of the fiscal year 1988. Specifically the six CRR units included the Atomic and Plasma Radiation Division, the Radiation Physics Division, the Radiometric Physics Division, the Radiation Source and Instrumentation Division, the Ionizing Radiation Division, and the Nuclear Physics Group. Toward the end of that year, however, two divisions, the Atomic and Plasma Radiation Division and the Radiation Physics Division were detailed to the new CAMOP unit. Therefore, we have included both the organizational chart for the old CRR structure and the chart showing the new structure in this report. Each organizational unit tells its own story in its own way. In general there is an introduction followed by a series of short reports on current activities, publications during the year, talks given, committee participation, and professional interactions.

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

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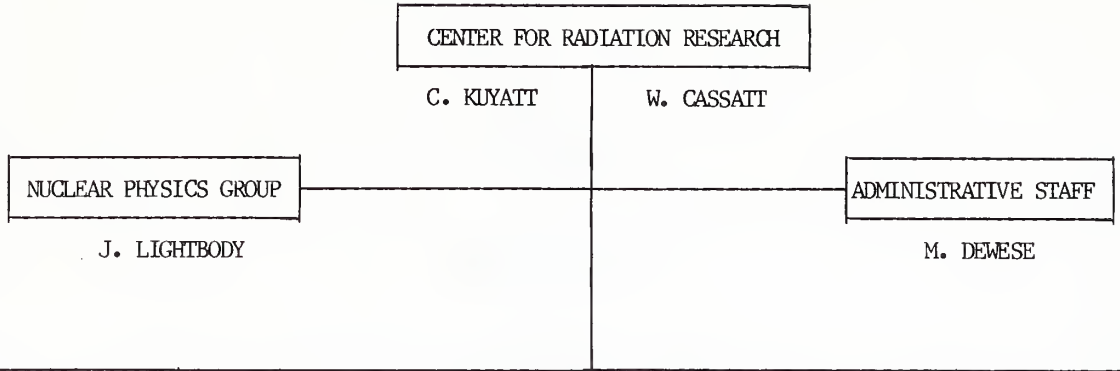

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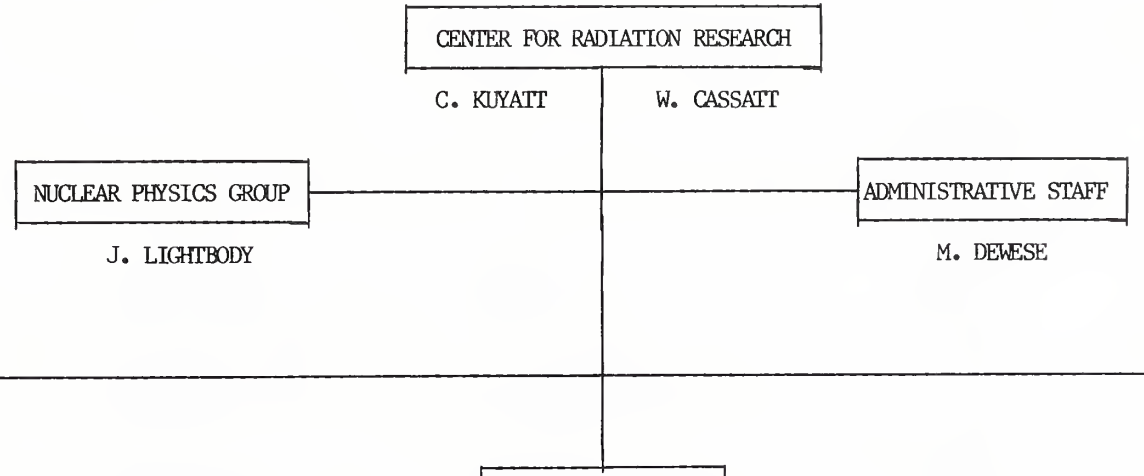

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TECHNICAL ACTIVITIES

Division 531, Atomic and Plasma Radiation Division

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, wavelengths, and transition probabilities. Since in most cases atomic radiation originates from plasmas, we are also engaged in research on the effects of the plasma environment on atomic radiation, such as studies of spectral line broadening and line shifts. We explore these effects in order to gain an understanding of atomic processes in plasmas as well as to utilize them for the development of new measurement techniques. Furthermore, well-defined atomic radiation sources are also developed as VUV radiometric standards and wavelength standards.

Our activities, which support many areas of science and technology, are undergoing significant changes in direction, since appreciable changes have occurred in the external forces that drive our priorities. There is, for example, much increased demand for the detailed understanding of atomic processes in cool plasmas, both for modelling purposes and diagnostics. These needs have arisen mainly from materials processing by plasmas, such as the widely used plasma etching of semiconductors, as well as surface cleaning by plasmas, and materials deposition by plasma sputtering techniques. For commercial applications, the understanding of all these processes on the atomistic level is the key to optimizing the operating conditions and to achieving competitive advantages. Likewise, process monitoring and modelling in plasma chemistry and spectrochemistry can be achieved on a fundamental level only with reliable atomic radiation and collision data. For these technologies heavy neutral elements, including rare earths, are of principal interest.

Very different demands arise from VUV and X-ray laser physics. In this research area, transition energies and lifetimes (or radiative decay rates) of highly stripped ions are essential for the selection and testing of potential laser systems. VUV and X-ray laser research has not only assumed importance for defense applications, but also for biological and bio-medical studies (e.g. the "water window"). We are very active both in generating atomic data, and in the development of lasing schemes. Also, the nation's research program on magnetic fusion energy is steadily progressing, and the atomic data we produce for highly stripped heavy

ions are needed there for modelling the cross-field ion transport, for estimating the effects of impurities on the plasma energy balance, and for plasma diagnostics, such as the measurement of ion temperatures. Beyond this, there is also the fundamental scientific need for an experimentally well-tested, fully relativistic atomic structure theory that accurately describes the properties of highly ionized as well as heavy atoms, including QED effects. Finally, our vacuum ultraviolet radiometry work with plasma sources is now providing miniaturized calibrated radiation source packages to allow radiometric calibrations on board spacecraft. These 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. It currently has 17 professional physicists, among them 16 Ph.D.s. During 1988 the division has had 17 guest scientists, from China (2), Israel (3), India (1), Sweden (3), Canada (1) and U.S.A. (7).

Some of our significant accomplishments during the past year are:

- We have proposed and are involved in experiments, with NRL and KMS Fusion groups, on two new X-ray and XUV laser schemes: Lasing at 26 Å in I^{24+} ions and at 600 Å in Mo^{6+} ions, and patent applications and manuscripts are underway.

- We have demonstrated population inversion and gain in a C IV line in the theta pinch recombining plasma. Experiments in collaboration with Bell Labs. with a reflective cavity give a gain of 12 for the 253 nm UV transition in C IX.

- We have published, or have in press, several major critical data compilations:

  Spectral data tables for all or most ions of Fe, Ni, Cu and Mo. Transition probability tables for all atoms and ions of the iron group elements Sc through Ni - to be published in two volumes of 500 pages each.

- We have devised a very sensitive and clean experimental test of possible violations, or confirmation, of the Pauli Exclusion Principle (PEP) by looking for a helium transition whose very existence would be a consequence of PEP violations, and a preliminary experiment is in preparation.

- A procedure to accurately represent electron-impact excitation cross sections of ions in compact formulas has been developed and applied to relativistic distorted-wave Born cross sections of Be-like and Na-like ions. This is an ideal method to accurately condense the inherently massive volume of data required in modeling applications such as short-wavelength laser design and fusion plasma diagnosis.

- Advanced versions of computer codes to calculate nonrelativistic and relativistic wave functions and transition probabilities have been developed and are being tested for a wide range of atoms and ions. In addition, methods to calculate QED corrections for many-electron atoms are being developed. Theoretical energy levels from these codes are sufficiently accurate to complement high-precision spectroscopic measurements.

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 of basic interest for testing theoretical descriptions of atomic properties, which are affected by large relativistic and quantum-field (QED) contributions. They are also necessary data for the modeling and diagnostics of high-temperature plasmas occurring in x-ray laser research, nuclear fireballs, solar flares, tokamaks and other fusion-research machines, etc. 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 NIST, plasmas generated in the TEXT tokamak at the University of Texas, and sliding-spark and vacuum-spark plasmas at NIST.

We completed analyses of the spectra of Al-like ions (Cu^{16+} through Mo^{29+}) and K-like ions (Cu^{10+} through Mo^{23+}) obtained with the TEXT tokamak. The energy levels of these ions were compared with Dirac-Fock calculations to test the theory and to use the smooth variation of the deviations from experiment for interpolations along the isoelectronic sequences. One result of the comparisons was that inclusion of previously uncalculated QED corrections for the M-shell electrons substantially improved agreement between theoretical and experimental values for the $3s^2 3p\ ^2P$ ground-term doublet splitting of the Al-like ions. The experimental wavelengths from these measurements are sufficiently accurate to be used as standards in fusion-plasma and x-ray laser plasma research. Similar work on ions of the Mg and Cl isoelectronic sequences is in progress (J. Sugar, V. Kaufman, Y.-K. Kim).

We finished work on prominent transitions in the Fe-like ions Ru^{18+} to Gd^{38+}. The spectra were obtained from laser-produced plasmas at NBS, Los Alamos, and Rochester. The energy levels for this sequence were also compared with calculations of the Dirac-Fock relativistic type and the differences were used to accurately predict missing levels and levels for ions not observed. Wavelengths for forbidden (magnetic-dipole) transitions between levels of the $3p^6 3d^8$ ground configuration, which are important for tokamak plasma diagnostics, were derived from the experimental levels. We have papers in press on the spectra and energy levels of gallium-like ions Rb^{6+} to Mo^{11+} and germanium-like ions Rb^{5+} to Mo^{10+} (J. Reader and collaborators from Lund University, Sweden, and the Naval Research Laboratory).

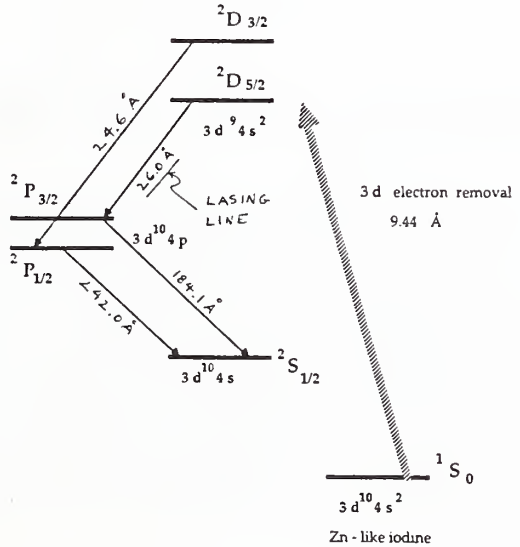
During the coming year we plan visits to both the TEXT tokamak and the Rochester OMEGA laser facility to excite higher-temperature

spectra of heavy elements. One of the experiments planned for the Rochester visit is to extend our previous work on Na-like spectra to the rare-earths region of the periodic table (50 to 60 electrons stripped from the atoms). The one-electron spectra of this sequence are of special theoretical interest, and accurate measurements of the high-ionization stages are also needed for both x-ray laser and magnetic-fusion research.

(b) Atomic-ion x-ray lasers

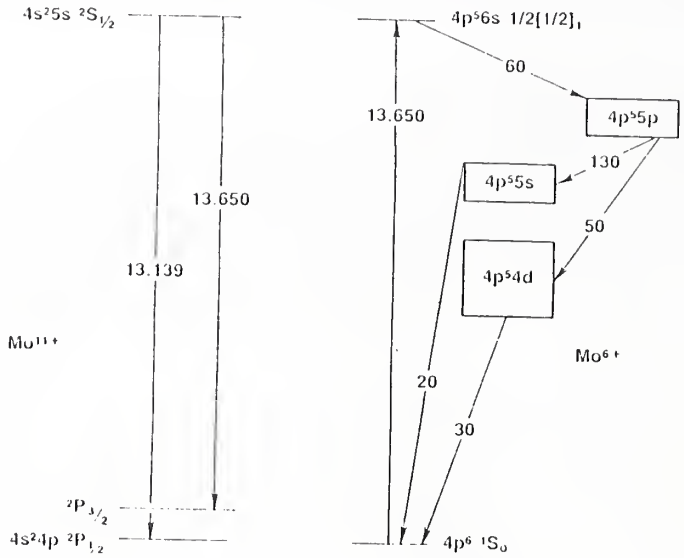
J. Sugar, collaborating with P.D. Morley (KMS Fusion), has predicted that inner-shell photoionization can produce lasing at wavelengths below 50 Å in plasmas generated from laser-exploded foils. Sugar worked out the case for copper-like iodine (I^{24+}) which should lase on the $3d^9 4s^2 \rightarrow 3d^{10} 4p$ doublet calculated at 24.565 and 26.026 Å (see figure). Experiments to test the idea are underway at KMS fusion, and a joint paper is in press.

Scheme for 26 Å laser in Cu - like iodine (I^{24+})



J. Reader's work on the spectra of molybdenum ions revealed a coincidence between a Mo^{6+} line and a Mo^{11+} line at 136.50 Å. Reader and U. Feldman (Naval Research Lab) have proposed a scheme for Mo^{6+} lasing at 600 Å based on using the 136.5-Å Mo^{11+} line to photopump the upper level of the coincidence transition in Mo^{6+} (see figure). Experiments to test

the idea are underway. Reader has discovered that a previous analysis of the Mo^{6+} spectrum done in another laboratory is totally erroneous. He is now analyzing this spectrum to identify the candidate lasing transitions and has found all levels of 5 principal configurations.



(c) Laser Spectroscopy and High-Accuracy Determinations of Atomic Energy-Level Structures

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 goals of 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. Our measurements, calculations, and critical analyses of the energy-level data for helium contribute to a broad effort towards increased understanding of this system.

ATOMIC BEAM SOURCE. An atomic beam apparatus designed for high precision laser spectroscopy of rare gases in metastable states has been constructed and tested. A flux of metastable helium atoms of about 10^{14}/sec/sr has been obtained, corresponding to about 2 x 10^9 metastable atoms per second at a collimation sufficient to reduce the residual Doppler width to 10 MHz (0.0003 cm^{-1}) in the visible region. We are currently readying our first laser observations of the beam source, a

measurement of the 2 ^{1}S - 3 ^{1}P transition. We plan a series of measurements of the 2 ^{1}S - n ^{1}P transitions including highly excited Rydberg states. Accurate wave number determinations for this series should allow determination of the 2 ^{1}S 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 IN HELIUM DISCHARGES. Additional precise measurements of transitions not accessible with the metastable-beam apparatus are required to establish the energies of a number of low-lying helium levels. We are currently observing some of these transitions using Doppler-free laser methods in a low-pressure helium discharge. We have obtained spectra of the 2 ^{3}P - 4 ^{3}S, 2 ^{1}P - 4 ^{1}D, and 2 ^{1}P - 4 ^{1}S transitions and are now attempting to make precise measurements of their wave numbers. As an outgrowth of our laser measurements in helium, we have also recorded emission spectra of low-pressure rf discharges in helium by Fourier spectroscopy. These spectra have not yet been fully analyzed, but they should provide precise measurements for some important transitions not easily observed by laser methods. Most significant of these are the 2 ^{3}S - 2 ^{3}P and 2 ^{1}S - 2 ^{1}P transitions which lie at 1.08 and 2.05 microns. These discharge measurements combined with the results of our metastable beam work and previous laser measurements will provide more accurate absolute ionization energies for virtually all low-lying levels of helium (C. Sansonetti).

MEASUREMENTS WITH FABRY-PEROT WAVEMETER. In all of our laser observations, high accuracy measurements of the dye laser wavelength are required to realize the full potential of the experiments. We have continued to upgrade the Fabry-Perot wavemeter developed in our lab to meet this requirement. Improvements in the optical system and laser beam switch have increased the reliability of the instrument, reduced the laser power required to about 0.5 mW, increased the measurement rate from about 0.7 to 2 Hz, and reduced digitization errors in the computer acquisition of the interference patterns. The instrument has been tested in the green spectral region and has now been used successfully from 4700 to 7000 Å. Throughout this region absolute accuracies of better than 3 MHz (10^{-4} cm^{-1}) are routinely obtained (C. Sansonetti).

(d) Platinum Ultraviolet Reference Wavelengths

The spectrum of a platinum hollow-cathode discharge will be used for on-board wavelength calibration of the High-Resolution Spectrograph (HRS) for the Hubble Space Telescope. Since the absolute wavelength accuracy of this instrument will be the limiting factor in a number of important planned observations, during the past several years we measured the Pt spectrum from 1032 to 4100 Å with our 10.7-m normal-

incidence vacuum spectrograph. Some 3000 lines of Pt I and Pt II have been determined with an average uncertainty of ±0.002 Å. These measurements have been incorporated into the calibration codes for the HRS and are also now used in the reduction of data obtained with the still active (10 years old) IUE satellite. We have in press a paper giving accurate energy levels and wavelengths for the Pt II lines (J. Reader, N. Acquista, C.J. Sansonetti; and R. Engleman, Jr. from Los Alamos). These measurements and our other Pt measurements will also be used extensively for calibrations in high-resolution laboratory UV and VUV spectroscopy.

During the past year we made new scans of the Pt spectrum using photon-counting techniques for detection. Computer reduction of these scans will give accurate intensities for the lines. We plan to produce an extensive atlas of the entire spectrum which will be highly useful for HRS calibrations and for laboratory spectroscopy. A complete paper giving all of our Pt wavelengths is also planned. (J. Reader, N. Acquista, C.J. Sansonetti, and J. Sansonetti).

(e) Atomic Energy Levels Data Center

This center critically evaluates and compiles data on energy levels and spectral lines of atoms and atomic ions. We have just completed a compilation of the energy levels for all 29 copper spectra (Cu I - Cu XXIX) (J. Sugar and A. Musgrove). We also made substantial progress on a similar compilation of energy levels for the sulfur spectra (W.C. Martin, R. Zalubas, and A. Musgrove).

We are including critically evaluated wavelengths as part of a computerized data base on atomic spectra to be built up jointly by the Atomic Energy Levels and Atomic Transition Probabilities Data Centers. We have compiled the wavelengths and energy-level classifications for the 21 scandium spectra and have completed most of a similar compilation for the silicon spectra (V. Kaufman and J. Sugar). Our compilations of wavelengths and energy-levels classifications for all lines of Mo^{5+} through Mo^{41+} and Ni^{5+} through Ni^{27+} were published recently. Similar compilations for the spectra of all Fe and Cu ions stripped of 5 or more electrons have recently been completed or are near completion. (J. Sugar, W.L. Wiese, and Japanese collaborators).

The fourth supplement to our Bibliography on Atomic Spectra, covering the literature from 1984 through 1987, is in press (A. Musgrove and R. Zalubas). A report on laboratory research on atomic spectra of interest for astrophysics was prepared and published in the Trans. IAU (W.C. Martin). We answer many individual requests for information on atomic spectroscopic data and supply lists of references of interest for fusion-plasma research for the bibliographies issued semiannually by the International Atomic Energy Agency.

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 collision 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

(1) A set of computer codes for relativistic atomic structure and collision data has been developed, updated, and implemented on the CYBER 205 at NIST. This work was carried out in collaboration with J. P. Desclaux (French Atomic Energy Commission, Grenoble, France) and P. Indelicato (Division 526 and Université de Paris). New capabilities are (i) Multiconfiguration Dirac-Fock (MCDF) wavefunction code in which the Breit interaction is now calculated in the Coulomb gauge to be consistent with QED procedures for higher order relativistic corrections; (ii) Transition probability code in which MCDF wavefunctions derived from the above code are used to calculate magnetic and electric multipole transition probabilities; (iii) Relativistic distorted-wave Born cross section code in which cross sections for both excitation and ionization of ions with arbitrary target configuration can be calculated; and (iv) Angular momentum algebra code which carries out all angular momentum algebra needed for the above codes.

All codes are based on fully relativistic theory, include correlation, and can be applied to neutral as well as highly charged atoms, hydrogen through transuranium elements. Using these codes, a variety of atomic data were calculated ranging from energy levels to ionization cross sections. As a result, two articles have been published, four articles have been accepted for publication, and a few more are being prepared for publication. (M. A. Ali, Y.-K. Kim, W.-J. Qian and E. B. Saloman, Div. 536)

(2) A systematic study of relativistic distorted-wave Born cross sections for the $2s^2\ {}^1S_0$ - $2s2p\ {}^{1,3}P_1$ excitation of Be-like ions by electron impact has been carried out. We found that the triplet excitation, which is electric dipole (E1) and spin forbidden, gradually becomes E1 allowed due to intermediate coupling, while configuration

mixing in the ground state ($2s^2 + 2p^2$) remains important throughout the periodic table, changing triplet excitation cross sections by as much as 30%. These cross sections are fitted with only four or five coefficients for each transition for incident energies from the threshold to 10 keV. The fitted coefficients, in turn, are expressed in terms of simple power series in atomic number. In order to obtain reliable Z dependence, data for a total of about 15 atoms in the periodic table are needed. About 80 coefficients thus determined reproduce cross sections for both the triplet and singlet excitations from thresholds to 10 keV for all Be-like ions in the periodic table. These coefficients provide a compact yet accurate way to store and reproduce desired cross sections in various modeling codes. (Y.-K. Kim and W.-J. Qian)

(3) In one-electron atoms at high Z, one of the largest uncertainties in the energy levels has been the effect of higher-order vacuum polarization corrections. These are corrections that are third or higher order in the external potential that go beyond the Uehling approximation. To calculate this correction for bound electrons in high-Z atoms, a coordinate space formulation of the problem that takes into account the finite size of the nucleus has been developed in collaboration with G. Soff of GSI, West Germany. Work being done on this topic consists of a systematic application of the method to calculate energy level corrections for various states over a wide range of nuclear charge.

In high-Z two-electron atoms, the dominant uncertainty in the theoretical prediction for the energy levels is due to uncalculated higher-order relativistic corrections in the Feynman diagram with two photons exchanged between the bound electrons. The nonrelativistic limit and first relativistic corrections for this diagram are known, but at high Z, higher-order relativistic corrections are important, and a complete numerical calculation is needed. In a collaboration with S. A. Blundell, W. R. Johnson, and J. Sapirstein of the University of Notre Dame, such a calculation is being carried out for the ground state of helium-like ions. We plan to extend this calculation to excited states where a comparison with experiment can be made.

One of us initiated and participated as a coordinator for a program on "Relativistic, Quantum Electrodynamic and Weak Interaction Effects in Atoms" that was held at the Institute for Theoretical Physics at Santa Barbara (January-June, 1988). Over 30 experts on atomic theory and quantum electrodynamics for many countries participated in the program. (Y.-K. Kim also participated in this workshop, April-May, 1988). One of the goals was to bring quantum electrodynamics to bear on the practical problem of calculating the structure of atoms and ions having more than one electron, especially atoms and ions with high nuclear

charge, where relativistic and QED effects are significant. Much of the effort was devoted to developing a consistent formulation of a many-body QED theory. Another goal of the program was to improve the theoretical calculations of parity-violating amplitudes. Other problems such as spectra of Rydberg atoms, positronium, and positron production in heavy-ion collisions, which involve basic theory were also investigated. A book containing lectures given in the program is being edited in collaboration with W. R. Johnson of the University of Notre Dame and J. Sucher of the University of Maryland. (P. J. Mohr)

(4) Our computation of the dielectronic recombination rates of the ions isoelectronic to the elements of the second row of the periodic table has been completed. A simple model has been used to analyze the reduction of the effective rate of dielectronic recombination by the thermal equilibrium of some of the bound, highly-excited final states produced by the recombination with the plasma electrons in low to moderate density plasmas. The computer codes have been upgraded to include configuration interaction and intermediate coupling in the atomic model. We participated in the IAEA Experts Meeting on Electron-Ion Collision Processes for the Ions of Oxygen and Carbon in Fusion Plasmas and the IAEA Meeting on Atomic Data for Fusion Plasmas. (L. J. Roszman)

(5) A method has been developed to calculate matrix elements of the electric dipole operator between Russell Saunders (L-S coupled) states, for which radial functions have been found via a Multiconfiguration Hartree-Fock (MCHF) procedure where all orbitals are left free to vary. In the past, most of the core had to be frozen in order to calculate the required angular factors under the assumption that the core orbitals were orthonormal. The capability to allow completely relaxed calculations for both the upper and lower states separately lets one account for the same degree of correlation in each state, thereby taking full advantage of the MCHF method. As a first case, we have taken the transitions $1s^2 2s^2 2p^2 3p\ ^4D, ^4P, ^4S \rightarrow 1s^2 2s^2 2p^2 3s\ ^4P$ in neutral nitrogen. Because the last term appears with a mixing coefficient of about 0.35 in the calculation of the $1s^2 2s2p^4\ ^4P$ term of nitrogen, we have also calculated oscillator strengths for allowed transitions to that state, which will make it possible to calculate lifetimes from data taken in an experiment done by Zhu and Wiese of the division. (M. A. Suskin and A. W. Weiss)

(6) Computer codes have been written for calculating dipole transition probabilities, utilizing correlated wavefunctions from the Superposition of Configurations (SOC) programs. These codes are completely general in the sense that no assumptions are made concerning the orthonomality of the orbital sets of the two terms of the transition. Applications are currently being made to alkali and alkaline-earth elements (and isoelectronic ions), Li, Na and Be (also Be+, Mg+, B+ and

$C^{2}+$). Wavefunctions are being computed including core correlation and core-valence intershell correlation, as well as the usual valence correlation corrections. (A. W. Weiss)

(7) The development of a computer code to generate spectral line profiles for multi-electron ions in plasmas continues. Spectral line profiles generated from this code have been used in the analysis of laser-produced plasma experiments at the University of Rochester Laboratory for Laser Energetics and the Princeton Plasma Physics Laboratory. A joint effort is in progress with V. L. Jacobs (Naval Research Laboratory) and C. F. Hooper, Jr. (University of Florida) on the calculation of plasma-broadened line profiles of helium-like and lithium-like satellites of hydrogenic and helium-like argon resonance lines, including non-LTE populations and broadening due to autoionization, radiative decay, electron collisions, and the plasma ion microfield. Another collaboration is underway with T. D. Hahn and W. L. Wiese to determine the ion broadening parameters of neutral carbon, nitrogen, and argon spectral lines obtained in a wall-stabilized arc. (L. A. Woltz)

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

M. A. Ali (Howard University) spends one day a week here during the academic year working with Y.-K. Kim on relativistic atomic structure calculations. He spent the entire summer of 1988 working with Kim.

W.-J. Qian (Liaoning University., Shenyang, China) has completed a one-year visit with us, collaborating with Kim on the study of relativistic distorted-wave Born cross sections of Be-like and Na-like ions.

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

(b) Data Center on Atomic Transition Probabilities

During 1988, a major accomplishment of the data center was the completion, after 8 years of critical evaluation work, of two volumes "Atomic Transition Probabilities--Scandium through Manganese," and "Atomic Transition Probabilities--Iron through Nickel." These will appear as hard bound supplements to the Journal of Physical and Chemical Reference Data, about 500 pages each, with a total of about 18000 transitions. During the last year, data for V II, Mn I, Fe II, Ni I, and Ni II were evaluated and compiled, which are included in the above-mentioned publication and much proofreading was done.

The literature on f-values is continually monitored, and an up-to-date bibliography is maintained. Also, every six months, references are provided for inclusion in the "International Bulletin on Atomic and Molecular Data for Fusion," published by the International Atomic Energy Agency. We prepared a mini-bibliography on all astrophysically important literature references to be published in "Reports on Astronomy" by the International Astronomical Union. (J. R. Fuhr and W. L. Wiese)

The programming is complete to house the Bibliography on Atomic Transition Probabilities within dBase III. The task of entering all past citations remains, but once done, literature searches extending from the present back to 1914 will be possible. Among the key fields are author, title, species, isoelectronic sequence, and year of publication. The bibliography can be indexed on up to seven fields at a time, and the results given in printed form or as ASCII files on disc. (M. A. Suskin)

III. Plasma Radiation Group

The plasma measurements program provides essential data and measurement techniques for the analysis of plasmas, mainly for temperature and density determinations, for VUV source radiometry, and for VUV lasing schemes. The determination of collisional rate coefficients is of critical importance in plasma modeling, especially for VUV laser schemes and fusion-type plasmas. Determination of atomic transition probabilities and plasma line broadening parameters have provided many of the data needed for measurements of plasma densities and temperatures of low temperature plasmas widely used for technological applications, such as in semi conductor and materials processing, spectrochemistry and plasma chemistry. Radiometric measurements of high intensity VUV and X-ray sources have led to advances in source development for x-ray lithography. Our 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 in increasing demand for that purpose.

(a) Experimental Test of the Pauli Exclusion Principle (PEP)

New developments in quantum field theory indicate that the Pauli principle is not necessarily absolutely rigorous, but that small violations may be allowed. This very exciting and important result calls for rigorous experimental testing of the exclusion principle. This fundamental principle is responsible for the stability of atoms and nuclei, for example, neutron stars. PEP follows from the indistinguishability of identical particles. However, some atomic states which satisfy indistinguishability are still forbidden by PEP. We have been designing, and are embarking on, a series of experiments designed to search for such states. The simplest and most accurately calculable of such states are in helium. For each normal state of helium one can describe a state whose wavefunction exhibits a PEP-forbidden symmetry. These PEP-forbidden states have slightly different energies than the normal states, and they may be very precisely calculated. We plan first to perform a relatively simple measurement with moderate (i.e., about 1 part in 10^{10}) sensitivity to PEP violation. Subsequently, we plan to perform a much more involved and powerful experiment which involves enrichment of any PEP-violating ground states. Implications of an observed PEP-violation would be comparable to those associated with parity violation, first observed at NBS. (D. E. Kelleher)

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

1. In the Li-like carbon atoms, population inversions have been achieved between excited levels on a microsecond timescale for the first time on a theta pinch. This is accomplished in a plasma generated from various acetylene/hydrogen gas mixtures. Three-body recombination was conceived to be the mechanism for these population inversions. However, theoretical modeling using the measured electron temperature and electron density profiles could not explain the observations. Charge transfer from neutral hydrogen to He-like carbon at the plasma boundary is being investigated as the mechanism for recombination.

Also, using a confocal mirror cavity, a gain factor of 12 was measured on the 2530 Å of C IV line in experiments conducted in collaboration with a group from Bell Laboratories. Experiments are continuing to further improve the gain..

2. One of the most successful soft X-ray lasers developed recently is based on 3p to 3s transitions in Ne-like atoms present in very dense laser-produced plasmas. However, several observed phenomena have defied explanation to date, in spite of using sophisticated computer models. For example, considerable gain has been observed for transitions from J=2 sublevels and significantly lower gain has been observed for transitions from the J=0 sublevel, contrary to expectations. A problem with modeling has been that there is no experimental verification in plasmas for the rates used in the computer codes. Of central importance are absolute measurements of population densities and collisional/radiative transition rates, supported by electron density and electron temperature measurements, to calibrate the computer codes. Experiments are underway to make such basic and quantitative measurements on Ne-like argon and Ne-like silicon using the NBS theta pinch.

Also, under a recent grant from NATO, collaborative experiments between the Institute of experimental Plasma Physics at the University of Bochum, West Germany and NBS have just started to measure the excitation rate of Ne-like argon and Li-like neon as another part of an effort for theoretical code calibration. (R. Datla, R. C. Elton, J. R. Roberts)

(c) Tokamak Spectroscopy

In order to develop diagnostics for the measurements of absolute densities of high Z impurities in tokamak plasmas, experiments on Si-like Ni, Cu, Zn, Ge and Se are conducted on the TEXT tokamak, a national tokamak facility, operated by DOE at the University of Texas, Austin. New forbidden lines have been identified and their intensities measured absolutely. The absolute density of each ion can be measured if the upper and lower levels in these transitions are statistically

populated. Analysis of the data is continuing to develop a criterion for statistical population along the isoelectronic sequence as a function of electron density and forbidden transition probability. (R. Datla, J. Roberts)

(d) Vacuum Ultraviolet Radiometry with Plasmas

Quite a bit of work has been done during this past fiscal year on the characterization of the Pt-Ne sealed hollow cathode lamp. Procedures were developed and a goniometer was designed and constructed for use in characterizing and calibrating these lamps. The following particulars were determined for a sample lamp: warmup time, stability, emission as a function of current, repeatability with ignition, spatial characteristics, impurity lines, signal as a function of pitch and yaw, and emission lifetime. A paper presenting these results is in preparation.

The data which we previously obtained in the calibration of the hollow cathode lamps for the throughput test of the Hubble Space Telescope were analyzed. A portion of the data was used in the paper "Accurate Energy Levels for Singly Ionized Platinum (Pt II)," which is soon to be published in J. Opt. Soc. Am. B. The complete body of data will be used in an atlas of lines emitted by these lamps which is in preparation.

A project was initiated to develop a body of atomic branching ratios for use in vacuum ultraviolet radiance calibrations. Analysis of existing material has already resulted in collections of branching ratios for the hydrogen, helium, lithium, and beryllium isoelectronic sequences. It is planned that the results for these sequences will be published in the near future and that these data will also be available on computer disks. Work will continue on developing branching ratios for additional isoelectronic sequences.

We are continuing to consult with scientists from NRL and NASA-Goddard on the Solar Ultraviolet Spectral Irradiance Monitor (SUSIM) and the Shuttle Solar Backscatter Ultraviolet (SSBUV) experiment. Other notable activities during this year were our participation in the CORM annual meeting held at NBS on May 18 and 19 and the publication of a condensed version of our calibration document which appeared in the NBS Journal of Research. Efforts were continued to upgrade the accuracy and reliability of our calibrations. Work during the past year included the installation of some automated positioning equipment and computer integration for better data acquisition and analysis. A linearity test was performed to insure accurate data for measurements covering a large range in signal levels. Eight deuterium lamps were calibrated as secondary standards for our group and for the Radiometric Physics

Division. In addition nine calibrations of various types were performed for customers during the year. (J. M. Bridges, J. Z. Klose)

(e) The transition probabilities of 29 prominent lines of neutral nitrogen were measured in emission with a wall-stabilized high-current arc and carefully analyzed. Our data are on average about 15-20% above those of two earlier emission studies. The intensity contributions of the extended line wings, which were not considered in the earlier experiments, fully account for this difference. On the other hand, our results--which are normalized against lifetime data--are still 8% lower than the latest theoretical data. Deviations of similar magnitude and in the same direction have also been observed in some other cases and seem to point to a basic systematic discrepancy between advanced experiments and theory (Q. Zhu, W. L. Wiese)

INVITED TALKS

Division 531, Atomic and Plasma Radiation

Datla, Raju U., "Recombination Into C IV in a θ-Pinch Plasma," University of Maryland Colloquium, Baltimore, MD, February 2, 1988.

Kelleher, D. E., "The Paron Calutron: An Experimental Test of the Pauli Exclusion Principle," JILA Colloquium, Boulder, CO, January 12, 1988.

Kelleher, D. E., "Field Effects on Autoionizing Resonances," International Line Shapes Conference, Torun, Poland, July 28, 1988.

Kim, Yong-Ki, "Relativistic Effects in Electron-Ion Collisions, Lawrence Livermore National Laboratory, December 14, 1987.

Kim, Yong-Ki, "Relativistic Distorted-Wave Cross Sections for Electron-Ion Collisions," Lawrence Livermore National Laboratory, June 21, 1987.

Klose, Jules Z., "Radiance of a Pt/Cr-Ne Hollow Cathode Spectral Line Source," Council for Optical Radiation Measurements, NBS, Gaithersburg, MD, May 18, 1988.

Martin, William C., Atomic Spectroscopic Data of Astrophysical Interest," Scientific Session of Commission 14, General Assembly of International Astronomical Union, Baltimore, MD, August 4, 1988.

Mohr, Peter J., "Structure of High-Z One- and Two-Electron Atoms," Atomic Physics Seminar, University of Notre Dame, South Bend, IN, October 15, 1987.

Mohr, Peter J., "Quantum Electrodynamics Tests in High-Z Atoms," Physics Dept. Colloquium, University of South Carolina, Columbia, SC, November 19, 1987.

Mohr, Peter J., "Quantum Electrodynamics Tests in High-Z Atoms," Atomic Physics Seminar, University of Southern California, February 24, 1988.

Mohr, Peter J., "Quantum Electrodynamics of Highly-Ionized Atoms," NATO Advanced Study Institute: Atomic Physics of Highly-Ionized Atoms, Cargese, Corsica, June, 1988.

Mohr, Peter J., "Quantum Electrodynamics of High-Z Few-Electron Atoms," V Division Seminar, Lawrence Livermore National Laboratory, August 23, 1988.

Reader, Joseph, "Spectra of Highly-Ionized Atoms," Symposium on Innovative Science and Technology, Los Angeles, CA, January 14, 1988.

Division 531, Invited Talks (cont'd.)

Sugar, Jack, "Spectroscopy at NBS Related to Fusion Energy Research," University of Arizona, Tucson, AZ, November, 1987.

Sugar, Jack, "The Tokamak as a Spectroscopic Light Source," Japan Atomic Energy Research Institute, Tokai-mura, Japan, March, 1988.

Wiese, W. L., "Spectroscopic Data Compilations at NBS," Meeting of the International Network of Atomic Data Centers, Oak Ridge, TN, November 9, 1987.

Wiese, W. L., "The Spectroscopic Data Base for Carbon and Oxygen," Specialists Meeting, International Atomic Energy Agency, Vienna, Austria, May 10, 1988.

Wiese, W. L., "Accuracy of Atomic Transition Probabilities," Symposium on the Accuracy of Stellar Abundance Determinations, 20th General Assembly of the International Astronomical Union, Baltimore, MD, August 4, 1988.

Wiese, W. L., "Towards More Reliable Atomic Transition Probabilities," Physics Colloquium, University of Zagreb, Yugoslavia, September 22, 1988.

Wiese, W. L., "A Unified Set of Atomic Transition Probabilities for Argon," Institute of Physics, Belgrade, Yugoslavia, September 27, 1988.

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Division 531, Atomic and Plasma Radiation

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Kaufman, V., and Sugar, J., In I Isoelectronic Sequence: Wavelengths and Energy Levels for Xe VI Through La IX, J. Opt. Soc. Am. B 4, 1924 (1987).

Kaufman, V., and Sugar, J., Wavelengths and energy level classifications of scandium spectra for all stages of ionization, J. Phys. Chem. Ref. Data [in press].

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Kaufman, V., Sugar, J., and Rowan, W. L., Wavelengths and energy levels of the K I isoelectronic sequence from Cu through Mo, J. Opt. Soc. Am. [in press].

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Kim, Y.-K., Sugar, J., Kaufman, V., and Ali, M. A., QED corrections to spin-orbit splitting in the ground state of Al-like ions, J. Opt. Soc. Am. [in press].

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Kim, Y.-K., Martin, W. C., and Weiss, A. W., Relativistic and correlation effects in the 2s3p configuration of Be-like ions, J. Opt. Soc. Am. B [in press].

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Martin, G. A., Fuhr, J. R., and Wiese, W. L., Atomic Transition Probabilities--Scandium through Manganese, J. Phys. Chem. Ref. Data 17, Suppl. 3 (1988).

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Wiese, W. L., Atomic Transition Probabilities, in Reports on Astronomy, Vol. XX A (Reidel Publ. Co., Dordrecht, Holland), 1988.

Wiese, W. L., The Atomic Transition Probabilities of Argon--a continuing challenge to plasma spectroscopy, J. Quant. Spectrosc. Radiat. Transf. [in press].

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 (in preparation).

Cromer, C. L. and He, M., Double-Resonance Optogalvanic Spectroscopy of Ne in a New Ultra-Low Pressure Discharge (in preparation).

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

Hahn, T., and Wiese, W. L., Transition probability ratios between 4s-5p and 4s-4p lines of neutral argon (to be submitted to Phys. Rev. A).

Kelleher, D. E., An Overview of the Ion Dynamic Effect in Line Broadening, and a Generalization of the Unified Theory, to be published by Springer Verlag.

Klose, J. Z. and Wiese, W. L., Branching Ratio Technique as Applied to Vacuum UV Radiance Calibration: Extensions and an Expanded Data Set (in preparation).

Klose, J. Z., Brightness Comparison of Several Platinum Hollow Cathode Lamps (in preparation).

Litzen, U., and Reader, J., $4s^2 4p^2$ - $4s4p^3$ transition array and energy levels of the germanium-like ions Rb VI - Mo XI (in preparation).

Mohr, Peter J., Quantum Electrodynamics Calculations, in Spectrum of Atomic Hydrogen: Advances, ed. by G. W. Series (submitted to World Scientific, Singapore).

Mohr, Peter J., and Soff, G., Vacuum Polarization in a Strong External Field, (submitted to Phys. Rev. A).

Mohr, Peter J., and Sucher, J., Level Shifts in Bound-State Quantum Electrodynamics, in Relativistic, Quantum Electrodynamic, and Weak Interaction Effects in Atoms, ed. by W. R. Johnson, AIP Conference Proceedings, No. XXX (in preparation).

Mohr, Peter J., Blundell, S. A., Johnson, W. R., and Sapirstein, J., Evaluation of Two-Photon Exchange Graphs for the Helium Isoelectronic Sequence (in preparation).

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

Mohr, Peter J., Quantum Electrodynamics of High-Z Few-Electron Atoms, in Atomic Physics of Highly-Ionized Atoms, ed. by R. Marrus (Plenum, New York), in preparation.

Mohr, Peter J. and Soff, G., Influence of Higher-Order Vacuum Polarization Corrections in Hydrogen-Like Uranium (in preparation).

Oza, Dipak H., Exchange Asymmetry in Elastic Scattering of Electrons by Sodium Atoms, submitted to Phys. Rev. A.

Qian, W.-J., Kim, Y.-K., and Desclaux, J.-P., Relativistic distorted-wave cross sections for electron impact excitations of beryllium-like ions, submitted to Phys. Rev. A.

Reader, J., Acquista, N., Sansonetti, C. J., and Sansonetti, J., Wavelengths of Platinum Hollow-Cathode Discharge (in preparation).

Roszman, L. J., Dielectronic recombination rates for O^{2+} and O^{5+} including some density effects (in preparation).

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Roszman, L. J., Revised dielectronic-recombination rate coefficients for the fluorine isoelectronic sequence (in preparation).

Sansonetti, C. J., Fabry-Perot Wavemeter for Rapid Precise Laser Wavelength Measurements, (in preparation).

Sansonetti, C. J., Precise Laser Wavelength Measurements: What Can We Learn from Classical Spectroscopy? (in preparation).

Shirai, T., Nakai, Y., Ozawa, K., Ishii, K., Sugar, J., and Mori, K., Spectral Data for Copper Ions, Cu VI - Cu XXIX (in preparation.)

Shirai, T., Funatake, Y., Mori, K., Sugar, J., Wiese, W. L., and Nakai, Y., Spectral Data and Grotrian Diagrams for Highly Ionized Iron, Fe VIII-Fe XXVI (in preparation).

Shirai, T., Mori, K., Sugar, J., Wiese, W. L., and Nakai, Y., Spectral Data and Grotrian Diagrams for Highly Ionized Chromium, Cr VI-Cr XXIV (in preparation).

Sugar, J., Kaufman, V., and Indelicato, P., Analysis of Magnesiumlike Spectra from Cu XVIII to Mo XXXI, (in preparation).

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

Sugar J., and Musgrove, A., Energy Levels of Copper, Cu I through Cu XXIX, J. Phys. Chem. Ref. Data (in preparation).

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

Wiese, W. L., Brault, J. W., Danzmann, K., Helbig, V., and Kock, M., A Unified Set of Atomic Transition Probabilities for Neutral Argon, submitted to Phys. Rev. A.

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Wiese, W. L., The Spectroscopic Data Base for Carbon and Oxygen, (to be submitted to Phys. Scripta).

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Woltz, L. A., and Hooper, C. F., Calculation of spectral line profiles of multi-electron emitters in plasmas (submitted to Phys. Rev. A).

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

TECHNICAL AND PROFESSIONAL COMMITTEE PARTICIPATION AND LEADERSHIP

Division 531, Atomic and Plasma Radiation

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.

Member, Optical Society of America, W. F. Meggers Award Committee

Peter J. Mohr

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

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

Member of International Advisory Committee, conference series on Physics and Highly-Ionized Atoms.

James R. Roberts

Member of TEXT Users Organization.

Jack Sugar

Chairman, OSA Fellows and Honorary Members Committee.

Mark Suskin

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

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

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.

Vice President, Commission on Fundamental Spectroscopic Data, International Astronomical Union.

Member, IAEA network of Atomic Data Centers for Fusion.

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 the IAEA semiannual Bulletin of "Atomic Data for Fusion."

2. J. M. Bridges consulted with NASA-Goddard scientists on tests and calibrations to be performed for the Shuttle Solar Backscatter Ultraviolet experiment.

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

4. J. Z. Klose and J. M. Bridges consulted with NRL scientists on calibration work to be performed for the Solar Ultraviolet Spectral Irradiance Monitor.

5. J. Z. Klose continues to consult with scientists at the Space Telescope Science Institute on calibration work for the Hubble Space Telescope.

6. 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.

7. Peter J. Mohr served as coordinator for the program on Relativistic, Quantum Electrodynamic, and Weak Interaction Effects in Atoms, January - June, 1988 at the Institute for Theoretical Physics, University of California, Santa Barbara.

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

8. 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.

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

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

11. J. R. Roberts and R. U. Datla consulted with staff of the Naval Research Laboratory on population inversion experiments in Ar VIII and IX and recombination mechanisms in UV lasers.

12. L. J. Roszman continues to advise and consult 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.

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

14. J. Sugar consulted with KMS Fusion scientists on the development of x-ray lasers.

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 October 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.

W. L. Wiese, Editor, Atomic Transition Probabilities, Handbook of Chemistry and Physics, CRC Press.

TRIPS SPONSORED BY OTHERS

Division 531, Atomic and Plasma Radiation

Yong-Ki Kim visited the Centre d'Etudes Nucéaires de Grenoble, France, to collaborate with J. P. Desclaux on relativistic atomic collision codes, October-November, 1987, paid by a research grant from NATO.

Yong-Ki Kim participated in the Workshop on QED and Relativistic Effects in Atoms, Santa Barbara, CA, April-May, 1988.

Yong-Ki Kim was invited to attend the Workshop on Relativistic Effects in Atomic Collisions, Lawrence Livermore National Laboratory, Berkeley, CA, June 20, 1988.

Peter J. Mohr was invited to the University of Notre Dame, South Bend, IN for an Atomic Physics Seminar, October 15, 1987.

Peter J. Mohr was invited to the University of South Carolina, Columbia, SC for a Physics Department Colloquium, November 19, 1987.

Peter J. Mohr was invited to Santa Barbara, CA to serve as coordinator for the program on Relativistic, Quantum Electrodynamic, and Weak Interaction Effects in Atoms, January-June, 1988.

Peter J. Mohr was invited to the University of Southern California, February 24, 1988 to participate in an Atomic Physics Seminar.

Peter J. Mohr was invited to Cargese, Corsica to participate in the NATO Advanced Study Institute: Atomic Physics of Highly-Ionized Atoms, June, 1988.

Peter J. Mohr was invited to Paris, France to participate in the Eleventh International Conference on Atomic Physics (ICAP XI), July 4-8, 1988.

Peter J. Mohr was invited to Lawrence Livermore National Laboratory, Berkeley, CA, to give an invited talk August 23, 1988.

Larry J. Roszman was invited to Lawrence Livermore National Laboratory, Berkeley, CA to attend a workshop on Electron-Ion Collision Theory and Computations, June 20-22, 1988.

Jack Sugar was invited to and gave a lecture at the University of Arizona in November, 1987.

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

Jack Sugar visited Japan Atomic Energy Research Institute (JAERI) in Tokai-mura, Japan under the U.S.-Japan fusion cooperation program to work with Japanese collaborators on atomic data compilations in March, 1988.

W. L. Wiese will travel to Yugoslavia and Poland September-October, 1988. He will visit the Universities of Zagreb, Belgrade and Krakow to discuss ongoing collaborative projects under cooperative NIST S & T programs and give seminar talks. All expenses paid by U.S.-Yugoslav Joint Board and Marie Curie/Sklodowska Foundation.

CALIBRATION SERVICES PERFORMED

Division 531, Atomic and Plasma Radiation

Type of Service	Customer	SP 250	No. of Tests	Income
Radiometer	IBM	40040S	1	$ 2.1k
Radiometer	Perkin Elmer	40040S	1	2.6k
Argon Mini-Arc	Goddard Space Flight Center	Contract	4	10.4k
Argon Mini-Arc	ETH, Zurich	40040S	1	2.3k
Deuterium Lamp	Sandia Corp.	40030S	1	1.5k
Deuterium Lamp	Univ. of Colorado	40030S	1	1.5k

SPONSORED SEMINARS AND COLLOQUIA

Division 531, Atomic & Plasma Radiation

Ian P. Grant, Oxford University, Oxford England, "QED for Atoms and Molecules Using Basis Sets," October 13, 1987.

J. Bayfield, University of Pittsburgh, "Excited Hydrogen Atoms in Strong Microwave Fields: Search for Chaos in Quantum Mechanics," October 14, 1987.

Hans Schlueter, Ruhr University, Bochum, West Germany, "Spectroscopic Studies on RF Field-Strengths in Plasmas," October 27, 1987.

Julian Coutts, JILA, University of Colorado, Boulder, CO, "Collision-Induced Absorption in Calcium--Rare Gas Collision Complexes," November 6, 1987.

Elisabeth Källne, JET Joint Undertaking, Oxford, England, "X-Ray Spectroscopy at the Large Tokamaks," November 9, 1987.

Lawrence Woltz, University of Florida, Gainesville, FL, "Spectral Line Profiles of Multi-Electron Emitters in Plasmas," December 1, 1987.

W. L. Wiese, NIST, Atomic & Plasma Radiation Division, "The Transition Probabilities of Argon--A Challenge for Spectroscopy," December 15, 1987.

Ray Elton, Naval Research Laboratory, Washington, DC, "Soft X-Ray Lasing at NRL in Neon-Like Plasmas," January 5, 1988.

Sveneric Johansson, University of Lund, Lund, Sweden, "The Unpredictable Stars: On Anticorrelation Between Laboratory and Stellar Spectra," January 12, 1988.

Verne Jacobs, Naval Research Laboratory, Washington, DC, "Autoionization Phenomena in High-Temperature Plasma Processes," February 2, 1988.

Victor Kaufman, NIST, Atomic & Plasma Radiation Division, "Analyses of Tokamak and Other Spectra Using the Methods of Isoelectronic Sequences," February 16, 1988.

John Gillaspy, Harvard University, Cambridge, MA, "Quest for Bose-Einstein Condensation in Spin-Polarized Hydrogen," March 1, 1988.

Ulf Litzén, University of Lund, Lund, Sweden, "Spatially Resolved Laser-Produced Spectra of Highly Ionized Transition Metal Elements," March 8, 1988.

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

Manfred Kock, University of Hannover, Hannover, West Germany, "Plasma Spectroscopy at the University of Hannover--Hollow Cathode Lamps, Branching Ratios, and Photoionization Cross Sections," March 18, 1988.

Ingvar Lindgren, Chalmers University of Technology, Goteborg, Sweden, "Towards a Relativistic Many-Body Procedure for Atomic Systems, March 25, 1988.

C. C. J. Roothaan, University of Chicago, Chicago, IL, "General Scheme for Fractional Parentage in Atoms," April 21, 1988.

Steven Rolston, Lyman Laboratory, Harvard University, Cambridge, MA, "Antiprotons and Antihydrogen," May 19, 1988.

John Hoffnagle, IBM Almaden Research Center, San Jose, CA, "Chaotic Motion of Ions in a Pauli Trap," May 31, 1988.

M. Klapisch, Hebrew University, Jerusalem, Israel, "Atomic Processes in Hot Plasmas-Model Computations with HUJI Code, August 15, 1988.

Robert Hilborn, Amherst College, Amherst, MA, "Spectroscopic Tests of the Symmetrization Postulate for Bosons," September 8, 1988.

TECHNICAL ACTIVITIES

Division 533, Radiation Physics

The Radiation Physics Division focuses on measurement programs related to the use of electron, laser, ultraviolet, and soft x-ray radiation in the energy range from about 5 eV (250 nm) to 1 keV (1.3 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 NIST 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. A scanning tunneling microscope is being used 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 relate the behavior of condensed matter systems to their fundamental atomic and molecular properties.

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 NIST 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. It is available for collaborative research by NIST 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 $\approx$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 parameters can be used to determine surface structure or study surface magnetic phenomena and the dependence on temperature, composition, adsorption, etc. The electron-atom scattering parameters can be used to probe spin-orbit and exchange interactions in electron scattering and to completely describe the selected collision process.

In relatively new research directions, several innovative electron measurement techniques pioneered at NIST 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 ultra-high vacuum scanning tunneling microscope has also been constructed to investigate, on an atomic scale, 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 (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 studying surface magnetism using spin polarized photoemission techniques on materials prepared with molecular beam epitaxy methods. This work is being done on an undulator beamline at NSLS.

As can be seen in the following sections, the Division staff have 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 NIST and with universities, industry, and other government agencies. Some highlights of the past year include:

1. A new, greatly improved SEMPA instrument for measuring magnetic microstructure with greater speed, sensitivity, and reliability is operational. The development was featured in several corporate magazines, and a major new collaboration was initiated with Perkin-Elmer.

2. Our scanning tunneling microscope has been used to measure unusual "atomic chains" formed with a low coverage of Cs adsorbate on GaAs(110). The vertical resolution of the ultra-low noise instrument is about .01 Angstroms.

3. SURF-II had a record, stored-beam current of 258 mA in May, 1988, and a record quarterly average of 200 mA during Apr-Jun, 1988, about 20% higher than last year's record. Increased current means increased flux. Experiments can be done faster, more sophisticated measurements can be made, and the quality of the work is higher.

4. There were a number of new users at SURF-II this year, including industrial users. Some of the new users were from U. California (Berkeley), U. Nebraska, ARACOR, Lockheed, and KMS Fusion Corporation. In addition, we are collaborating with United Detector Corporation and Science Applications Inc to develop new uv and soft x-ray detectors for radiometric applications, including silicon photodiodes with enhanced uv response and stability.

5. High Tc superconductors were investigated using x-ray fluorescence from photon- and electron-irradiated samples as a measure of the local, partial density of states. There were eight publications on this project, a collaboration between NIST, U. of Tennessee, U. Uppsala, and Oak Ridge National Labs.

6. A new "competence" project for "Advanced Studies in Laser Cooling and Trapping" is being initiated as a collaboration between three Divisions with expertise in atomic, molecular, and optical physics. The Radiation Physics Division will develop a vuv laser radiation source to cool hydrogen atoms to within a few °K.

7. Thirty major visiting scientist collaborations were active in FY88: nine in the Far UV Physics Group; seven in the Electron Physics Group; and fourteen in the Photon Physics Group.

FAR UV PHYSICS GROUP

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

Calibrated transfer standard detectors for the far ultraviolet continue to be made available to the scientific community and industry, and recalibrations of detectors already in use are performed as requested. Two facilities with coverages of 5-50 nm and 50-254 nm are used. A beamline at the SURF-II facility is dedicated to this activity in the shorter wavelength region. During FY88, 39 calibrations of user photodiodes were provided, a significant increase over last year's total of 21.

The NIST far uv detector calibration competence forms the basis for the radiometric needs of the space research community. In addition, nearly any measurement activity making use of far ultraviolet photons e.g. for plasma diagnostics, remote sensing, or irradiation applications, requires a determination of the magnitude of the flux incident on the experiment. Such a measure has been provided by NIST transfer standard photodiodes for almost two decades.

Windowless photoemissive diodes are fabricated within NIST for use in the region 5-122 nm. Working standards of this type are calibrated by direct comparison with the photoionization current from a rare gas ionization "chamber". A special windowless thermopile is used to transfer these calibrations to the longer wavelengths, where commercially available MgF_2-windowed photodiodes fabricated to our specifications are used as working standards. Intercomparison calibrations with both types of these working standards are then used to arrive at calibrations of detectors to be supplied to outside users.

In a collaboration with industry, the radiometric characteristics of newly-developed Si photodiodes that may serve as future standards in the far uv have begun to be studied. Silicon photodiodes are used in numerous applications to measure visible and infrared radiation and are normally opaque to shorter wavelength radiation. The special silicon detectors developed in this collaboration were designed to optimize sensitivity to uv and soft x-ray radiation. Our measurements indicate that they are the most efficient photodiodes ever measured in this wavelength region, having an efficiency of about 3000 percent at 10 nm, about 300 times greater than commonly used photodiodes. These highly efficient solid state detectors could be used for calibrating radiation measurement instrumentation, but may also be sensitive enough that they can be used as active elements in remote sensing and other applications. If tests of stability and homogeneity also give positive results, this development could lead to a new, high-efficiency radiometric standard and form the technical basis for a new generation of high-efficiency array detectors for uv and soft x-ray imaging applications.

SURF-II Operation (L. Hughey, A. Hamilton, R. Madden, and W. Wooden)

The performance of SURF-II continues to improve. The average beam current over the past year is about 170 mA (last year it was 90 mA), while the average over the last five months is over 200 mA. A new record beam of 258 mA was recorded during this period. In addition to this, the beam lifetime has been improved. The half-life of a 200 mA beam is now about 2 1/2 hours as compared to 1 1/2 hours a year ago for similar operating conditions. SURF-II has also operated very reliably this year. Beam was provided to users more than 90% of the scheduled beam time (nine hours/day; 4 days/week) in FY88.

A number of improvements at SURF have been responsible for the higher current and longer lifetime. The output of the injector accelerator (a 10 MeV microtron) was improved by 25-30%, resulting in more electrons injected into the storage ring. Improvements in the magnetic field gradient profile as a function of electron energy have resulted in an increase in the ratio of full energy electrons to injected electrons. Additional increases in the ratio of full energy electrons to injected electrons are due to the development of automatic systems for controlling the r.f. power in the storage ring cavity and the vertical beam expansion (fuzz) as functions of electron energy. These automatic systems are also responsible for achieving more consistency in full energy beam current.

Another improvement was: (1) finding one length of r.f. transmission line, for use during the energy ramp, to promote a resonant beam oscillation that provides an even greater ratio of full energy to injection energy electrons; and (2) finding a second transmission line length, for use at full energy, to promote another stable, self-stimulated beam oscillation that results in a significant beam lifetime increase.

SURF-II User Programs (R. Madden)

SURF-II was utilized by a variety of NIST and outside users in FY88 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. The High Resolution Spectrometer beamline, BL-3, was commissioned. Staff of the Photon Physics Group and the University of Maryland are now characterizing the high resolution, 6.65 m spectrometer and initiating an experimental program in atomic and molecular physics.

Division 533, Technical Activities (cont'd)

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

We have supported at SURF-II the establishment by the NIST Surface Science Division of an experimental capability to study well-characterized 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 UPS, this group, in collaboration with a group from the Naval Research Laboratory, investigated the electronic structure and surface chemistry of high Tc superconductors and related materials. Using resonant photoemission, they found the electrons to be highly correlated and almost covalent in nature. The controversy over the existence of Cu^{3+} in high Tc compounds was resolved by studying the Cu resonant satellites. Their behavior is indicative of Cu^{2+} rather than Cu^{3+}. Currently a unique O 2p satellite observed in these materials is under investigation.

Chemisorption studies of these materials showed that they react strongly with H_2O to form surface hydroxides. This is the first step in the degradation of these materials when exposed to air. The surfaces react less strongly with CO_2, but the reaction is significant.

Two new areas of research have been initiated by this group, again in collaboration with the Naval Research Laboratory. The first is a study of the electronic states and surface chemistry of prototype dispenser cathode materials. In a H_2O chemisorption study of Ba and BaO on W(110) and W(111), they observed that a thick layer of hydroxide was formed, indicating that the H_2O was able to penetrate the hydroxide layer and react with the underlying W. The second new area is the study of the electronic states of metal-on-metal systems, in which controlled amounts of one metal are deposited onto a single crystal of a different metal. The resulting electronic energy states are not, as one might presume,

simply a superposition of the individual states of the two materials. Rather, totally new states are observed for thin overlayers. This is an exciting result, suggesting the possibility of tailoring unique electronic structures for new materials applications.

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 is now ready for installation on BL-1, 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 T_c superconductors and of metal overlayers. The other Surface Science instrumentation has been moved to BL-8 to continue the electron attenuation length and photoemission measurements.

B. Radiometric Instrumentation Calibration Beam Line, BL-2 (M. Furst and R. Graves)

During FY88 there were 7 user groups who used the SURF-II calibration facility over a period of 39 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, Laboratory for Atmospheric and Space Physics/University of Colorado, North Carolina State University, Space Sciences Laboratory/U. California (Berkeley), Naval Research Laboratory, and Space Sciences Center/University of Southern California. NASA continues to provide partial support for the facility.

Two of the user groups were new to the facility. The group from Berkeley made radiometric measurements of components of the EUV Explorer satellite that will be used for stellar flux measurements. The group from the University of Southern California measured the efficiency of an EUV normal incidence spectrometer that will be used to measure the full solar disk emission spectrum over the range 15-60 nm.

The cryopumps have been upgraded on the large vacuum chamber that is used to simulate upper atmospheric vacuum conditions. The new pumps reduce down time for users since they have a larger pumping capacity and permit a longer time period between regenerations.

C. High Resolution Spectrometer Beamline, BL-3 (M. Ginter and D. Ginter, U. Maryland; and R. Morrison, Talladega College)

The High Resolution Spectrometer Facility installed on BL-3 has been put through a final set of tests in preparation for its use in two sets of experiments. The tests indicated that a resolving power of 80,000 is attainable and absolute absorption measurements with 2% accuracy should be possible. These characteristics make it one of a few instruments in the world capable of absolute measurements with such high resolution.

Our first experiments will exploit the very high resolution to measure the photoabsorption cross-section in the region of the 3s np window resonances in argon. Although the cross-sections of these resonances have been measured at lower resolution, our new studies of the absolute cross-sections at high resolution will enable theorists to compare their calculations with experiment in a more meaningful way.

The second experiments, which form the main objective of our new program, will study the Stark effect on the Rydberg levels of para-hydrogen. In this work we expect to uncover some of the "quantum chaos" observed in similar studies with high resolution laser spectroscopy (by K.H. Welge and others). The experiments will provide the first detailed look at the photon absorption of highly excited molecular states in an electric field at energies where the transition to chaos is just occurring. The work is closely correlated with theoretical work in our group that has successfully predicted the onset of chaos in atomic hydrogen in a magnetic field.

D. Angle-Resolved Photoelectron Spectroscopy Beamline for Molecular and Chemical Physics, BL-5 (T. Ferrett, J. Hardis, S. Southworth, and A. Parr, all from Radiometric Physics Division; J. Dehmer, Argonne Nat. Lab)

Studies were made of resonant photoionization processes in N_2O and NO, motivated in both cases by recent developments in theory. The high resolution capability of the ARPES instrument was used to study vibrationally-dependent shape resonance effects in N_2O. Vibrationally-dependent effects in the resonant photoionization of polyatomic molecules are not well understood. New insight into these effects was obtained by comparison of the ARPES measurements with corresponding fluorescence measurements and with recent theoretical calculations.

Our previous ARPES measurements, along with recent theoretical developments, have led to the prediction of complex resonant states in NO which arise due to the interaction among several types of resonant excitations. In addition, the ionization dynamics may be further complicated by competition with neutral dissociation processes. In order to characterize these complex resonances, we have made new, more detailed ARPES measurements on NO.

The ARPES instrument was moved to the Daresbury storage ring during the summer to continue the research program with higher resolution irradiation capabilities, in collaboration with colleagues at Daresbury.

E. Optical Properties of Materials Beamline, BL-8 (R. Madden; R. Keski-kuha, GSFC; D. Husk, U. Virginia)

The 2.2m grazing incidence spectrometer on BL-8 was used with a reflectometer chamber at the exit slit for studies of optical properties of materials. The characteristics of multilayer reflectors for the 10-20 nm region were studied by R. Keski-Kuha of Goddard Space Flight Center, and by a group collaboration from the Laboratory for Atmospheric and Space Physics (U. Colorado) and Lockheed. The beamline was also used by a U. Virginia group to measure the fluorescent yield of phosphors.

The measurement system was upgraded with a new sample manipulator and an improved vacuum system. In FY89 we intend to further improve the existing system and begin planning for a new monochromator and measurement chamber to support the newly developing vacuum ultraviolet and soft x-ray multilayer technology.

F. Detector Calibration Beamline, BL-9 (R. Canfield and J. Kerner)

The recently activated SURF-II detector calibration facility continues to provide calibrations in the 5-50 nm spectral range. Refinements to the technology have been made as experience has been developed.

To extend measurements to shorter wavelengths, we are currently assembling a proportional counter module which will serve as an absolute standard for detector calibrations into the soft x-ray region (up to 1 keV). Initially the module will be mounted on BL-9 and be used to intercompare calibrations made with the standard ionization chamber in the 200-300 eV range.

The design puts the detector being calibrated behind a thin-windowed gas flow proportional counter so that both detectors view the same incident beam. Calibrated filters are used to reduce the beam intensity for the photon counting measurements. The module also features a thin window isolation from the UHV section of the beamline.

Several research activities have also been carried out with this facility during FY88.

Photoemission measurements of two classes of high temperature superconductors have been made, with emphasis on the copper/copper oxide features found in the 77 eV region. These measurements help in understanding chemical differences related to processing parameters and

to the degree of superconductivity present. The work will continue as new materials and processing techniques become available.

A group of filters used in x-ray laser measurements were characterized in collaboration with personnel from Lawrence Livermore Labs and AT&T Bell Labs. Calibration of power density in laser research at Livermore was dependent on these measurements. Also, several special narrow-band detection devices were characterized in collaboration with staff from KMS Fusion Inc. These will be used in plasma diagnostics in the laser fusion program.

A variety of experimental silicon photodiodes were characterized in collaboration with staff from United Detector Technology Corporation in an attempt to optimize development parameters with a view toward radiometric applications. The measurements indicate that solid state photodiodes can be made to be very efficient and relatively stable in the region 10-200 nm. Further testing will be done to determine their suitability for radiometric applications.

ELECTRON PHYSICS GROUP

The Electron Physics Group has ongoing research efforts in electron collision physics including electron-atom collisions, electron-surface interactions, surface magnetism, electron interaction theory, electron polarization phenomena, tunneling and scanning electron microscopy, 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 saw the expansion of the Electron Physics Group in both staff and experimental capabilities. Our new scientific staff members include J. Stroscio (from IBM and previously Cornell), M. Scheinfein (U. Arizona/Cornell), R. Cutkosky (NIST/MIT), R. French (Harry Diamond Labs), and in a shared appointment with the Surface Science Division, M. Stiles (AT&T Bell Labs/Cornell). These appointments bring us considerable additional competence in tunneling and electron microscopy, electronics, and solid state and surface theory, and we are very pleased that they joined our Group.

In the past year three major, new experiments were brought into full operation: the scanning tunneling microscope (STM), the second generation scanning electron microscope with polarization analysis (SEMPA-II), and the spin polarized photoemission facility at Brookhaven (NSLS). It is highly unusual for our experimental capabilities to increase so greatly within a one year period. The expedited completion of some of these development projects was a direct reflection of the skill and effort of the new staff members we were able to add to the group last year.

Division 533, Technical Activities (cont'd)

We continue our focus on interfacial phenomena with special emphasis on the use of microscopy to study microstructures, clusters, defects, growth, and dynamics on the atomic scale. Our SEMPA work involves studying the effects of size, dimensionality, shape, topography and epitaxial substrate on magnetic microstructures. The photoemission and inverse photoemission experiments focus on understanding magnetic phenomena in novel epitaxial systems through measurements of spin resolved band structure. Our STM measurements investigate the electronic structure of atoms, molecules, clusters, and microstructures on surfaces. The STM allows us to study the growth of microstructures with atomic resolution. It also permits us to verify, for example, that the novel epitaxial structures we grow have the physical structure we planned and that their observed magnetic phenomena results from our tailoring of the physical structure.

Magnetic Microstructure Research (J. Unguris, M. Scheinfein, R. Celotta, D. Pierce, and M. Kelley)

We are investigating sub-micron magnetic structures using Scanning Electron Microscopy with Polarization Analysis (SEMPA). The SEMPA technique was developed at NIST and 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 are therefore directly related to the magnetization in the region probed by the incident electron beam. The result is an image of the direction and magnitude of the magnetization vector that is obtained at the same time as the usual SEM image of surface topography. In practice magnetic structures can be resolved with a resolution of about 10 nm (0.01 microns), which is the highest resolution available of any technique for looking at magnetic structures in reflection. In addition, because the escape depth of the secondaries is approximately 2 nm, SEMPA is an ideal probe of surface and thin film magnetism.

We have recently completed construction of a new SEMPA facility centered about a new SEM that is more reliable than the old one and is also a scanning Auger microprobe. The Auger microprobe provides us with a map of the chemical composition with about the same resolution and from the same area as the magnetic and topographic images. This provides us with a unique tool to study the relationships between magnetic microstructure and surface chemistry.

Current work at the new facility involves studying the structure of domain walls at the surface of iron crystals. We have found that the domain walls have a different width and rotational sense at the surface than in the bulk. We have observed these walls for surfaces prepared in different ways and at temperatures up to the Curie temperature (750 C).

In addition to basic research, we also have been collaborating with private industry by using SEMPA to help solve applied magnetics problems. An example of this is our current work with Honeywell on a new type of memory chip based upon magnetic bits with micron dimensions. We were able to image the magnetization inside of these bits with a spatial resolution previously unavailable to Honeywell and thus provide them with information useful in extending the performance of this device.

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 applicability of this technique to outstanding scientific and technological problems of concern. We expect these collaborative efforts to be scientifically fruitful, intellectually stimulating, and mutually beneficial during the next year.

Scanning Tunneling Microscopy (J. Stroscio, R. Dragoset, P. First, D. Pierce, and R. Celotta)

The scanning tunneling microscopy (STM) program in the Electron Physics Group is aimed toward understanding the physics of low dimensional structures. This focus contributes toward the microstructure emphasis in the Electron Physics Group by extending our capabilities to examine and study structures with atomic resolution. The STM operates by the principle of quantum tunneling of electrons from a sharp probe to the examined specimen, which is held within atomic distances of the probe. Our STM has recently been fine tuned and is currently operating with 3 Å lateral resolution and an extremely high perpendicular sensitivity of 0.01 Å (1 pm). The STM is operating in an ultrahigh vacuum system with thin film growth and characterization facilities.

We have begun investigating metal structures grown on GaAs substrates by molecular beam epitaxy (MBE) techniques. GaAs is thought to be the semiconductor of the future because of its very high electron mobility which is useful in ultra-high-speed semiconductor applications. Using the STM, we have discovered an extremely novel system of one-dimensional atomic structures that form with Cs atoms on GaAs(110) surfaces. This is the first observation of such structures being formed with this system.

In the STM images the Cs atoms are individually observed to line up (atom by atom) in single atomic chains along the high symmetry direction of the GaAs(110) substrate. The Cs chains are observed to be > 50 Å apart, thereby representing a truly one-dimensional system of metal atoms. Interesting scientific questions concerning the physics of such one-dimensional structures, such as are these atomic metal "wires" really metallic (as defined by a partially filled electron band), are being pursued with the STM. By exploiting the dependence of the quantum

tunneling on voltage difference between the probe and sample, we are able to investigate the electronic properties of these structures, such as the development of the electronic band structure and nature of the metal-semiconductor bonding. Although these atomic "wires" are formed naturally, they demonstrate the ultimate limit of structures that may be fabricated with semiconductor technology.

A second area of investigation with the STM is concerned with the study of ultra-thin magnetic films on surfaces. This work is synergistic with our studies of magnetic microstructures using the SEMPA technology. We are presently studying epitaxially grown bcc Fe films on GaAs(110) substrates. Fe is one of the few materials which grows epitaxially on GaAs. Previous studies by NRL researchers have shown anomalous magnetic behavior in ultra-thin films. The origin of this behavior has been attributed to defects or strain in the Fe films.

Our initial measurements show that Fe does not grow in a layer by layer mode on GaAs but forms 3-dimensional clusters during an initial growth phase at 25 C. These clusters are observed to be about 50 Å in diameter. The morphology of these clusters show a preferential growth direction with grain boundaries that might explain some of the anomalous behavior in the magnetic properties. Further studies on the temperature dependence of the growth process is being investigated.

Although the physical microstructure of the magnetic thin films can be obtained with the STM on an atomic scale, the magnetic properties cannot. With the objective of probing magnetism on the atomic scale, we have been developing an STM type of system to be sensitive to surface magnetism. The experiment is a hybrid of technology developed in the Electron Physics Group, consisting of a scanning tunneling microscope with electron spin detection of electrons emitted from the tunnel junction. Earlier research by Russell Young at NIST showed the feasibility of secondary electron detection with the STM, and researchers at IBM Zurich have recently confirmed these experiments.

The "magnetic" STM and associated components are currently being fabricated and will be assembled in early FY89. The successful completion of a magnetic microscope with atomic resolution would open up a new frontier in micromagnetism.

Electron - Atom Collisions Studies (M. Kelley, J. McClelland, and D. Oza)

Our purpose is to study, in as complete a manner as possible, the interactions important in low energy collisions between electrons and atoms. 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 dependence of various collision cross sections on the initial state of the incident electrons and atoms.

Such state-selected experiments provide substantially more information about the collision than is available from conventional measurements of differential scattering cross sections. We are particularly interested in the influence on the collision of the spin state of the incident electrons and atoms. Determination of this spin dependence provides very direct information about both exchange and the spin-orbit interaction, and provides a very stringent reliability test for current theoretical scattering calculations.

We have made spin dependent measurements for both elastic and inelastic scattering. Elastic scattering measurements were performed at an incident electron energy of 54.4 eV and at scattering angles in the range from 20° to 135° The most surprising result was that, even for sodium, a relatively light target, the spin-orbit interaction plays a significant role in the scattering. The effect on the scattering cross section is comparable in magnitude to that due to exchange. Current state-of-the-art theoretical calculations do not accurately reproduce our measurements, indicating that further theoretical work is necessary.

We have also studied inelastic scattering by way of superelastic scattering from the first excited state. Spin-polarized and oriented sodium atoms are prepared in the excited 3P state by optical pumping with circularly polarized light. By detecting only electrons that have de-excited these atoms and gained the 2.1 eV excitation energy of the atoms, we are able to study the 3S - 3P transition with very great detail. Our measurements span the energy range from 2.0 eV to 52.3 eV and the angular range from 10° to 130°. We find that spin plays a very important role at energies up to 20 eV. At the higher energies, around 50 eV, we are no longer able to see any spin dependence.

We are also attempting to provide the theoretical data for comparison with our experiments. Extensive ab initio scattering calculations are being made. These calculations include the four lowest lying atomic levels exactly and use an optical potential to account for the higher levels and the continuum. When complete, these calculations should provide the best theoretical estimates to date for the spin dependencies observed in our measurements.

Our current efforts are directed at extending the energy range in which these measurements are possible. Specifically, we wish to perform elastic scattering measurements at energies below the ionization threshold of 5.1 eV. Theoretical calculations should be quite good at the lower energies, and we wish to provide both elastic and inelastic data for comparison with theory over the range of energies where current calculations have the most difficulty, from somewhat below to several times the ionization threshold.

Inverse Photoemission Spectroscopy (M. Hart, D. Pierce, and R. Celotta)

In recent years we have applied the spin polarized electron source developed in this group to the study of ferromagnetic metal surfaces. By coupling this low energy spin polarized source with a UHV chamber equipped with a sample manipulator, an Auger spectrometer, and a LEED system a variety of unique experimental techniques have been employed to investigate the magnetic, chemical, and electronic properties of metal surfaces. Currently, we are focusing on a spin polarized inverse photoemission (SPIPES) technique to study 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.

We have recently completed 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.

We are now investigating the electronic and magnetic properties of ultra-thin, epitaxial, metallic films deposited on metallic substrates with SPIPES. The first thin film system under study, cobalt overlayers evaporated in situ on Ci(111), has yielded interesting preliminary results. Changes in both the energy and spin character of the unoccupied minority and majority spin cobalt d bands have been observed with varying film thickness. These observations may lead to significant conclusions about the nature of ferromagnetic systems with reduced dimensionality.

Spin Polarized Photoemission at NSLS (D. Pierce and R. Celotta)

We have been participating in an effort at the National Synchrotron Light Source (NSLS) to study novel magnetic systems created in situ by molecular beam epitaxy (MBE). To date, the work has concentrated on the establishment of a spin-polarized, angle and energy resolved photoemission apparatus on the U-5 beamline of the UV storage ring.

This project is unique in a number of ways. First, the research team consists of 11 principle investigators from 9 institutions nationwide. These are national labs (NIST, Argonne, NRL, and NSLS), universities (Rice, Texas at Austin, Northwestern, and U. California at Irvine) and an industrial lab (AT&T Bell). This group functions both as an NSF Materials Research Group as well as an NSLS Participating Research Team. Second, the beamline is the only spin polarized facility in the United States and the only one in the world with a movable spin analyzer to permit angular studies. Third, it is one of very few beamlines in the U.S. to have an MBE capability. Finally, because of the demanding nature of the experiment, we are fortunate to have the highest flux UV beamline at NSLS. It is based on an undulator currently installed in a straight section of the ring. During the next two years this same group, acting as an Insertion Device Team, will install a new state-of-the-art undulator now under construction.

The beamline has recently been used to take spin polarized photoemission data. In the first experiment, our colleagues at NSLS have examined the angle resolved spectra of Fe(110) both in a clean state and with adsorbed sulfur. The ability to make both angle and spin resolved photoemission measurements extends greatly previous work and, even in the first experiments, calls into question previous interpretations made in the absence of spin resolved data.

We have begun measurements on the Fe on Cu(100) system. The first few layers are thought to grow epitaxially as fcc Fe, as opposed to the normal bcc form. The object of the experiment will be to observe the magnetic properties, e.g. anisotropy, Curie temperature, remanence, magnetization, etc., as a function of layer thickness and growth methodology, and to correlate them with the spin dependent electronic structure we measure. We expect this facility to greatly extend our ability to study new and interesting magnetic systems.

Electron Optics (M. Kelley and M. Scheinfein)

We have added substantially to our capabilities for the design and characterization of new electron-optical instruments. These new capabilities include sophisticated numerical algorithms used to compute electrostatic and magnetic lens fields, and improved methods of determining the optical properties of these fields. Paraxial and aberration properties can be accurately determined for electrostatic or magnetic lenses. Non-paraxial, all-order, electrostatic ray-tracing is also used for more accurate modelling of novel designs. Furthermore, a third order matrix method has been developed for use in the design and characterization of our electron optical systems.

The second generation electron spin polarimeter (SEMPA detector) and transport optics were designed, built, and interfaced to the JEOL JAMP 30 Scanning Auger Microprobe. The system, complete with scan compensation, has been fully characterized and determined to function as originally designed.

A third generation SEMPA detector and transport optics were designed to further improve the performance of the system. The technology for this new detector, which has been built and tested at NIST, has been transferred to Physical Electronics, Inc (PHI), who will develop a commercial instrument based on this design. In addition, a novel optical system for secondary electron extraction has been designed and implemented for the PHI system. This novel system is currently being applied in the PHI laboratory for their own scanning ion microscopes.

The third generation SEMPA detector has also been interfaced to a standard 180° hemispherical analyzer with input and output optics. This instrument is used to study spin-polarized photoelectron spectroscopy in a project cooperatively pursued with researchers at Brookhaven National Labs. The new optical system will eliminate spurious polarization asymmetries induced by instabilities in the positioning of the beam in the Brookhaven storage ring.

Electron Theory (D. Penn)

Our purpose is to study various aspects of electron-electron interactions in solids with application to high T_c superconductivity and surface magnetism.

We have examined the significance of satellites at binding energies of about 12 eV that are observed in photoemission experiments in the high T_c superconductors La-Sr-Cu-O and Y-Ba-Cu-O. The satellites are assumed to be caused by intra d-shell shake-up processes with a Cu $3d^8$ final state. Using the t matrix approach, we studied the effect of the electronic correlations on the one electron band structure. We found that it takes a large Coulomb interaction energy of 5 eV at the Cu site to account for the position of the satellite. This shows that the $3d^8$, two hole, bound state is a high energy excitation comparable to the 3d band width, and that electron correlations are important in the high T_c materials.

We have also studied the interaction between two test changes in a solid which can be described in terms of a total dielectric function, ϵ, that includes electronic and lattice polarization. We have shown that the eigenvalues of ϵ^{-1} are ≤ 1 for crystal stability. We have constructed such a dielectric function in the mean field approximation

and shown that the correct phonon modes are determined by the low energy poles of ϵ^{-1}. Such an approach may be useful in the study of superconductivity.

We are continuing to study 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 are formulating a theory for this asymmetry. In contrast to the standard interpretation, we expect the sp-electrons to be of crucial importance. Whereas the d-electrons carry the main moment, the sp-electrons have the largest overlap with the helium.

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 NIST 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 soft x-ray laser. For many of the activities, synchrotron radiation from NIST-SURF-II or Brookhaven-NSLS is used as a source of tunable vacuum ultraviolet and soft x-ray radiation.

Multiphoton Ionization Applied to Ultrasensitive Trace Analysis
(T. Lucatorto and C. Clark)

This is a collaborative effort with the Mass Spectrometry Group in the NIST 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.

Our RIMS studies have used special narrow bandwidth pulsed lasers to perform isotopically selective ionization. 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 $3x10^{10}$. 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 ablation as a method of atomization that is matched to the duty cycle of the ionization laser. Preliminary studies indicate that there are three mechanisms that limit the effectiveness of the laser pulsed ablation technique: laser plasma formation, thermal stress induced exfoliation, and molecular compound formation (e.g. oxides). In an attempt to reduce the adverse effects of these mechanisms, we have begun experiments on thin films of relatively volatile metals. Films of Zn produced by sputtering have been ablated and show advantageously low plasma formation. Present efforts are directed towards developing a suitable technique to co-sputter Zn and the analyte so that the Zn serves as a non-interfering matrix in the compositional analysis of the analyte.

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 analytical 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. 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.

Preliminary data sheets have been completed for ten elements this past year. Included are calculations of previously unmeasured excited state photoionization cross sections, transition rates, and autoionization rates. In the next year more data sheets will be

completed. In addition the format of the data sheets will be further refined, in collaboration with the RIS-RIMS community, including the Institute for Resonance Ionization Spectroscopy at the U. Tennessee.

Soft X-Ray Emission Studies of Advanced Materials (D. 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 almost two years now and is the proud accomplishment of a joint NIST-U. Tennessee-Oak Ridge National Laboratory collaboration. Recent experiments have proven it 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 Hawaii, the University of Connecticut, the University of Uppsala, AT&T Bell Laboratories, and NIST 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 $YBa_2Cu_3O_{7-\epsilon}$ and Bi-Sr-Ca-Cu-O superconducting ceramics. This last area of research has been funded as part of a DoC initiative on high temperature superconductors. With additional resources from this initiative, we have added a solid-state physicist (D. Mueller/Cornell) and a visiting scientist to the high Tc superconductivity project.

A few of the highlights of this program are:

a) High Tc Superconductors:

The oxygen K, soft x-ray emission spectra for the $YBa_2Cu_3O_x$ compounds with x=6, 6.5, and 7 was obtained and compared with x-ray emission spectra determined from recent band structure calculations. The K emission spectrum of O provides a measure of the p-type local partial density of states (p-LPDOS) at the oxygen sites. Good agreement is found with the calculated spectrum for x=7. As x decreases from 7 to 6.5, a chemical shift of the entire spectrum to lower energy indicates that screening is modified for all oxygen sites. The integrated intensity of the spectra is nearly unchanged by oxygen removal, indicating an increase in p-PDOS per oxygen site. These

results and changes in the spectral shape suggest that itinerant electron density near the O atoms is reduced and bound electron density is increased as oxygen is removed.

We have also measured the soft x-ray K emission spectrum from oxygen in the Bi-Sr-Ca-Cu-O superconductor and found it identical with the O K emission from the 123 superconductor. The O K and the Bi valence-$N_{6,7}$ emission were in good agreement with spectra modeled after calculations based on linearized augmented plane wave method and local density band structure calculations.

b) Electronic Structure of Buried Interfaces

As semiconductor devices become smaller and smaller, and as it has become possible to synthesize new materials based on thin layered structures, the measurement of interface properties within a bulk has become extremely important to industry. This is because it is often the microstructural properties of the interface that control the behavior of the material. Interface measurements are very challenging since most diagnostic methods generate responses from the surface of the material and the bulk of the medium that completely overwhelm the response of the interface.

It is difficult to study the electronic structure of the interface between different materials basically because the interface is buried under a layer of material. Surface sensitive probes like photoelectron spectroscopy cannot be effective. X-ray fluorescence spectroscopy, although not surface sensitive, is not normally efficient enough. However, this drawback was overcome in the present experiments by making a multilayer structure consisting of 50 layers of carbon films interdigitated with silicon films. In one group of samples the thickness of the silicon film was varied from 0.3 nm to 3.0 nm, with carbon film thickness fixed at 3.0 nm. In another group of samples the silicon film thickness was fixed and the thickness of the carbon was varied. By this sample preparation technique, it was possible to enhance the signal-to-noise ratio by a factor of 50 over a single C-Si interface.

The fluorescence was excited by near threshold soft x-rays from the National Synchrotron Light Source at Brookhaven National Laboratory and detected by an ultrahigh sensitivity spectrometer. The interface signal was clearly distinguishable

from the signal generated in the bulk. The silicon $L_{2,3}$ emission band from the interface resembled that of SiC and the silicon emission from the bulk resembled that of amorphous silicon.

This is a cooperative program with Lawrence Berkeley Laboratories and the University of Wisconsin.

c) Electronic Structure of Semiconductor Materials

In collaboration with AT&T Bell Labs, we studied the local valence band density of states in $Al_xGa_{1-x}As$. This material has important applications in the semiconductor industry because it has a higher conductivity and smaller, variable (with x) band gap relative to silicon.

The soft x-ray fluorescence from the valence band to the 2p aluminum core holes probes the local band structure with mostly s like symmetry. One observes a shift of several tenths of an eV in the energy position of the partial density of states localized at the aluminum site relative to the gallium in the crystal lattice. This is a new insight into semiconductor alloys that has not been incorporated into the theoretical description of these systems. Information like this has not been obtained before because techniques like photoelectron spectroscopy are not atom-specific, but rather provide a measure of the total valence band density of states integrated over all the atomic sites.

We plan to study other materials, like InP, with our Bell Labs collaborators. Also of interest are the properties of multilayer materials made with alternating $Al_xGa_{1-x}As$ and GaAs thin films to form superlattices.

d) Radiation damage in insulators

In a collaboration with the University of Hawaii, we studied electron induced radiation damage for two silicon compounds, Beryl (Be-Al-Si-O) and SiO. The Beryl radiation damage suggests a localized damage about the silicon, whereas the Al and Be retain their oxide-like structures. Silicon is reduced as a result of electron bombardment to a mixture of amorphous and crystalline Si. The radiation damage in SiO is similar to that of Beryl in that a mixture of amorphous and crystalline Si is observed. The study of radiation damage in these compounds is important because of their use as window materials in uv lasers.

During the next year we will be continuing our studies of the high Tc superconductors and commence studies on implanted species of importance to the semiconductor industry. A new monochromator has been added to the instrumentation to allow for narrow band irradiation.

Ionization Dynamics of Fundamental Atomic Systems (D. Ederer; D. Caldwell and J. Jimeniz-Mier, U. Central Florida)

A series of studies done in collaboration with 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. The 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.

This year measurements are being made in the energy range of a two-electron excitation resonance to determine how the correlation introduced by an additional excitation channel affects the alignment of the ion. These measurements will be completed in FY88.

Atomic Structure of Laser-Excited Atoms (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, and a high temperature (up to 2500°C) heat-pipe oven.

Photoabsorption studies of laser-excited and laser-ionized atoms have uncovered the dramatic effects of relatively small changes in electron screening on orbital collapse. Presently we are focusing attention on the 3p-photoabsorption spectra of the transition metals (Sc, Ti, V, Cr, Mn, Fe,.....). These spectra are all characterized by a single giant 3p → 3d resonance structure in the 50 eV energy range. Cr, however, is an exception because it has an additional, well-developed Rydberg structure lying above the giant resonance. Up to now the unique status of Cr was thought due to its being the only member with an unpaired 4s-electron in the ground state ($3p^6\ 3d^5\ 4s\ ^7S$). Our recent high resolution measurements of the isoelectronic Mn^+ spectrum, which

showed no well-developed Rydberg structure, show this not to be true however. The definitive Mn^+ spectrum obtained is stimulating a parallel theoretical effort to explain the exceptional behavior of Cr.

This work is a collaboration with the Atomic and Plasma Radiation Division, the University of Hamburg, and the National Institute of Higher Education (NIHE), Dublin.

Development of a Measurement Program to use the Time Structure of the Electron Beam at SURF (D. 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 we plan to install it on the SURF Storage Ring. The work will be advanced by the arrival of a guest scientist, who will work full time on this program during FY89.

Our long-term collaboration to study laser-prepared states with the Universite de Paris-Sud in Orsay, France, is winding down. A review of photoionization from excited states, co-authored by D. Ederer and F. Wuilleumier, has been 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."

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 our 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 tends to argue against such renormalization.

A compilation of experimental and theoretical x-ray attenuation coefficients for this energy range (as well as a bibliography of the NIST data base), prepared in collaboration with J.H. Scofield of Lawrence Livermore National Laboratory, was published this year.

This work is a collaboration with the Ionizing Radiation Division.

Atomic Properties and Data (E. Saloman)

Relativistic multi-configuration Dirac-Fock methods have been applied to the calculation of atomic and ionic energies and transition probabilities. An initial study has been completed. It is an investigation of the energies and oscillator strengths in the ground state configuration of the sulfur isoelectronic sequence. Results have been obtained for all transitions within this configuration for the 77 ions from sulfur to uranium. They demonstrate striking effects in the f-values corresponding to atomic numbers where different configurations become important. A report on these effects was published in Physical Review A. The detailed data will be published in Atomic Data and Nuclear Data Tables.

Next year calculations will be made to determine certain transition probabilities which are very sensitive to the method used to calculate them. The significance of the change in the wavefunctions of "spectator electrons" between initial and final states will be explored.

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

Theoretical Atomic, Molecular, and Optical Physics (C. Clark and L. Pan)

Theoretical AMO physics in the Photon Physics Group was focused on two main areas: core- and multiply-excited states of atoms in gas and condensed phases, and high-order multiphoton processes.

Our atomic structure work has been carried out in support of experimental efforts in our Division, in the Atomic and Plasma Radiation Division, and in other institutions; and with other theorists in the Surface Science Division and elsewhere. The principal achievements of this work have been:

1) Identification and classification of $3p \rightarrow 5s$ photoabsorption features in atomic Mn, and preliminary interpretation of the $3p \rightarrow 3d$ "giant resonance" features in Mn, Mn^+, and Cr;

2) Analysis of $4d^9 4f$ fine structure seen in electron energy loss spectroscopy of Ba in the $YBa_2Cu_3O_{7-x}$ high-T_c superconductor; determination of the valency of Ba in this compound from comparative analysis of photoabsorption data; and identification of $4d^{10}5p^6 \rightarrow 4d^9 5p^5 5d^2$ double excitation in Ba photoabsorption;

3) Interpretation of x dependence of oxygen K emission peaks in $YBa_2Cu_3O_{7-x}$ compounds in terms of fractional valence of oxygen, based on Hartree-Fock atomic structure calculations; and investigation of role of O^- and O^{2-} resonances in electron-stimulated desorption of oxygen from surfaces;

4) Identification of term dependence in the $4d^9nf$ series of I VIII and Xe IX;

5) Computation of multichannel quantum defect (MQDT) parameters of the $2p^5ns$ and $2p^5nd$ channels of Ne in good agreement with experimental determinations; and critical evaluation of effects of core polarization and the relationship of MQDT and Slater-Condon descriptions.

Work on high-order multiphoton processes has centered around the development of a general computer code for evaluating perturbation theory of atomic hydrogen in a radiation field to arbitrarily high order. This code has begun to produce results on level shifts and nonlinear susceptibilities up to 90^{th} order, an order of magnitude higher than any previous calculations. The principal qualitative results obtained thus far are:

1) Development of a parameterization technique that separately treats background and resonant contributions, so that the behavior of level shifts and nonlinear susceptibilities can be described by a few parameters even in a spectral region containing infinitely many resonances;

2) The determination of a "critical intensity" at which the contributions from higher orders of perturbation theory exceed those of lower order. These intensities are comparable to those at which saturation of multiphoton ionization is observed in experiments;

3) Computation of cross-sections for generation of high harmonic radiation, and the evaluation of critical intensities that are in good correspondence with those inferred from the "plateau" behavior of recent experiments.

SPONSORED WORKSHOPS, CONFERENCES, AND SYMPOSIA

Division 533, Radiation Physics

R.J. Celotta organized and chaired the Research Advisory Committee Symposium on NBS Activities in Scanning Tunneling Microscopy, NBS, Gaithersburg, MD, May 20, 1988.

M.H. Kelley organized the Atomic Physics Program Contractor's Workshop with U.S. Department of Energy, Office of Basic Energy Sciences, Division of Chemical Sciences, Hyatt-Regency Hotel, Bethesda, MD August 31 - September 1, 1988.

T.B. Lucatorto organized, jointly with University of Tennessee, the 4th International Conference on Resonance Ionization Ionization Spectroscopy and Its Applications, NBS, April 11-15, 1988.

R.P. Madden organized a symposium on Major VUV Radiometric Facilities for the SPIE meeting on X-Ray Instruments, Multilayers and Sources, San Diego, CA, August 14, 1988.

D.T. Pierce organized and chaired the Gordon Research Conference on Electron Spectroscopy, Wolfboro, NH, July 18-22, 1988.

INVITED TALKS

Division 533, Radiation Physics

Celotta, R.J., "Scanning Electron Microscopy with Polarization Analysis: Studies of Magnetic Microstructure," Am. Vac. Society, Annual Meeting, Anaheim, CA, Nov. 2, 1987.

Celotta, R.J., "Polarized Electron Probes in Atomic and Surface Physics," Australian Bicentenary Congress, Sydney, Australia, January 26, 1988.

Celotta, R.J., "An Introduction to Scanning Tunneling Microscopy," STM Symposium, National Bureau of Standards, Gaithersburg, MD, May 20, 1988.

Celotta, R.J., "Improved Low-Energy Diffuse Scattering Electron-Spin Polarized Analyzer," Gordon Conference on Electron Spectroscopy, Wolfeboro, NH, July 20, 1988.

Dragoset, R.A., "Scanning Tunneling Microscopy," Physics Seminar, University of Maryland Baltimore County - Physics Department, Catonsville, MD, Feb. 10, 1988.

Furst, M.L., "SURF-II Radiometric Instrumentation Calibration Facility," SPIE Conference on X-ray Instrumentation in Astronomy, San Diego, CA, August 17, 1988.

Kelley, M.H., "Spin Dependence in Electron Atom Scattering," IXth Atomic Physics Workshop, U.S. Dept. of Energy, Office of Basic Energy Sciences, Division of Chemical Sciences, Bethesda, MD, August 31, 1988.

Lucatorto, T.B., "Enhanced Isotope Abundance Sensitivity and Sample Utilization Efficiency in Pulsed RIMS," Workshop on Advanced Laser Techniques in Chemical Analysis, NIST, November 4, 1988.

McClelland, J.J., "Scattering of Spin-polarized Electrons from Optically Pumped Sodium," Physics Colloquium at Wesleyan University, Middletown, CT, October 1, 1987.

McClelland, J.J., "Scattering of Spin-polarized Electrons from Optically Pumped Sodium," Physics Colloqium at University of Kentucky, Lexington, KY, October 21, 1987.

McClelland, J.J., "Improved Low-Energy Diffuse Scattering Electron-Spin Polarized Analyzer," Gordon Conference on Electron Spectroscopy, Wolfeboro, NH, July 20, 1988.

Ott, W.R., "Far-Ultraviolet Detectors, Spectrometers, and Optics," Council for Optical Radiation Measurements Annual Meeting, National Bureau of Standards, Gaithersburg, MD, May 18, 1988.

Division 533, Invited Talks (cont'd)

Penn, D.R., "Analysis of Spin Polarized Inelastic Electron Scattering," Workshop on Magnetism of Surfaces, Laguna Beach, CA, October 30, 1987.

Penn, D.R., "Spin Polarization of Secondary Electrons in Metals," Rice University, Houston, TX, January 26, 1988.

Penn, D.R., "Total Dielectric Function, Algebraic Sign, Electron-Lattice Response, and Superconductivity," Chalmers University, Chalmers, Sweden, April 15, 1988.

Penn, D.R., "The Role of Inelastic Exchange Scattering in Spin Polarization Experiments," The 4th Joint MMM-Intermag Conference, Vancouver, British Columbia, Canada, July 14, 1988.

Pierce, D.T., "Experimental Studies of Surface and Thin Film Magnetism with Polarized Electrons", Physics Seminar, Arizona State University, October 26, 1987.

Pierce, D.T., "Results from Spin Polarized Electron Spectroscopy of Surface Magnetism that Puzzle Me," Surface Magnetism Workshop, Laguna Beach, CA, October 29, 1987.

Pierce. D.T., "Experimental Studies of Surface and Thin Film Magnetism with Polarized Electrons," Surface Science Seminar, Rutgers University, May 10, 1988.

Pierce, D.T., "Prospects for a Spin Sensitive STM," Research Advisory Committee Seminar, National Bureau of Standards, Gaithersburg, MD, May 20, 1988.

Pierce, D.T., "Recent Advances in Compact, Efficient Spin Polarization Analyzers," Workshop on Polarized Electron Sources and Polarimeters in Conjunction with the 8th International Symposium on High Energy Spin Physics, University of Minnesota, Minneapolis, MN, September 8, 1988.

Pierce, D.T., "Quest for Higher Spin Polarization Semiconductor Photocathodes," Workshop on Polarized Electron Sources and Polarimeters in Conjunction with the 8th International Symposium on High Energy Spin Physics, University of Minnesota, Minneapolis, MN, September 9, 1988.

Saloman, E.B., "National Bureau of Standards Data Base of Photon Absorption Cross Sections From 10 eV to 100 GeV," SPIE Conference on X-ray and Vacuum Ultraviolet Interaction Data Bases, Calculations, and Measurements, Los Angeles, CA, January 14, 1988.

Division 533, Invited Talks (cont'd)

Scheinfein, M.R., "Considerations for Ultimate Attainable Spatial Resolution in Microanalysis," Joint U.S./ France Workshop on Electron Beam Induced Spectroscopies at High Spatial Resolution, Aussois, France, March 14, 1988.

Scheinfein, M.R., "Scanning Electron Microscopy with Polarization Analysis (SEMPA)," Joint U.S./ France Workshop on Electron Beam Induced Spectroscopies at High Spatial Resolution, Aussois, France, March 15, 1988.

Stroscio, J.A., "Scanning Tunneling Microscopy of Semiconductor Surfaces," Fifteenth Annual Conference of the Physics and Chemistry of Semiconductor Interfaces, Asilomar, CA, February 1, 1988.

Stroscio, J.A., "Observation of Single Atom Adsorbates with the Scanning Tunneling Microscope," American Physical Society March Meeting, New Orleans, LA, March 21, 1988.

Stroscio, J.A., "STM Applied to Si and GaAs," RAC Symposium on NBS Activities in Scanning Tunneling Microscopy, Gaithersburg, MD, May 20, 1988.

Stroscio, J.A., "Scanning Tunneling Microscopy of Adsorbates on Surfaces," Middle Atlantic Regional Meeting of the American Chemical Society, Millersville University, Millersville, PA, May 25, 1988.

Stroscio, J.A., "Scanning Tunneling Spectroscopy of Single Atoms on Surfaces," Gordon Research Conference on Electron Spectroscopy, Wolfeboro, NH, July 18, 1988.

Unguris, J., "Scanning Electron Microscopy with Polarization Analysis," The Metallurgical Society Fall Meeting, Cincinnati, OH, October 12, 1987.

Unguris, J., "New Uses for Polarized Electrons," Eastern Regional Electron Spectroscopy Society Meeting, Martin Marietta, Baltimore, MD, May 10, 1988.

Unguris, J., "Scanning Electron Microscopy with Polarization Analysis - An Update," Greater Washington Area Surface Science Seminar, National Bureau of Standards, Gaithersburg, MD, May 20, 1988.

PUBLICATIONS

Division 533, Radiation Physics

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, J. de Physique, Coll. 9, Supp au n°12, Tome 48, C9-1053 (1987).

Callcott, T.A., Tsang, K.-L., Zhang, C.H., Ederer, D.L., and Arakawa, E.T., Area Detectors for X-ray Spectroscopy, Nucl. Inst. and Meth. A 266, 578 (1988).

Callcott, T.A., Tsang, K.-L., Zhang, C.H., Ederer, D.L., Clark, C.W., Blendell, J.E., Wassdahl, N., Rubensson, J.E., Bray, G., Mortensson, N., Nordgren, J., Nyholm, R., and Cramm, S., Electronic Density States of High Temperature Superconductors From Soft X-ray Spectroscopy, Extended Abstracts for the 1988 Spring Meeting of Materials Research Society, Reno, NV, April 5-9, 1988. Eds: D.W. Capone, W.H. Butler, B. Batlogg, C.W. Chu, MRS Publ. EA-14, Pittsburgh, PA, 1988 p 13-16.

Celotta, R.J., Unguris, J., and Pierce, D.T., Scanning Electron Microscopy with Polarization Analysis - SEMPA, Proceedings of the 45th Annual Meeting of the Electron Microscopy Society of America, 178 (1987).

Celotta, R.J., Levine, J., Editors, Methods of Experimental Physics, 24, Geophysics, Part A, Laboratory Measurements, Academic Press, (1987).

Celotta, R.J., Levine, J., Editors, Methods of Experimental Physics, 24, Geophysics, Part B, Field Measurements, Academic Press, (1987).

Celotta, R.J., Robins, J.L., Unguris, J., Pierce, D.T., Jonker, B.T., and Prinz, G.A., Domain Images of Ultrathin Fe Films on Ag(100) Appl. Phys. Lett. 52(22), 1918 (1988).

Celotta, R.J., Unguris, J., and Pierce, D.T., Summary Abstract: Scanning Electron Microscopy with Polarization Analysis: Studies of Magnetic Microstructures, J. Vac. Sci. Technol. **A6**(3) (1988).

Celotta, R.J., Advances in Microscopy: Scanning Tunneling and Electron Polarization Microscopy, Appl. Surf. Sci. **31**, 59 (1988).

Cubaynes, D., Bizau, J.M., Wuilleumier, F.J., Ederer, D.L., Picque, J.L., Carre, B., Ferray, M., and Gounand, F., The Main Phases of Development in Photoemission Studies on Laser-Excited Atoms Using Synchrotron Radiation, Journal De Physique, Coll. C9, Supp. no 12, Tome 48, C9-453 (1987).

Division 533, Publications (cont'd)

Cutkosky, R.D., Frequency Dependencies of Precision Resistors, Rev. Sci. Instrum. 59(2), 381 (1988).

Cutkosky, R.D., Precision Weight Calibration with a Specialized Robot, 1988 Measurement Science Conference Proceedings, 271, January 1988.

Dragoset, R.A. and Vorburger, T.V., Scanning Tunneling Microscopy (STM) of a Diamond-turned Surface and a Grating Replica, SPIE Proceedings 749, 54 (1987).

Ederer, D.L., Canfield, L.R., Callcott, T.A., Tsang, K.-L., Zhang, C.H., and Arakawa, E.T., Soft X-ray Absorption and Emission Spectra and The Electronic Structure of Some Exotic Materials, SPIE Proceedings 911, 75 (1988).

Ederer, D.L., Schaefer, R., Tsang, K.-L., Zhang, C.H., Callcott, T.A., and Arakawa, E.T., Electronic Structure of Icosahedral and Other Phases of Aluminum-Manganese Alloys Studied by Soft X-ray Emission Spectroscopy Phys. Rev. B 37, 8594 (1988).

Ederer, D.L., Zhang, C.H., Tsang, K.L., Callcott, T.A., and Arakawa, E.T., The Al $L_{2,3}$ and Mg Double Ionization Emission Spectra of Dilute Al in Mg Alloys, Phys. Rev. B 37, 2401 (1988).

Kurtz, R.L., Ederer, D.L., Barth, J., and Stockbauer, R., Performance of the SURF-II High-Throughput Toroidal Grating Monochromator, Nucl. Inst. and Meth. A 266, 425 (1988).

Lucatorto, T.B., Laser Photoionization Spectroscopy book review for IEEE Jour. Quan. Elect., September 11, 1987.

Matthew, M.A.D., Netzer, F.F., Clark, C.W., and Morar, J.F., Giant 4p Quadrupole Resonances in the Rare Earths, Europhysics Letters 4, 677 (1987).

McClelland, J.J., Scholten, R.E., Kelley, M.H., and Celotta, R.J., Spin Sensitivity of a Channel Electron Multiplier, Rev. Sci. Instrum. 59(3), 506 (1988).

Pierce, D.T., Klebanoff, L.E., Jones, R.K., and Celotta, R.J., Spin-resolved Inverse-Photoemission Study of Ni(001) and its Chemisorption, Phys. Rev. B 36(15), 7849 (1987).

Pierce, D.T., Experimental Studies of Surface Magnetism with Polarized Electrons (Proc. of European Conf. on Surface Science), Surf. Sci. 189-190, 710 (1987).

Division 533, Publications (cont'd)

Pierce, D.T., Celotta, R.J., Kelley, M.H., and Unguris, J., Electron Spin Polarization Analyzers for Use with Synchrotron Radiation, Nucl. Inst. & Meth., **A266**, 550 (1988).

Pierce, D.T., Unguris, J., and Celotta, R.J., High Resolution Imaging of Magnetization, Materials Research Society, MRS Bulletin **13**(6), 19 (1988).

Penn, D.R., Tanuma, S., and Powell, C.J., Proposed Formula for Electron Inelastic Mean Free Paths Based on Calculations for 31 Materials, Surf. Sci. **192**, L849 (1987).

Penn, D.R., Tanuma, S., and Powell, C.J., Dependence of Electron Mean Free Paths on Electron Energy and Material, Proceedings of Analytic Electron Microscopy Conference, 365 (1987).

Penn, D.R., Electron Mean Free Path Calculations Using a Model Dielectric Function, Phys. Rev. B**35**, 482 (1987).

Penn, D.R., Tanuma, S., and Powell, C.J., Summary Abstract: Dependence of Inelastic Electron Mean Free Paths on Electron Energy and Material, J. Vac. Sci. Technol., **A6**(3), 1041 (1988).

Penn, D.R., Allen, P.B., and Cohen, M.L., Total Dielectric Function: Algebraic Sign, Electron-Lattice Response, and Superconductivity, Phys. Rev. B, **38**, 2513-2525 (1988).

Saloman, E.B., Effects of Configuration Mixing in M1 and E2 Transitions Between Ground-State Terms of Sulfur-Like Ions, Phys. Rev. A 38, 577 (1988).

Saloman, E.B., Hubbell, J.H., and Berger, M.J., National Bureau of Standards Data Base of Photon Absorption Cross Sections From 10 eV to 100 GeV, SPIE Proceedings, 911, 100 (1988).

Saloman, E.B., Hubbell, J.H., and Scofield, J.H., X-ray Attenuation Cross Sections for Energies 100 ev to 100 keV and Elements 5=1 to Z=92, Atomic Data and Nucl. Data Tables 38, 1 (1988).

Tsang, K.-L., Zhang, C.H., Callcott, T.A., Canfield, L.R., Ederer, D.L., Blendell, J.E., and Clark, C.W., Soft X-ray Absorption and Emission Spectra of the $YBa_2Cu_3O_{7-x}$ Superconductor, Proceedings of the First Drexel Conference on Superconductivity, World Scientific, Singapore 1988.

Tsang, K.-L., Zhang, C.H., Callcott, T.A., Canfield, L.R., Blendell, J., Ederer, D.L., Clark, C.W., Wassdahl, N., Rubensson, J.E., Bray, G., Mortensson, N., Nordgren, J., Nyholm, R., and Cramm, S., Soft X-ray Absorption and Emission Spectra and The Electronic Structure of the $YBa_2Cu_3O_{7-x}$ Superconductor, J. de Physique, Coll. C9, supp an n°12, Tome 48, C9-1193, (1987).

Tsang, K.-L., Zhang, C.H., Callcott, T.A., Canfield, L.R., Blendell, J., Ederer, D.L., Clark, C.W., Wassdahl, N., Rubensson, J.E., Bray, G., Mortensson, N., Nordgren, J., Nyholm, R., and Cramm, S., Soft X-ray Absorption and Emission Spectra and The Electronic Structure of the $YBa_2Cu_3O_{7-x}$ Superconductor, Phys. Rev. B. 37, 2293 (1988).

Unguris, J., Celotta, R.J., Pierce, D.T., and Hembree, G.G., Magnetic Microstructure Imaging Using Scanning Electron Microscopy with Polarization Analysis, Proceeding of Analytical Electron Microscopy Conference, 350 (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, Phys. Rev. A. 37, 4207 (1987).

PUBLICATIONS IN PREPARATION

Division 533, Radiation Physics

Armentrout, C.J., Geddes, J.B., Lee, P., Snider, R.T., and Canfield, L.R., UV to SXR Surveys Using a Compact, Biplanar Diode Array (to be submitted, Proc. of the Seventh International Conference on High Temperature Plasma Diagnostics).

Bengtsson, L., Travis, J.C., Lucatorto, T.B., Kreider, K., and Brown, L., Laser Ablation of Thin Films as a Free Atom Source for Pulsed Rims (to be published, Proc. of the Fourth International Conf. on Resonance Ionization Spectroscopy and Its Applications, 1988).

Cooper, J.W., Clark, C.W., Cromer, C.R., Lucatorto, T.B., Sonntag, B.F., Kennedy, E.T., Costello, J.T., Junwen, C., and Tomkins, F.S., Autoionizing Resonaces in Mn, Mn+, and Cr 3p Subshell Absorption (to be submitted, Phys. Rev. Lett.).

Furst, M.L. and Madden, R.P., SURF-II Radiometric Instrumentation Calibration Facility (to be submitted to SPIE Proceedings, 982).

Korde, R., Canfield, L.R., and Wallis, B., Stable, High Quantum Efficiency Silicon Photodiodes for Vacuum-UV Applications, SPIE Proceedings 932).

McClelland, J.J., Scheinfein, M.R., and Pierce, D.T., Use of Thorium as a Target in Electron Spin Analyzers (to be submitted, Rev. Sci. Instrum.).

Pan, L., Taylor, K.T., and Clark, C.W., Computation of the A.C. Stark Effect in the Ground State of Atomic Hydrogen (to be submitted, Phys. Rev. Lett.).

Penn, D.R., Tanuma, S., and Powell, C.J., Calculations of Electron Inelastic Mean Free Paths for 31 Materials (to be published, Surface and Interface Analysis).

Penn, D.R., Chang, K.J., and Cohen, M.L., Electronic Correlations and Satellites in Superconducting Oxides (to be published, Phys. Rev. B).

Penn, D.R. and Apell, P., Free Electron Like Stoner Excitations in Fe (to be published, Phys. Rev. B).

Saloman, E.B., A Resonance Ionization Spectroscopy/Resonance Ionization Mass Spectrometer Data Service (to be published, Proc. of the Fourth International Conference on Resonance Ionization Spectroscopy and Its Applications, 1988).

Division 533, Publications in Preparation (cont'd)

Saloman, E.B., Energy Levels and Transition Probabilities in the Ground State Configuration of Sulfur-Like Ions (to be published, Atomic Data and Nuclear Data Tables).

Scheinfein, M.R., Pierce, D.T., Unguris, J., McClelland, J.J., and Celotta, R.J., Improved Low-Energy Diffuse Scattering Electron-Spin Polarization Analyzer (to be submitted, Rev. Sci. Instr.).

Scheinfein, M.R., Unguris, J., Pierce, D.T., and Celotta, R.J., Scanning Electron Microscopy with Polarization Analysis (SEMPA): High Spatial Magnetic Imaging Status Report (to be published, Proc. of Aussois Workshop on Electron Beam Induced Spectroscopies at High Spatial Resolution, March, 1988).

Wassdahl, N., Rubensson, J.E., Bray, G., Rindstedt, J., Martensson, N., Nordgren, J., Nyholm, R., and Cramm, S., Cu L and O K Emission Spectra of the $YBa_2Cu_2O_{7-x}$ Superconductor Excited by Monochromatized Synchrotron Radiation (to be submitted, Physics Letters).

TECHNICAL AND PROFESSIONAL COMMITTEE PARTICIPATION AND LEADERSHIP

Division 533, Radiation Physics

Robert J. Celotta

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

Member, NML EEO Committee, 1986-88.

Charles W. Clark

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

Co-director, NATO Advanced Study Institute "Atoms in Strong Fields."

Member, Ad Hoc Committee on Page Charge Analysis, Optical Society of America.

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.

Robert P. Madden

Member, 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.

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

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

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

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 Atmospheric Program on Solar Spectral Irradiance Measurements, 1981-1988.

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

Chairman, NBS-CRR Calibrations Advisory Committee, 1985-88.

Member, NBS-NML Classification Committee for the NBS Personnel Demonstration Project, 1987-88.

Daniel T. Pierce

Member, Editorial board, Journal of Electron Spectroscopy.

Chairman, 1988 Gordon Conference on Electron Spectroscopy.

Chairman, Executive Committee, Surface Science Division of American Vacuum Society, 1988.

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

MAJOR CONSULTING AND ADVISORY SERVICES

Division 533, Radiation Physics

L.R. Canfield consulted with Raj Korde of United Detector Technology on applications of silicon photodiode detectors in the far ultraviolet.

L.R. Canfield consulted with Obert Wood and William Silvfast of AT&T Bell Laboratories and David Nilson of the Lawrence Livermore National Laboratory on aluminum thin film filters for x-ray laser applications.

L.R. Canfield consulted with Charles Armentrout and Joseph Geddes of KMS Fusion on narrow band detectors and filters for the far uv and soft x-ray regions.

L.R. Canfield consulted with Fred Hererro and Walter Hoegy of the Goddard Space Flight Center on the photoemission of materials on board a Venus orbiter spacecraft.

L.R. Canfield advised production personnel at Science Applications Corporation and Ball Aerospace Systems on photoemissive detectors for the vacuum ultraviolet.

L.R. Canfield advised A.L. Lane of the Jet Propulsion Lab on problems associated with detectors for space applications.

L.R. Canfield advised Howard Ogawa of Southern California University and Gary Rottman of the University of Colorado on the use of a narrow-band detector for solar flux measurements in a rocket flight.

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

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, MIT, Argonne National Laboratory, Perkin Elmer Corporation, and the Naval Research Laboratory.

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

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

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

R.P. Madden consulted for NASA by serving on the "Spacecraft Instrument Calibration and Stability" Working Group of the "Ozone Trends Panel" contributing to the report to Congress entitled "Present State of Knowledge of the Upper Atmosphere 1988: An Assessment Report" as required under the Clean Air Act Amendments of 1977, Public Law 95-95.

R.P. Madden, at the request of the Director of the Earth Science and Applications Division of the Office of Space Science and Applications, NASA, is coordinating an international round-robin intercomparison of solar irradiance monitoring space experiments.

R.P. Madden is on a Naval Research Laboratory advisory panel reviewing national programs in lithography research.

W.R. Ott consulted with scientists from Lockheed Corporation and several DoD organizations on measurement needs for remote sensing applications with ultraviolet and soft x-ray radiation.

M.R. Scheinfein and M.H. Kelley consulted with NSLS staff at Brookhaven National Laboratory on spin-polarized angle-resolved photoelectron spectroscopy.

J. Unguris, M.R. Scheinfein, and M.H. Kelley consulted with the Physical Electronics Division of Perkin Elmer Corporation on commercialization of a SEMPA microscope.

JOURNAL EDITORSHIPS

Division 533, Radiation Physics

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

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

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

TRIPS SPONSORED BY OTHERS

Division 533, Radiation Physics

R.J. Celotta presented a talk at the Australian Bicentenary Congress, Sydney, Australia, January 26, 1988.

C.W. Clark gave a Quantum Electronics Seminar at the State University of New York, Stony Brook, NY, October 30, 1987.

D.L. Ederer presented a talk at the University of Notre Dame, South Bend, IN, October 15, 1987.

D.L. Ederer gave a lecture at the Naval Postgraduate School, Monterey, CA, January 8, 1988.

D.L. Ederer presented at talk at the University of California, Riverside, CA, January 12, 1988.

D.L. Ederer presented a talk at the University of Southern California, Los Angeles, CA, January 13, 1988.

D.L. Ederer presented at talk at Argonne National Laboratory, Argonne, IL, June 17, 1988.

J.J. McClelland gave a Physics Colloquium at Wesleyan University, Middletown, CT, October 1, 1987.

J.J. McClelland gave a Physics Colloqium at University of Kentucky, Lexington, KY, October 21, 1987.

D.R. Penn gave a Physics Colloquium at Rice University, Houston, TX, January 26, 1988.

D.R. Penn presented a colloquium at Chalmers University, Chalmers, Sweden, April 15, 1988.

D.R. Penn gave an invited talk at The 4th Joint MMM-Intermag Conference, Vancouver, British Columbia, Canada, July 14, 1988.

D.T. Pierce gave a Physics Seminar at Arizona State University, October 26, 1987.

D.T. Pierce gave an invited talk at the Surface Magnetism Workshop, Laguna Beach, CA, October 29, 1987.

D.T. Pierce gave a Surface Science Seminar at Rutgers University, May 10, 1988.

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

M.R. Scheinfein gave a talk at the Joint U.S./ France Workshop on Electron Beam Induced Spectroscopies at High Spatial Resolution, Aussois, France, March 15, 1988.

M.R. Scheinfein gave a talk at the Joint U.S./ France Workshop on Electron Beam Induced Spectroscopies at High Spatial Resolution, Aussois, France, March 15, 1988.

J.A. Stroscio gave an invited talk at the 15th Annual Conference of the Physics and Chemistry of Semiconductor Interfaces, Asilomar, CA, February 1, 1988.

CALIBRATION SERVICES PERFORMED

Division 533, Radiation Physics

Type of Service	Customer Type*	SP 250 Item No.	Number Calibration or Tests
Far UV radiometric transfer standard detectors (photodiode calibrations)	1,4-8	N.A.	39
Spectrometer calibrations using SURF as an absolute source	5-7	N.A.	12
Totals			51

* 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

Abraham, Daniel T., University of California at Irvine, "Spin Dependent Elastic and Elastic Scattering from Magnetic Surfaces," March 14, 1988.

Apell, Peter, Chalmers University of Technology, Sweden, "De-Excitation of Multiply Charged Ions," February 19, 1988.

Bartschat, Klaus, Universitat Münster, West Germany, "Excitation and Ionization of Atoms by Electron and Photon Impact," February 29, 1988.

Bashkansky, Mark, Columbia University, "Review of Recent ATI Experimental Results," December 11, 1987.

Bentley, Murry, Johns Hopkins University, "Fully Variational Hartree-Fock Calculations of Quasi-Bound Atomic States," June 8, 1988.

Bruhwiler, Paul, University of Virginia, "Charged Density Waves in Alkali Metals," April 1, 1988.

Cadez, Iztok, Institute of Physics, Belgrade, "Vibrational Excitation of Hydrogen via Recombinative Desorption of Atomic Hydrogen Gas on a Metal Surface," December 3, 1987.

Clark, R.N., University of Washington, "Chaotic Behavior of a Simple System," December 29, 1987.

Delos, John, College of William and Mary, "Atoms in Strong Fields: Quantum Manifestitations of Classical Order and Classical Chaos," June 3, 1988.

Dreyfuss, Russell, IBM T.J. Watson Research Labs., Yorktown Heights, "Laser Probing of Laser Ablation," November 17, 1987.

Dutcher, John, Simon Fraser University, "Brillouin Light Scattering Studies of Magnetic Surface Anisotropy," June 3, 1988.

Fairbank, William, Colorado State University, "Photon Burst Mass Spectrometry," November 4, 1987.

Falcone, Roger, University of California (Berkeley), "New Short Pulse X-Ray Sources From Laser Heated Solids," July 6, 1988.

Garton, W.R.S., Imperial College, "Atoms in High External Fields," January 12, 1988.

Division 533, Sponsored Seminars and Colloquia (cont'd)

Garton, W.R.S., Imperial College, "External Field Effects in Atomic Spectra," November 17, 1987.

Glab, Wallace, Argonne National Laboratory, "Highly Excited States of Molecular Hydrogen in a Strong Electric Field," June 27, 1988.

Greene, Chris, Louisiana State University, "Two-electron Excitations in Atomic Ca," March 30, 1988.

Lefebvre-Brion, H., Universite de Paris-Sud, "Autoionization and Photodissociation in Diatomic Molecules: Application to O_2 and HCI Molecules," August 4, 1988.

Liebsch, Angskar, Institute Theoretical Physics, KFA-Julich, West Germany, "Linear and Nonlinear Response at Metal Surfaces," May 23, 1988.

Liu, Ya-Wen, Beijing University, "Progress at the Beijing Storage Ring Facility," April 29, 1988.

Izerda, Yves, Naval Research Laboratory, "Stoner Excitations in Magnetic Thin Films," April 26, 1988.

Livins, Peter, University of Virginia, "Shake-up in Soft X-ray Emission," April 5, 1988.

Malafsky, Geoffrey, Penn State University, "Primary Ion Energy Effects in the Sputtering of Single Crystal Metals," July 7, 1988.

Menendez, Manuel, University of Georgia, "Fast Atomic Collisions: A Pathway to the Three Body Coulomb Problem," July 11, 1988.

Mundschau, Michael, Technischen Universitat Clausthal, "Low-Energy Electron Microscopy," January 19, 1988.

Nayfeh, M.N., University of Illinois, "Fragmentation and Ionization of Diatomic Molecules in Intense Laser Fields," May 6, 1988.

Perera, Rupert, Lawrence Berkeley Laboratory, "Soft X-rays in Multilayers, Present and Future," March 31, 1988.

Pogatshnik, Gerry, Oak Ridge National Laboratory, "In Search of Oxide Color Center Lasers," May 6, 1988.

Silvera, Isaac, Harvard University, "Spin Polarized Hydrogen: Prospects for Base Condensation with Lyman-α Laser Cooling," October 13, 1988.

Scimica, Thomas, University of Hawaii, "Variable Angle X-ray Emission Spectroscopy: Applications to Transition Metals," April 29, 1988.

Division 533, Sponsored Seminars and Colloquia (cont'd)

Starace, Anthony, University of Nebraska, "Electron Correlation Effects in Nonresonant Multiphoton Ionization Processes," October 15, 1987.

Thompson, Jeffrey, Oak Ridge National Laboratory, "Observation of the Ca Ion by Photoelectron Spectroscopy," June 9, 1988.

Wasson, David A., California Institute of Technology, "Many-Electron Response to Strong Laser Pulses," December 22, 1987.

Weigold, Erich, Flinders University, "Wave Function Mapping in Atoms and Molecules," July 26, 1988.

Wuilleumier, Francois, LURE, "Recent Developments in Laser-Synchrotron Expeirments," April 14, 1988.

TECHNICAL ACTIVITIES

Division 534, Radiometric Physics

Introduction

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

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

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

The restaffing of the Division continued during Fiscal Year 1988. Robert Booker, Julius Cohen, and Charles Popenoe retired during the year, Trish Ferret completed her postdoctoral tenure, and William Peifer's temporary appointment expired. The following joined the Division as new members of our scientific staff (previous association noted in parentheses):

Ms. Clara Asmail (Optical Science Center, Tuscon, AZ),
Dr. Christopher Cromer (Atomic and Plasma Radiation Division),
Mr. Edward Hunter (Ionizing Radiation Division),
Mr. Thomas Lusk (General Electric Co., Cleveland, OH),
Mr. James Proctor (University of Maryland, College Park, MD),
Dr. Bobbie Roop (University of Texas, Austin, TX),
Dr. Ambler Thompson (University of Maryland, Catonsville, MD).

With these changes, the Division comprised 31 permanent technical staff members on September 1. Eleven of these hold doctorate degrees.

As detailed in the following, the Division has made important progress during the year. For example:

The new optical densitometer using heterodyne interferometry and rf-attenuation standards has been used at visible wavelengths to measure spectral transmittances as low as 10^{-12} with better than 1% uncertainty, and is about to be extended into the ir. A program to explore potential radiometric applications of Rydberg atom detectors is in the planning stage. The atomic structure of these atoms may allow the convenient production of absolute photon detectors from the ir region to millimeter wavelengths.

The Division is extending its detector research and development programs to lower light levels and into the uv and near-ir spectral regions. There has been substantial progress in the development of stable, sensitive detector packages which can serve as economic transfer standards for industrial and research applications at the 0.1 to 0.5% accuracy level. The joint development of a high-accuracy, absolute, cryogenically cooled, electrically-calibrated radiometer by NIST and the National Physical Laboratory (U.K.) will become a new national standard for spectral detector responsivity with an expected accuracy of 0.005%.

The gold-point experiment has produced improved radiation temperature measurements, and further refinements of this experiment are expected. Apart from its importance for the impending redefinition of the International Temperature Scale, this effort has demonstrated that our pyrometric and spectroradiometric calibration services will benefit from more extensive utilizations of detector technology. The corresponding upgrading of our calibration facilities is expected to take place over the next several years.

Intercomparisons have shown conclusively that detector-based realizations of photometric scales are more precise than our present, IPTS-68 based scale. Accordingly, we are initiating a long-term effort to effect a transition of our photometric calibration services to a detector basis. The construction and initial check-out of a new photometric bench for luminous intensity and color temperature measurements have been completed. Silicon-cell based color temperature measurements have been validated against FASCAL.

A new ir imaging laboratory is under development to serve as a measurement facility for ambient temperature blackbodies. In the near future, an ir spectroradiometric capability and an ir imaging camera will be added to this effort.

The new long-wave ir calibration laboratory is nearing completion. This facility includes a large, cryogenically-cooled calibration chamber with an absolute cryogenic radiometer having a sensitivity in the nanowatt region, and will be used for calibrations of low-background ir blackbodies and as a research tool for ir radiometry at low temperatures.

A new measurement capability for ir spectral transmittance measurements in the 2.5 to 25 micrometer region has been established. Sets of fluorescent materials for front-surface measurements have been developed and will soon be available as new SRM's. Uniform, neutral diffuse reflectance transfer standards are being developed.

The conceptual design of the Division's new facility for measuring bidirectional scattering distribution functions has been completed. The construction of the facility is planned in fiscal year 1989.

The detailed progress reports for the Spectral Radiometry, Spectrophotometry, and Measurement Services Groups of the Division appear below, followed by a summary of our program plans for the new fiscal year.

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

The Spectral Radiometry Group is responsible for thermal radiometry, photodetector research and calibration, advanced radiometry research and applications, and facilities development for the Division. Included in the latter project area is the development of a facility for calibration and research in the low background infrared region, and participation in the development of a new capability for bidirectional scattering measurements. New programs in thermal imaging and in uv photodetector research have been initiated. The efforts will extend the calibration capabilities of the Division and will result in new research and development directions for the future. The detailed reports on the projects in the group are given below.

Photodetector Metrology (Zalewski, Thomas, Houston, Eppeldauer)

Our capabilities for detector calibrations have been expanded and improved in two ways. (1) Greater accuracy has been achieved over the range from the near uv to the near ir by using the light trapping, multi-detector technique and reasonably simple models of the reflectance and internal quantum efficiency of the Si photodiodes. (2) Based on earlier

work, the absolute external and internal quantum efficiencies of several types of InGaAs and Ge photodiodes have been measured at 1.15, 1.32, and 1.52 micrometers; thereby extending our calibration capability to cover what is sometimes called the "germanium region".

Using laser lines at 488 and 633 nm, Thomas has studied the stability of hermetically sealed, radiometric quality p-n silicon photodiodes. In order to avoid the interference effects found in commercial windowed silicon photodiodes, a device was constructed using a wedged quartz window with the p-n photodiodes sealed in dry nitrogen. This device was compared with one of the unsealed, n-p photodiode, commercially available QEDs (100% quantum efficient devices) that are used as our absolute standard detectors. Over a seven-month period these two very different devices have been observed to have a constant ratio of responsivity to within 150 ppm.

An intercomparison in the ir region has been completed with two other optical radiation measurement laboratories. Pyroelectric radiometer responsivity at 1.32 micrometers was intercompared with the fiber optics characterization group at the NIST Boulder Laboratory. An intercomparison with germanium photodiode responsivity at 1.15, 1.32 and 1.52 micrometers was made with the detector radiometry group at the Physikalisch Technische Bundesanstalt (FRG). The level of agreement was within 0.5% in both intercomparisons.

The high accuracy range of the QEDs has been extended from its former limits of 400 and 700 nm, to 250 and 900 nm, respectively. A method for determining the reflectance loss of a multi-detector light trapping radiometer by measuring the individual photocurrents has been developed. This technique enables an accurate uv extension of the absolute responsivity of a commercial QED that has been modified to allow the photocurrent from each photodiode to be read separately. For a multi-detector device employing p-n silicon photodiodes suitable for long wavelength operation, the accurate absolute responsivity range can be extended to the near ir.

Houston has completed a detector responsivity comparison with Canfield of the Radiation Physics Division of CRR. In the spectral range where both calibration techniques overlap, 250 to 300 nm, the agreement was within 1%. This was much less than the combined uncertainty estimate for the two different calibration techniques.

Eppeldauer studied a variety of amplifier/detector combinations and found one that has a sub-femtoampere noise level. Eppeldauer, Thompson, and Zalewski used ir devices to measure the absolute spectral radiance of several different low level, radioactively stimulated fluorescent samples.

Several more low noise amplifier/detector packages are being constructed. One will replace the photomultiplier in the gold-point experiment at certain wavelengths. The others will be used in future developments in the photometric calibration program.

Work is continuing on the calibration of two types of silicon photodiodes which will jointly cover the spectral range from 250 to 1100 nm. These photodiodes were selected on the basis of their improved performance, as compared to the photodiodes presently used in the DRTIP radiometers. In contrast to the rental approach of the DRTIP program, the new detector calibration program will consist of a calibrated detector sold outright to the customer. We are now also in a position to offer, as a special test, calibrations both in the near ir on radiometric quality InGaAs or germanium photodiodes and in the visible on spatially uniform, photopically corrected, radiometric quality silicon photodiodes.

Advanced Radiometry (Hardis, Peifer, Ferrett)

This effort includes the Kr^+ ion charge-exchange light source development and collaborative projects using synchrotron radiation to probe molecular structure and dynamics. The Kr^+ project studies the formation of metastable Kr during charge-exchange collisions of Kr^+ ions upon rubidium vapor. The krypton beam, after charge exchange, can be laser-excited into an atomic state that decays with equal photon flux in both the uv and near-ir. Alternatively, the metastable beam can be reionized and the process used as isotopically selective process for mass analysis.

This project also includes the Angle Resolved Photoelectron Spectroscopy (ARPES) experiments conducted at the NIST Synchrotron Ultraviolet Radiation Facility (SURF-II) and Synchrotron Radiation Source (SRS) at Daresbury Laboratory in the UK. These studies use the tunable, narrow-band uv radiation available from synchrotrons along with high-resolution electron spectrometers to measure photoemission processes to gain insights on molecular ionization dynamics. Our research is done with the cooperation of leading theorists in the U.S. and Europe, who must often pace their efforts by the availability and quality of experimental information.

During FY88, the design and construction of the Kr^+ project components was nearly completed. The Colutron ion source initially showed very poor beam qualities, which were resolved by modifying the lens and support components. A sample-gas feed system for the ion source was built, as were beam-line components such as a charge-exchange cell. The project involves both diode lasers and an argon-ion pumped tunable

dye laser. All were made operational. NIST participated in both the DOE Noble Gas Workshop and the RIS-88 Conference, in which researchers with similar goals presented their methods and progress. Dr. William R. Peifer, a postdoctoral scientist, was hired in October to work exclusively on this project. He left in March to pursue other interest. Dr. Chris L. Cromer joined the project from Atomic and Plasma Radiation Division (531) later in the year and made major contributions. Drs. Migdall and Hardis collaborated in this work as well.

The ARPES project concluded its long standing run at SURF and was shipped to SRS, where it is being reassembled. Before leaving NIST, experiments which studied autoionization features and vibronic coupling, were completed on CO_2, CO, and N_2O targets. The principal NIST investigators were Drs. Trish Ferrett, Steve H. Southworth, Albert C. Parr, and Jonathan E. Hardis.

Laser Spectrometry (Migdall, Zheng)

A laser heterodyne detection method is being developed to measure densities of optical filters over as many as 11 orders of magnitude with an absolute accuracy of about 1%. This technique allows the transmittance of optical filters to be compared to the electrical attenuation of an RF attenuator. Using this scheme, the accuracy of the RF attenuator calibrations can be transfered into the optical measurements. These methods to make the elctrical measurements are being improved to allow the accuracy needed to use the full potential of the technique. The current work has been done at a fixed wavelength of 632 nm, but a tunable dye laser has been demonstrated to work with the system, allowing for wide tunability. In addition, a CO_2 laser has recently been acquired and set up, with the necessary optical system to follow shortly. The 10.6 um measurements will use the same electronics system developed for the visible measurements.

Facilities Development (Fowler, Ebner, Proctor, Tobin)

The Low Background Infrared (LBIR) calibration facility (funded by DoD) is in the final stages of assembly. The room modifications have been implemented and the vacuum shell installed on it's frame. The major components have been procured or fabricated as appropriate and test fitted together. An auxiliary test chamber has been designed and fabricated for testing of paint and any other components utilized inside the chamber for outgassing properties. The final assembly and testing is

underway along with the software development. The new design water bath blackbody is assembled and partially characterized and is currently undergoing final characterization. We have built two in order to keep one here at NIST as a tie point for the characterization of other room temperature blackbody radiators. Several servo controlled translation tables have been designed, fabricated and assembled for use in the FASCAL, pyrometry and high temperature blackbody facilities. Numerous electronics systems in support of the laser heterodyne, cryogenic radiometer, detector calibration facilities and various other projects in the division have been designed, constructed and tested. The design of the Bidirectional Scattering Distribution Function (BSDF) apparatus is underway and progressing rapidly. A new alignment fixture and modified lamp base assembly has been designed for the spectral flux lamp project and are currently being tested and evaluated.

Thermal Radiometry Project (Saunders, Southworth, Hillard, Oroshnik)

This project is organized in two areas. The first area is to determine the freezing point of gold and how it relates to the IPTS-68 temperature scale. The experiment to measure the freezing point of gold was redesigned to incorporate more accurate silicon detectors which have recently become available. A detector amplifier package to measure 10^{-15} amperes was developed to replace the photomultiplier on the spectrometer. The problem of accurate area measurements of apertures was reviewed with advice from the Precision Engineering Division. The outcome of this research will yield apertures made on new state of the art grinding machines with errors of less then .1%. An experiment to intercompare the resistance temperature scale and optical radiation temperature scale has been designed and is presently underway. An investigation of the commercial, scientific and defense needs in pyrometry was carried out. Preliminary results indicate possible new technology to pursue and improve pyrometry to meet the nation's needs. Detailed programs to support pyrometry are being formulated.

The second area of this project is focused on developing a thermal imaging facility. The facility was put into operation this year and its first goal is to characterize a uniform, constant temperature, water bath blackbody (a new standard developed by the Division). This water bath blackbody has been characterized at a few wavelengths and the full characterization will be completed this year. This blackbody has a possible future use in characterizing thermal imaging cameras. An additional component of this project which is just getting underway is an effort to evaluate thermal radiometers used in the field by the Navy and Air Force. The medium temperature (400-1000°C) facility was redesigned and is being rebuilt.

Spectrophotometry (J. J. Hsia, Group Leader)

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

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

The FY88 accomplishments of the Group in three key areas are presented below.

UV-VIS-NIR-IR SPECTROMETRY

Measurement Services

In FY88 calibration services for industrial laboratories totaling $20K were performed. Barnes provided special calibration services for spectral transmittance, specular reflectance, diffuse reflectance, and opacity. Eckerle provided measurement assurance services for transmittance. Hunter and Barnes provided NASA with $51K worth of measurement services for 6°/hemispherical reflectance and bidirectional reflectance distribution function. Barnes provided 20 support measurements for NIST staff outside of this Group, mainly in this Division. Barnes has batch calibrated sixty, near infrared reflection wavelength standards for issuance as SRMs.

Transmittance International Intercomparison

An intercomparison of the regular spectral transmittance scales of NIST, Gaithersburg, MD (USA); PTB, Braunschweig (FRG); NPL, Teddington, Middlesex (GB); and OMH, Budapest (H) was conducted by Eckerle. Three sets of neutral glass filters with transmittances ranging from approximately 0.92 to 0.001 transmittance units were used. The difference between the results from the reference spectrophotometers of

the laboratories is generally smaller than the total uncertainty of the interchange. The relative total uncertainty ranges from 0.05% to 0.5% for transmittance from 0.92 to 0.001. The contribution to the relative uncertainty caused by the samples was the limiting factor in the intercomparison.

Secondary Standardization Laboratory

Hsia visited the laboratories at the Rochester Institute of Technology (RIT), to discuss measurement methods and problems. At RIT's suggestion, Reiff and Barnes are developing neutral, uniform diffuse reflectance transfer standards. These standards will be used in establishing secondary spectrophotometric standardization laboratories.

Transmission Densitometry

Fink has calibrated 270 x-ray step tablets (SRM 1001) and 225 photographic step tablets (SRM 1008) for use in the calibration of transmission densitometers in the transmission density range 0 to 4. He supervised the evaluation of microcopy resolution test charts (SRM 1010a). Fink has also calibrated two master step tablets in the opal-glass scale with the reference transmission densitometer (Inverse Fourth Instrument). Sinha, Barnes, and Fink completed the hardware installation and software development for transmission density measurements using a new transfer densitometer and a new microcomputer.

Infrared Spectrometry

Lin has established a new measurement capability for monochromator-based, regular transmittance in the long wavelength infrared from 2.5 to 25μm. Four papers related to this work have been prepared for publication. A 12° specular reflectance sample holder is being constructed for the monochrator-based spectrometer. Wang has aligned the optics in the FTIR-based spectrometer to maximize the detector signal. His wavelength study showed 0.001 cm^{-1} stability. He will next investigate detector linearity and spectrometer inter-reflections.

SPECTROFLUORIMETRY

Eckerle completed the uncertainty analyses for the four fluorescent materials. Thompson and Eckerle have completed ten measurements on one master set. The corrected emission spectra were measured against one standard lamp. They also completed 5 measurements of one prepared quinine sulfate SRM. The data are being analyzed and several correction factors will be applied to check the consistency of the scale. Thompson

has completed measurements on 18 randomly selected sets to check the reproducibility of batch production. Fifty, corrected emission spectra SRM sets were completed at the end of FY88.

Thompson and Liu in collaboration with Mr. D. Blackburn and Dr. Kaufman of Division 420 have initiated some exploratory investigations of potential materials for future ultraviolet emission spectra SRMs. Thompson and Eckerle have completed emission spectral measurements on tritium activated phosphors in a collaborative project with Zalewski. The emission spectra of two LED have been measured.

BIDIRECTIONAL SCATTERING DISTRIBUTION FUNCTION (BSDF)

Experimental studies were performed prior to the conceptual design of a BSDF instrument for near-specular samples. The studies included relative BRDF measurements with different receiver solid angles, light spot sizes, polarization, and light traps. Proctor, Asmail, and Hsia have completed the conceptual design which includes mechanical arrangements of sample mounts, detector mounts, and layout of light sources and optical components.

A filter/diffuser set is being developed to cover BRDF from 0.3 to 10^{-7} Sr^{-1}. Eckerle has calibrated fourteen neutral density filter glasses ranging in optical density from 2 to 6. The measurements were performed at 441.6, 488, 532 and 632.8 nm. Hunter and Barnes have calibrated 45/0 BRDF on several pressed and sintered PTFE white samples of about 0.3 Sr^{-1} and on several sintered black PTFE samples of about 0.009 Sr^{-1}. Hunter has completed some polarization-effect studies on 45/0 BRDF measurements of pressed PTFE powder with density of 1 g cm^{-3}. He has also completed the repeatability study of ten pressed PTFE powder samples for 45/0 BRDF measurements. Three times standard error was 0.3% of the BRDF value.

Roop has initiated a study to develop approaches to produce near Lambertian infrared diffusers. She has set-up and tested the CO_2 laser system which will be used for heterodyne transmittance and scattering measurements. Roop also helped trouble shoot the visible heterodyne system to reduce the noise level in the data.

Hsia has provided consultation in establishing ASTM subcommittee E-12.09 on Scattering. The purpose of the Subcommittee is to develop standard testing methods for scattering measurements including BRDF.

Radiometric Measurement Services (D. A. McSparron, Group Leader)

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 NIST have acceptable levels of accuracy.

Calibration Volume

Direct calibration work was up again in this fiscal year. Calibration billings for the public increased by 15% and directly funded calibration work for other government agencies increased by 34%. The combined effect was an overall increase of 18%.

Detector Based Candela

Andor, in collaboration with the detector and spectrophotometry projects of the Division, produced and characterized a series of seven photopically-corrected silicon cell photometers. Three of these photometers were of a novel "trap detector" design. The absolute spectral response of the photometers was determined by measurements based on the silicon-self calibration method. This work constituted a detector-based realization of the candela. The cells were compared with the present blackbody based lamp working standards. The measured difference was 0.57%. The direction and magnitude of this difference was such as to confirm the proposed reassignment of the temperature of freezing gold (a 0.4 K shift in the gold point would shift the present photometric standards by 0.52%). This result also confirms that the main contributor to the NIST difference from world mean in the recent international intercomparison of photometric units was due to a gold point misassignment.

Intercomparisons

At the October 1986 meeting of the Consultative Committee on Photometry and Radiometry (CCPR) it was decided to conduct an international intercomparison of national scales of spectral irradiance with NIST serving as the central laboratory. The wavelength range 250 to 2400 nm was chosen for the intercomparison. Fourteen national laboratories (in addition to NIST) have agreed to participate. The National Physical Laboratory (England) is overseeing the construction

and selection of special lamps for the intercomparison. The selected lamps, three per participant, were sent to participants in late August 1988. NIST procured and shipped to requesting participants special sockets and alignment jigs. The participating laboratories are scheduled to make initial measurements in the fall of 1988 and submit their three lamps to NIST in early December. NIST measurements are expected to be completed by April 1989 and the participants will then remeasure the lamps. NIST will collect and analyze the data. A report on the results will be issued for possible action at the next CCPR meeting in September 1990.

Coordinated with the CCPR intercomparison, an international intercomparison has been organized among members of the uv solar monitoring community. The intercomparison will involve spectral irradiance measurements over the spectral range 200-400 nm. The intercomparison is scheduled to be carried out over the next 18 months. A complete workstation containing NIST calibrated uv light sources will be shipped to each of the labs in turn. Each lab will have the workstation twice and will use it to calibrate their instruments. The Radiometric Physics Division is designing and constructing the intercomparison workstation and will calibrate it at the beginning, in the middle, and at the end of the intercomparison. The participants in the intercomparison include the University of Colorado (SOLSTICE--Solar Stellar Irradiance Comparison Experiment), the Naval Research Laboratory (SUSIM--Solar UV Spectral Irradiance Monitor), NASA (SSBUV--Shuttle Solar Backscatter UV Radiometer), a joint Belgian-French group (SOLSPEC--Solar Spectrometer), and the Technische Studien Gmbh of West Germany (ASSI--Airglow Solar Spectrometer Instrument). These experiments are of immediate, critical importance to both the scientific community (atmospheric physics and weather prediction models) and the general public (ozone monitoring and greenhouse effects).

Pyrometry

The upgrade of the radiance temperature calibration facilities continued this year. Fowler designed a new, automated source bench and oversaw its construction and installation. The new bench has six source stations and will greatly improve the efficiency of pyrometric strip lamp calibrations. A new, large area, variable temperature blackbody was received and installed. Check out of this blackbody is now well underway. When fully characterized, it will allow more convenient calibration of traditional pyrometers (visual and automatic) and allow us for the first time to offer a calibration service for pyrometers operating at wavelengths other than 650 nm. It is planned to establish a new calibration service for silicon cell based pyrometers in the coming fiscal year.

A special project was carried out by Waters and Walker in support of the Center for Fire Research (CFR) and the Federal Aviation Administration. The FAA is developing flammability specifications for the materials used in commercial airliners. In order to establish a firm measurement base for this flammability testing, CFR procured a commercial, electrically calibrated radiometer (ECR). Waters and Walker characterized the linearity and reflectance of this ECR and calibrated it against the ECR used in the gold point experiment by Saunders. Several lamp standards of total irradiance were also calibrated to provide a convenient check procedure as CFR develops measurement protocols and standards for FAA use.

Photometry

The photometry program received a substantial boost this spring when Tom Lusk joined the NBS staff after a career of over 30 years as a photometrist/radiometrist in private industry. The combined efforts of Bruening, Saunders, Lusk, and Hu brought the spectral flux program to a conclusion. This program has provided the U.S. lighting industry with incandescent and High Pressure Sodium (HPS) lamp standards of geometrically-total spectral flux. From these lamps industry will derive spectral and photometric standards for all types of high-intensity discharge lamps. These standards will form the basis of a secondary lab support program coordinated through the Lamp Testing Engineer's Conference (LTEC).

Lusk and Wilkinson have continued the work started by Booker to equip the photometric lab with a modern optical bench. During the year, a design goal of 0.1% overall accuracy for transfer measurements made on the new bench was adopted. Andor's measurements in realizing a detector-based Candela were the first experiments making use of this capability. In the coming year, Lusk and Wilkinson will revamp the measurement protocols used for the routine photometric calibrations to place them on a detector base and make use of the capabilities of the new bench.

During the year, Andor carried out a series of experiments to replace the photomultiplier based color temperature meter with silicon cells and appropriate filters. Closures with the blackbody-based lamp standards were better than 5 K (present estimated uncertainties 10-15 K). In the coming year, Lusk and Wilkinson will incorporate this work into the routine color temperature calibration service.

Facility for Automatic Spectroradiometric Calibrations (FASCAL)

The routine calibration load on FASCAL, performed by Jackson, Gibson and Walker, was up substantially, partly because of the support

provided to the spectral flux project, and partly due to an attempt to clear the backlog in anticipation of the intercomparison work planned for next fiscal year. Modernization of FASCAL continued during the year. Gibson completed the conversion of the software library to 16-bit, BETTERBASIC programs. A new lock-in amplifier and a new closed circuit tv camera were installed. Finally a significant increase in capability was obtained with the installation of a Fowler designed, extension bench for two of the source stations. This new bench will allow source to receiver distances of up to three meter for irradiance work and it will also permit the operation of base-up sources.

One notable special test was performed during the year. Walker and Gibson performed a spectral irradiance calibration, 200 to 850 nm, of a special test fixture that was used to calibrated the Faint Object Spectrograph (FOS) on the space telescope. The FOS will address major scientific questions associated with quasars, active galaxies, and normal, distant, and local group galaxies, all within the context of understanding the origin, structure, composition, and evolution of the universe.

Program Plans

The evolution of Division programs has made it desirable to effect some changes in personnel assignments and group responsibilities which became effective October 1, 1988.

A new Detector Applications Project is responsible for developing solid-state detectors for specific applications, commissioning the new NIST/NPL cryogenic radiometer, making further refinements to the detector-based candela, and providing routine photometric calibrations. Synergisms between the laser heterodyne and krypton beam experiments have made it desirable to combine both into a single Advanced Radiometry project. We have established projects in Bidirectional Scattering Metrology and Biological Applications of Radiometry, in order to prepare the Division for a long-term involvement in these rapidly growing areas. A new Infrared Radiometry R&D Project is in the formative stage.

With these changes, the Division will operate under the following program structure in FY 1989. The project leaders who are responsible for the day-to-day management of these projects are listed in parantheses.

Photodetector Metrology (E. F. Zalewski)
Detector Applications (S. H. Southworth)
Facilities Development (J. B. Fowler)
Advanced Radiometry (A. L. Migdall)
Infrared Radiometry (to be assigned)

Spectrophotometry (K. L. Eckerle)
Bidirectional Scattering Metrology (J. J. Hsia)
Biological Radiometry (A. E. Thompson)
Radiation Thermometry (R. D. Saunders)
Radiometric Measurement Services (J. H. Walker)

To faciliate the incorporation of detector technology into the Division's measurement services for radiation temperature, spectral radiance, and spectral irradiance, the Radiation Thermometry and Radiometric Measurement Services projects of the Division will be combined into the new Thermal Radiometry Group, with Robert D. Saunders as group leader. Donald A. McSparron will oversee the implementation of detector metrology in all calibration programs within the Division, and will advise the group and project leaders in the Division who have calibration responsibilities on questions of scheduling, fiscal management, quality control, and customer relations. Albert C. Parr will serve as Deputy Division Chief in addition to his duties as leader of the Spectral Radiometry Group.

INVITED TALKS

Division 534, Radiometric Physics

Eppeldauer, G., Tsudagawa, M., Zalewski E., Houston, J., Electronic and Radiometric Characteristics of Near Infrared Photodiodes (13th IMEKO Symposium on Photonic Measurements, Braunschweig Germany, Fed. Rep. 1987).

Ferrett, T. A., Parr, A. C., Southworth, S. H., Hardis, J. E., and Dehmer, J. L., "Vibrationally-Resolved Photoionization Studies of the 7σ Level in N_2O", Presented at the Gordern Conference on electron Spectroscsopy, Wolfsburo, NH, July 18-22, 1988.

Hardis, Jonathan E., Peifer, William R., Cromer, Chris L., Migdall, Alan L., Snyder, J. J., and Bonanno, R., "Using 'Resonant' Charge Exchange to Detect Traces of Noble Gas Atoms", Presented at DOE Noble Gas Workshop, (March 30, 1988).

Hardis, Jonathan E., Peifer, William R., Cromer, Chris L., Migdall, Alan L., "Using 'Resonant' Charge Exchange to Detect Traces of Noble Gas Atoms", Submitted to the Proceedings of the Fourth International Symposium on Resonance Ionization Spectroscopy and its Applications. (1988).

Hardis, Jonathan E., Ferrett, Trish E., Southworth, Stephen H., and Dehmer, J. L., "Triply Differential Photoelectron Studies of Autoionization in Carbon Monoxide", DAMOP, Boston, MA (1987).

Hsia, Jack J., "Spectrophotometry", CORM'88, National Bureau of Standards, Gaithersburg, MD, May 18, 1988.

Hsia, Jack J., "NBS Spectrophotmetry Program," Center for Imaging Science Seminar," Rochester Institute of Technology, NY, April 26, 1988.

Lin, Lin, Hsia, Jack J. "Infrared Spectral Transmittance Measurement," CORM '88, National Bureau of Standards, Gaithersburg, MD, May 18, 1988.

McSparron, Donald A., "Photometric Standards", CORM'88, National Bureau of Standards, Gaithersburg, MD, May 18, 1988.

Mielenz, Klaus D., "NCSL Electro-Optic Measurements Workshop" National Conference of Standards Laboratories (NCSL) Annual Meeting, Washington, D.C., August 17, 1988.

Division 534, Invited Talks (cont'd)

Migdall, A. L., Cong, Z. Y., and Hardis, J. E., "Heterodyne Optical Densitometry at NBS", Presented at: New Developments and Applications in Optical Radiometry, Teddington, England, April 12-13, 1988 (to be published as proceedings).

Migdall, A. L., Cong, Z. Y., Hardis, J. E., and Snyder, J. J., "An Optical Heterodyne Densitometer", Proc. of the 2nd Workshop on Improvements to Photometry, NBS, Gaithersburg, MD, October 5-6, 1987.

Parr, Albert C., Ferrett, Trish A., "Photoionization of Small Molecules Using Synchrotron Radiation", SPIE, Los Angeles, CA (1988).

Parr, Albert C. Fowler, Joel B., and Ebner, Steve, "Low Background Infrared Calibration Facility at the National Bureau of Standards", SPIE, Orlando, FL (1988).

Parr, Albert C., Hardis, Jonathan E., Ferrett, Trish E., Southworth, Stephen H., and Dehmer, J. L., "Triply Differential Photoelectron Studies of Autoionization in Carbon Monoxide", DAMOP, Boston, MA (1987).

Parr, Albert C., "Infrared Calibration and Research at NBS", Air Force Cambridge Laboratory, Hanscom AFB, MA (1988).

Parr, Albert C., "LBIR Calibration Facility at NBS", Arnold Air Force Station, TN, (April 1988).

Saunders, Robert D., "Spectral Radiometry", CORM'88, National Bureau of Standards, Gaithersburg, MD, May 18, 1988.

Southworth, Stephen H., "Triply Differential Photoelectron Studies of Autoionization in Carbon Monoxide", (poster paper), International Symposium on Uses of Synchrotron Radiaton in Chemistry, Brookhaven National Laboratory, Upton, NY, November, 1987.

Southworth, Stephen H., " Photoelectron Spectrometry Studies of Resonant Molecular Photoionization", Advanced Light Source Users' Association Meeting, Lawrence Berkeley Laboratory, Berkeley, CA, June, 1988.

Zalewski, Edward, Migdall, Alan, "Characteristics of Germanium and InGaAs/InP Photodiodes," National Physical Laboratory, Teddington, England, April 12, 1988.

PUBLICATIONS

Division 534, Radiometric Physics

Ferrett, T. A. and Parr, A. C., "Photoionization of Small Molecules using Synchrotron Radiation", SPIE Vol. 911, p. 19, (1988).

Ferrett, T. A., Parr, A. C., Southworth, S. H., Hardis, J. E., and Dehmer, J. L., "Vibrationally-Resolved Photoionization Studies of the 7s Level in N_2O", Presented at the Spring Meeting of the APS, Baltimore, MD, April 18-21, 1988, Bull. of the Am. Phys. Soc. 33, 1038 (1988).

Hardis, J. E., Ferrett, T. A., Southworth, S. H., Parr, A. C., Roy, P., Dehmer, J. L., Dehmer, P. M., and Chupka, W. A., "Autoionization Dynamics in the Valence-Shell Photoionization Spectrum of CO_2", J. Chem. Phys. 89, 812 (1988).

Hsia, J. J., "National Scales of Spectrometry in the U.S.", Analytical Spectroscopy Library Vol. 2, Advances in Standards and Methodology in Spectrophotometry (C. Burgess and K. D. Mielenz, editors), Elsevier, 1988.

Mielenz, K. D. and Hsia, J. J., "Division 2 - Measurement of Light and Radiation," Proceeding of the 21st Session of the Commission Internationale de Eclairage, in Venice 1987, p.122-124, vol.I and p.38-41, vol.II

Mielenz, K.D., "International Intercomparisons of Photometric Base Units," J. of Phys. (National Bureau of Standards), 92, 335 (1987).

Mielenz, K.D., "Fluorescence Spectrometer in Analytical Chemistry and Color Sciences," Analytical Spectroscopy Library Vol. 2, Advances in Standards and Methodology in Spectrophotometry (C. Burgess and K. D. Mielenz, editors), Elsevier, 1988.

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Parr, A. C., Dehmer, J. L."Shape Resonance in Molecular Fields," Fundamental Processes in Atomic Dynamics, Ed. by J. S. Briggs, H. Kleinpoppen and H. Lutz, Plenum, New York, (1988).

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 the Vibronic Coupling in the C State of CO_2^+", Journal de Physiques, colloqoc, C 9 Supplement au n°12, Tome 48, (December, 1987).

Schaefer, A. R., "Tunable Dye Laser Spectrometry," Analytical Spectroscopy Library Vol. 2, Advances in Standards and Methodology in Spectrophotometry (C. Burgess and K. D. Mielenz, editors), Elsevier, 1988.

Southworth, S. H. Parr, A. C., Hardis, J. E , and Dehmer, J. L., "Resonance Structure in the Vibrationally Resolved Photoelectron Branching Ratios and Angular Distributions of the $2p^{-1}$ Channel of NO", J. Chem. Phys. 87, 5125 (1987).

PUBLICATIONS IN PREPARATION

Division 534, Radiometric Physics

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

Eckerle, K.L., Sutter, E., Freeman, G.H.C., Andor, G., and Fillinger, L., International Intercomparison for Transmittance (in preparation).

Eppeldauer, G., Long Term Changes of the Self-Calibrated Inversion Layer Photodiode Used as a Photometric Standard (to be published CIE Journal).

Ferrett, T. A., Parr, A. C., Southworth, S. H., Hardis, J. E., and Dehmer, J. L., "Vibrationally-Resolved Photoionization Studies of the 7σ Level in N_2O", (to be published in Journal of Chem. Phys.).

Geist, J., Migdall, A., and Baltes, H.P., "Analytic Representation of the Silicon Absorption Coefficient in the Indirect Transition Region", (to be published October 1, 1988, Applied Optics).

Hardis, J.E., Peifer, W.R., Cromer, C.L., Migdall, A.L., Parr, A.C., Using "Resonant" Charge Exchange to Detect Traces of Noble Gas Atoms (to be published Proceedings on the 4th International Symposium on Resonant Ionization and its Applications).

Hardis, J.E., Peifer, W.R., Cromer, C.L., Migdall, A.L., Parr, A.C., Using "Resonant" Charge Exchange to Detect Traces of Noble Gas Atoms (to be published Proceedings on the 4th International Symposium on Resonant Ionization and its Applications).

He, M., Bruening, R.J., High Pressure Sodium Discharge Lamp Characterization For Use As Standards of Geometrically Total Luminous Flux (to be published NBS TN)

Hillard, G.B., Nayfeh, M.H., Two-photon Ionization of Potassium in dc Electric Fields (to be published Phys. Rev. A.).

Lean, J.L., Kostkowski, H.J., Saunders, R.D., Hughey, L.M., Comparision of the NBS Surf and Argon Mini-Arc Irradiance Standards at Ultraviolet Wavelengths (to be published, Applied Optics).

Lin, L., Hsia, J.J., Infrared Spectrophotometer Linearity Measurements (in preparation).

Division 534 Publications in Preparation (cont'd)

Lin, L., Hsia, J.J., Interreflection Correction for Infrared Transmittance Measurements (in preparation).

Lin, L., Hsia, J.J., Infrared Spectral Transmittance Measurements (in preparation).

Migdall, A. L., Cong, Z. Y., and Hardis, J. E., "Heterodyne Optical Densitometry at NBS", Presented at: New Developments and Applications in Optical Radiometry, Teddington, England, April 12-13, 1988 (to be published as proceedings).

Saunders, R.D., Kostkowski, H.J., Roughened Quartz Surfaces and Teflon as Small-Angle Diffusers and Depolarizers Between 200 and 400 nm (to be published, Applied Optics).

Thomas, D.B., Zalewski, E.F., A Radiometer for Precision Coherent Radiation Measurements (to be published, Applied Optics).

TECHNICAL AND PROFESSIONAL COMMITTEE PARTICIPATION AND LEADERSHIP

Division 534, Radiometric Physics

Yvonne Barnes

Member, ASTM E-12 Committee, Appearance of Materials

Julius Cohen

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

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.

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

Laurence E. Fink

NBS Representative, ANSI PH2 on Photographic Sensitometry and PH2-28 on Densitometry

G. Barry Hillard

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

Jack J. Hsia

Director, Inter Society Color Council.

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

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

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

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

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

Jack Hsia (cont'd)

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

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

Secretary, CORM/NBS Task Force on Spectrophotometry.

Donald A. McSparron

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

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

Member, Lamp Testing Engineers' Conference.

Chairman, Tellers Committee, Optical Society of America.

Klaus D. Mielenz

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

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

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

Member, IES Subcommittee CO12, Nomenclature.

Exofficio member, CORM Board of Directors

Vice Chairman, CORM Task Force on Spectrophotometry.

Member, OSA International Affairs Committee.

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

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

Albert Parr

Visiting Senior Fellowship, Aberdeen University, Scotland.

Member, Queen Match Calibration Review for SDC.

Member, Organizing Committee, National Synchrotron Instrumentation Conference.

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.

Douglas B. Thomas

Member, U.S. National Committee of the CIE

Alternate, ASTM E-20 Temperature Measurements

Member, ASTM E44, Solar Energy Conversion.

Ambler Thompson

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

William R. Waters

Member, ASTM E-20, Temperature Measurement.

Edward F. Zalewski

Chairman, CIE TC2-06, Absolute Spectral Responsivity.

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

BOOK AND JOURNAL EDITORSHIP

Division 534, Radiometric Physics

Parr, Albert C., Member, Editorial Board, Review of Scientific Instrument Journal.

Burgess, C., Mielenz, K. D., Editors, Advances in Standards and Methodology in Spectrophotometry, Analytical Spectroscopy Library-Volume 2.

STANDARDS COMMITTEE MEETINGS

Division 534, Radiometric Physics

CORM Annual Meeting, NBS, May 18-19, 1988.

LTEC Spring Meeting, NBS, May 17, 1988.

MAJOR CONSULTING AND ADVISORY SERVICES

Division 534, Radiometric Physics

J. J. Hsia provided consultation to B. Guenther of NASA on large area reflectors for bidirectional reflectance measurement problems.

J. J. Hsia provided consultation to D. Rosseler of Research Laboratory, General Motor Company on specular reflectance calibration procedures.

J. J. Hsia provided consultation to V. Pilskalns and W. Gingrass of Eastman Kodak Company on infrared spectrophotometry.

R. D. Saunders provided consultation to the Nation Science Foundation on Polar Ozone Measurements.

J. H. Walker provided consultation to personnel from Sandia National Laboratory on pyrometric calibrations and standards.

J. H. Walker and W. R. Waters provided consultation to the Samuel E. Chappell of the Office of Standards Management on the U.S. position on draft OIML Recommendations for radiation temperature measuring instruments and standards.

D. A. McSparron provided consultation to G. Subrey of Pacific Safety Industries and D. Spadone, S. Waits, and D. Laster of the U.S. Navy on testing methods for phosphorescent paints.

D. A. McSparron provided consultation to M. Fecteau, S. Underwood, and C. Bradford of the U.S. Army and S. Parker, J. Terrell, and T. Larason of the U.S. Navy on measurement methods and standards suitable for testing Night Vision Imagings Systems (NVIS).

D. A. McSparron provided advice to P. Wychorski and V. Pilskalns of Eastman Kodak Company on means of achieving state of the art accuracy in photometric measurements.

A. C. Parr provided consultation to the Queen Match Committee of DoD on low backgound radiometrics problems in and number of project areas.

R. Saunders provided consultation to National Science Foundation on Artic Ozone Measurements.

STANDARD REFERENCE MATERIALS

Division 534, Radiometric Physics

1. SRM 1001, X-Ray Film Step Tablet

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

2. SRM 1008, Photographic Step Tablets

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

3. SRM 1010a, Microscopy Resolution Tests Charts

   For determining the resolving power of microscopy systems.

4. SRM 2061, Reflection Step Tablets

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

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

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

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

   For use in calibrating the photometric scale of specular reflectometers.

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

Division 534, Standards Reference Materials (con't)

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

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

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		13
	Defense & Aerospace		10	
	Instrument & Cal labs		1	
	Electrical & Materials		2	
Spectroradiometry -	Sources	39010C thru 39060S		38
	Defense & Aerospace		17	
	Instrument & Cal labs		8	
	Lighting & Photography		6	
	Foreign		3	
	Electrical & Materials		4	
Spectroradiometry -	Detectors	39070C thru 39080S		12
	Defense & Aerospace		5	
	Instrument & Cal labs		5	
	Lighting & Photography		1	
	Foreign		1	
Photometry		30701C thru 37180S		39
	Defense & Aerospace		15	
	Instrument & Cal labs		4	
	Lighting & Photography		8	
	Foreign		4	
	Electrical & Materials		8	
Spectrophotometry		38010C thru 38100S		19
	Defense & Aerospace		3	
	Instrument & Cal labs		7	
	Lighting & Photography		2	
	Foreign		1	
	Electrical & Materials		6	
				121

TRIPS SPONSORED BY OTHERS

Division 534, Radiometric Physics

J. Houston, NBS-PTB Scientist Exchange, sponsored by PTB to stay and work at the Braunschweig location from April 18 to June 16, 1988.

S. Southworth, to set up ARPES experiment in collaboration with Daresbury Laboratory, Daresbury, England form July 4-22, 1988.

T. Ferrett, to set up ARPES experiment in collaboration with Daresbury Laboratory, Daresbury, England form July 4-22, 1988.

SPONSORED SEMINARS AND COLLOQUIA

Division 534, Radiometric Physics

Asmail, Clara, "Static and Dynamic Light Scattering of Dispersive Systems," Optical Sciences Center, University of Arizona, Tuscon, AZ, April 8, 1988.

Poliakoff, Erwin, "Vibrational Gratings and Electron Traps: Fluorescence Probes of Photoionization," Gaithersburg, MD, April 27, 1988.

Ferret, Dr. T. A., NBS, "Photoelectron Spectroscopy of CO and CO_2 using Synchrotron Radiation", Spectral Radiometry Group Seminar, Gaithersburg, MD, January 11, 1988.

Porter, D., Rochester, NY, "The Usefulness and Limitations of Statistical Flow Charts", Radiometric Physics Division Seminar, January 29, 1988.

McKoy, Prof. V., California Institute of Technology, Pasadena, CA, "Studies of Resonant Multiphoton Ionization Processes in Molecules", NBS Atomic Physics Colloquium, February 8, 1988.

Dils, R. R., Acufiber, Vancouver, Washington, "Recent Advances in Optical Fiber Thermometry", Radiometric Physics Division Seminar, March 7, 1988.

Eland, Prof. J. H. D., Physical Chemistry Laboratory, Oxford University, "Two-Dimensional Mass Spectrometry", Radiometric Physics Division Seminar, July 15, 1988.

Comer, Prof. J., Department of Physics, Manchester University, "Electron Spectroscopy Studies of Molecular Resonances", Radiometric Physics Division Seminar, July 15, 1988.

TECHNICAL ACTIVITIES

Division 535, Radiation Source and Instrumentation

CW Racetrack Microtron Project — M. Wilson (project leader), R. Ayres, S. Bruce, R. Cutler, E. Lindstrom, P. Liposky, A. Raptakes, and J. Rose

This 185 MeV, 500 μA cw electron accelerator is shown in Figure 1. It consists of a 5 MeV injector feeding a racetrack microtron (RTM). In the microtron, a pair of 180° end magnets are used to recirculate the electron beam through an 8-m, 12-MeV rf linac up to 15 times for an energy gain of up to 180 MeV. The beam can be extracted from any of 14 separate return lines in 12-MeV steps. In the past year the beam transport line between the injector and microtron was installed, the two sections of the 8-m linac were rf-tested at full power, and all beam transport components on the linac axis and the end magnet vacuum chambers were installed. All magnets for the return lines were designed, and procurements have begun. The beam-optical design of the transport line between the RTM and the free-electron laser (FEL) was completed, and designs of magnetic components have begun. Initial operation of the microtron at 17 MeV (one pass through the linac) was successful on September 9, 1988.

The beam transport system from the exit of the injector linac to the RTM linac axis and along the linac axis through end magnet E1 is now complete, including alignment of all bending magnets and quadrupole focusing magnets, and leak checks of the vacuum envelope. A beam line for testing the beam after one pass through the 8-m linac has been installed at the exit of end magnet E1. (See Figure 2.) This beam line includes a high-power beam stop and sufficient beam profile monitors for beam emittance and energy spread measurements. All beam transport devices for one pass have been connected to the control system and tested.

The two sections of the 8-m MeV linac on the RTM axis have each been conditioned to a power level between 115 kW and 120 kW. This corresponds to a voltage gradient exceeding that required for accelerating the recirculating beam to the nominal full energy of 185 MeV. Further tests of the rf system were interrupted by two successive failures of the variable voltage stage of the klystron high voltage power supply, beginning in early January, 1988. At least one of these failures has been traced to an accumulation of water in the oil-filled high voltage tank due to improper sealing of a flange by the manufacturer. The fully repaired unit was received from the manufacturer in mid-August, 1988, and rf tests involving full power in all 4 accelerating sections were completed in late August. On September 9, the 5-MeV beam was transported to the RTM axis, injected into the linac and accelerated. The

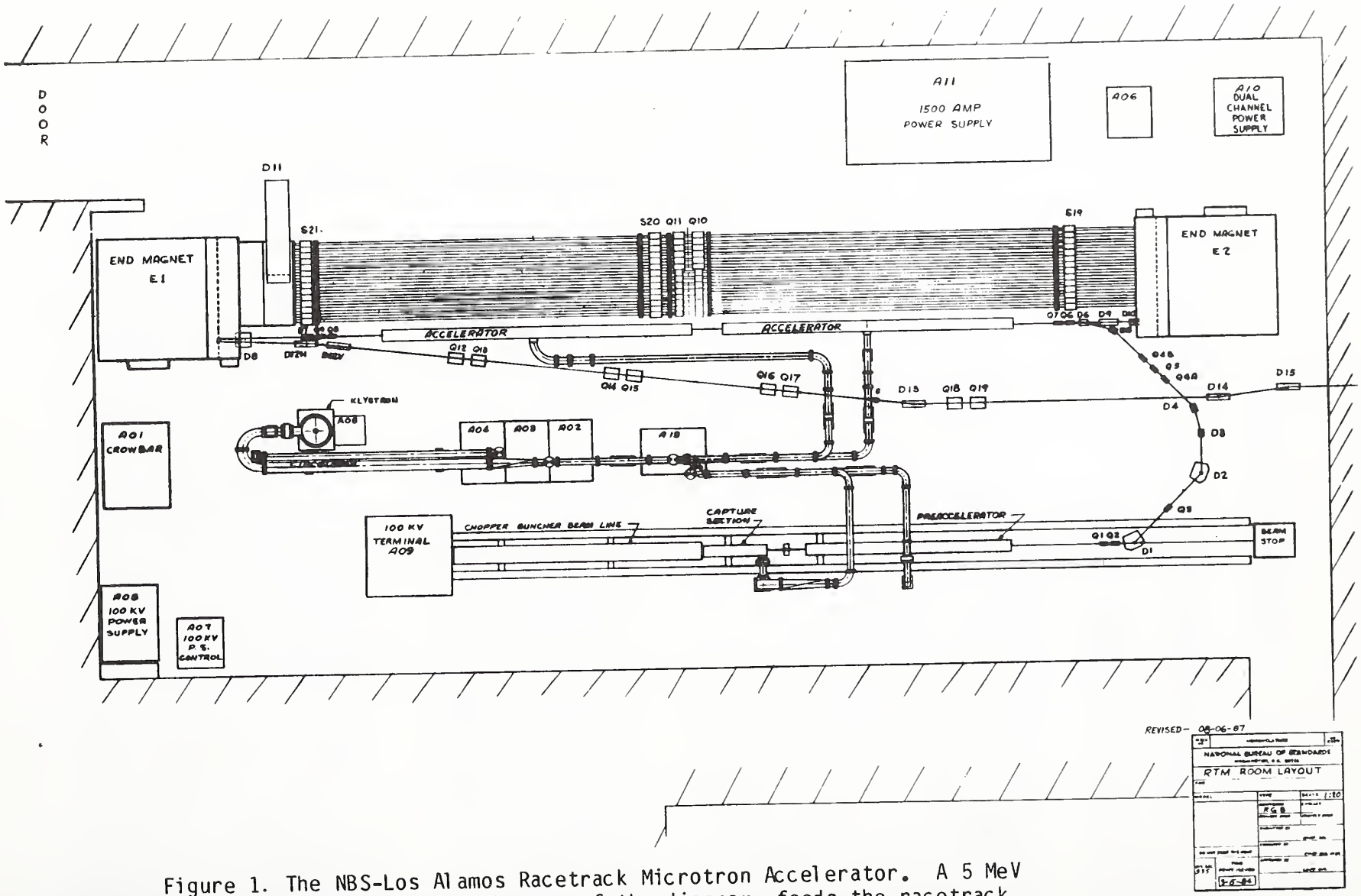

Figure 1. The NBS-Los Alamos Racetrack Microtron Accelerator. A 5 MeV injector, at the bottom of the diagram, feeds the racetrack microtron. In the microtron, a pair of 180° end magnets recirculates the beam through a 12 MeV linear accelerator up to 15 times for an energy gain of up to 180 MeV. The beam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

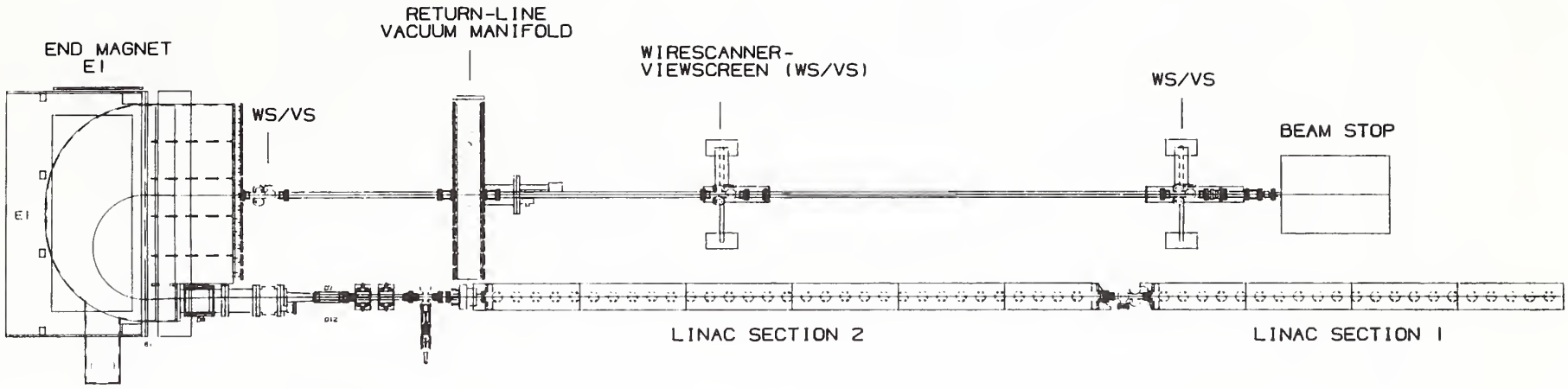

Figure 2. E1 end of the RTM with the temporary, diagnostic beam line for one-pass beam tests.

beam was then deflected by end magnet E1 into the 1-pass beam line (Figure 2), where the beam energy, energy spread, and emittance was measured.

Designs have been completed for the steerers, S_{19} - S_{21}, and for quadrupoles Q_{10} and Q_{11} on the RTM return lines. Drawings of the quadrupoles have been sent to the NIST shop for fabrication of the steel parts, and the coils have been ordered. A special, low-remnance nickel-iron alloy material has been ordered for the steerers. The electron beam optics design for the RTM-FEL beam transport line, shown in Figures 1 and 3, is complete. This design includes proper transport of the RTM beam over all energies between 29 MeV and 185 MeV, and provides for an achromatic beam on the FEL axis. Preliminary designs have been established for the movable deflecting magnet, D11, and the first two dipole magnets, D_{12H} and D_{12V}. The remaining magnets in the transport line are (See Figs. 1 and 3): three 2-inch-bore quadrupole doublets (Q_{12}-Q_{17}) and a dipole bending magnet (D_{13}) in the RTM room; two quadrupole doublets (Q_{18}-Q_{21}) that act as a telescope to form the optimal beam size and waist position on the FEL axis; an achromatic system of 4 dipoles (D_{14}-D_{17}) to guide the electron beam around the upstream cavity mirror; and a 90° dipole magnet (D_{18}) to bend the spent electron beam off the laser axis. Designs of these components are in progress.

Free-Electron Laser Facility — R. Johnson (project leader), P. Debenham, C. Johnson, and S. Penner (contractor)

This is a joint project with the Plasma Theory Branch of the Naval Research Laboratory (NRL). The overall goal is to construct and bring into operation a free-electron laser (FEL) driven by the racetrack microtron (RTM) electron accelerator at NIST. Good progress was made on many fronts this year. Detailed calculations were done to predict the FEL performance. Wiggler specifications were written, proposals from several potential vendors were evaluated, a vendor was selected, a contract was signed, and the vendor has begun construction of the wiggler. The shielded room that will house the FEL was cleared of other equipment. Three schemes to increase the RTM peak current were identified and are being investigated; this activity is described in the report on the High-Current Injector Project. Requirements for the user facility were identified, and we began clearing the existing experimental area. In the paragraphs to follow we discuss details of the FEL design and progress during the year.

Our colleagues at NRL have used the self-consistent, three-dimensional computer code SHERA (which they developed) to assess the effects of the transverse emittance of the electron beam on the performance of the FEL. They calculated values of the small-signal power gain, G_p, for normalized transverse emittance, ϵ_n, between 5 mm·mrad (or μm)

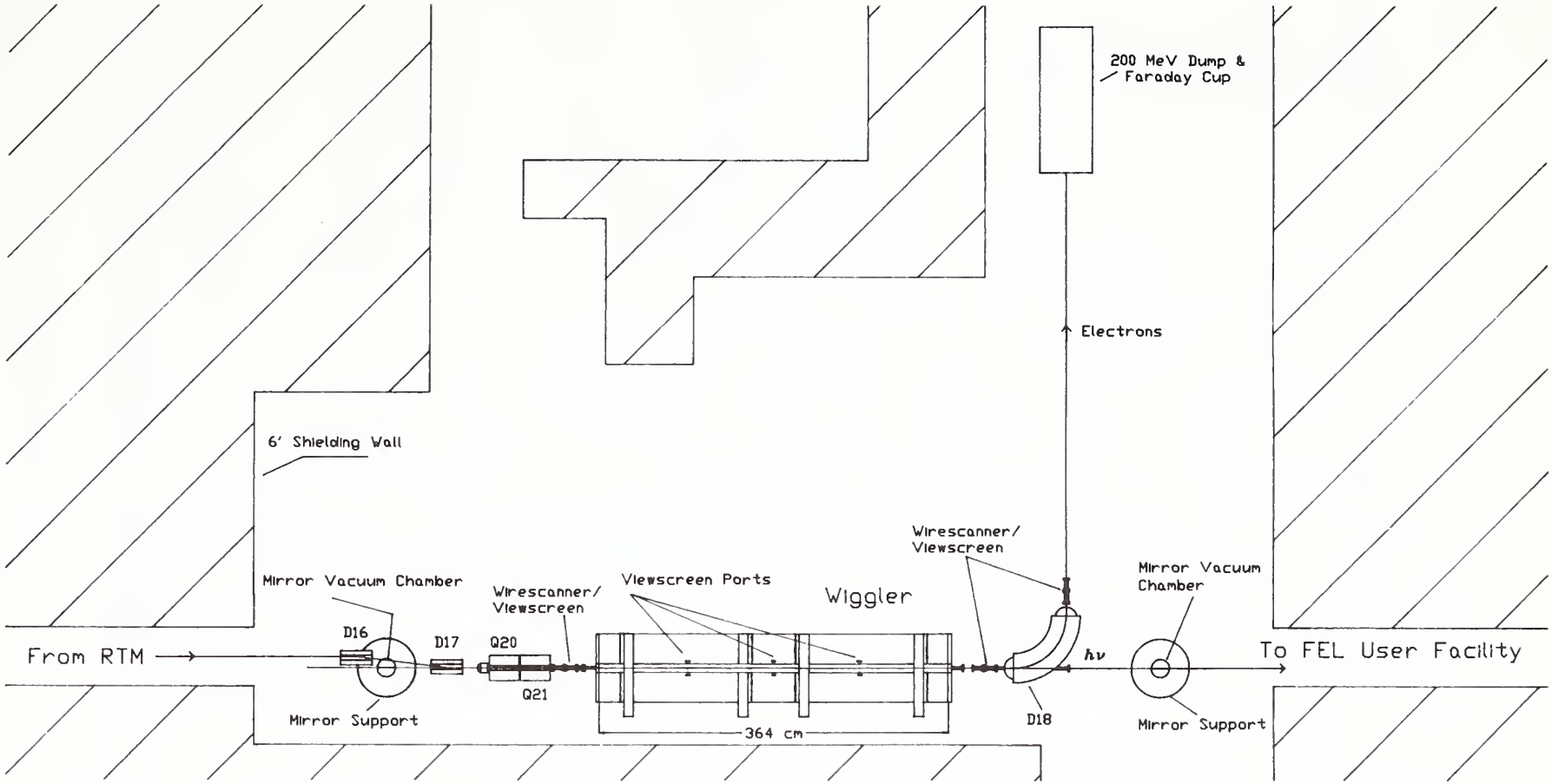

Figure 3. Plan view of the FEL wiggler, electron beam transport, and optical cavity.

and 20 μm, with the results shown in Figure 4. The design value of ϵ_n for the RTM is 5 μm, and the measured value for the 5 MeV injector beam is less than 1 μm. The power gain calculated for the design emittance will readily support lasing over the planned wavelength range.

NRL has developed a Gaussian optical beam formalism for including mirrors in SHERA to convert it to an oscillator code. This will allow us to study the evolution of radiation in the optical cavity and evaluate performance of the FEL in the presence of diffraction and mode mixing. Meanwhile, we have used published diffraction tables to estimate losses from the mirrors and intracavity vacuum chamber apertures. These losses are negligible for UV and visible wavelengths and are small for the IR wavelengths at which we plan to lase. The losses from diffraction on the vacuum chambers of the wiggler and the electron beam dump magnet are estimated to be 0.6% and 0.2% per pass, respectively, at 10 μm. These losses increase rapidly with wavelength and will prevent lasing at wavelengths above 12 μm.

Imperfections in the wiggler magnetic field can degrade FEL performance by causing the electrons to "walk" off the radiation axis and by altering the path length of the electrons and hence their phase relative to the radiation field. In order to evaluate these effects, NRL has developed computer codes to model the propagation of electrons through wiggler fields with no radiation field and has checked the results for agreement with analytic expressions. They have also modified computer code SHERA to include wiggler field errors. A preliminary SHERA calculation was performed for a wiggler with no electron steering correction and with 0.5% rms random (uncorrelated) field errors. The phase error calculated for this case would degrade performance significantly. The real wiggler, however, will have electron steering coils and field errors that are predominantly correlated, both of which will reduce phase errors substantially. NRL is currently incorporating these features into the formalism and computer codes.

For a saturated FEL in the one-dimensional, low-gain model with a perfect, untapered, N-period wiggler, the maximum efficiency for extracting power from the electron beam is 1/2N. Using this model, we have estimated the optical output power of our FEL for commercially available laser mirrors. The calculated cw output is in the range 50-200 W for 200 nm $\leq \lambda <$ 7 μm, and is approximately 20 W for 7 μm $< \lambda \leq$ 10 μm. We are performing more accurate, three-dimensional calculations.

The conceptual design of the optical cavity is complete. We have chosen a two-mirror, linear cavity with a mirror spacing of 8.062 m. This spacing gives a round trip light travel time of 53.78 ns, which, at the RTM injector frequency of 74.375 MHz, implies that there will be two electron pulses and four light pulses in the optical cavity at one time. Since the RTM is a cw accelerator and there is gain in the laser only

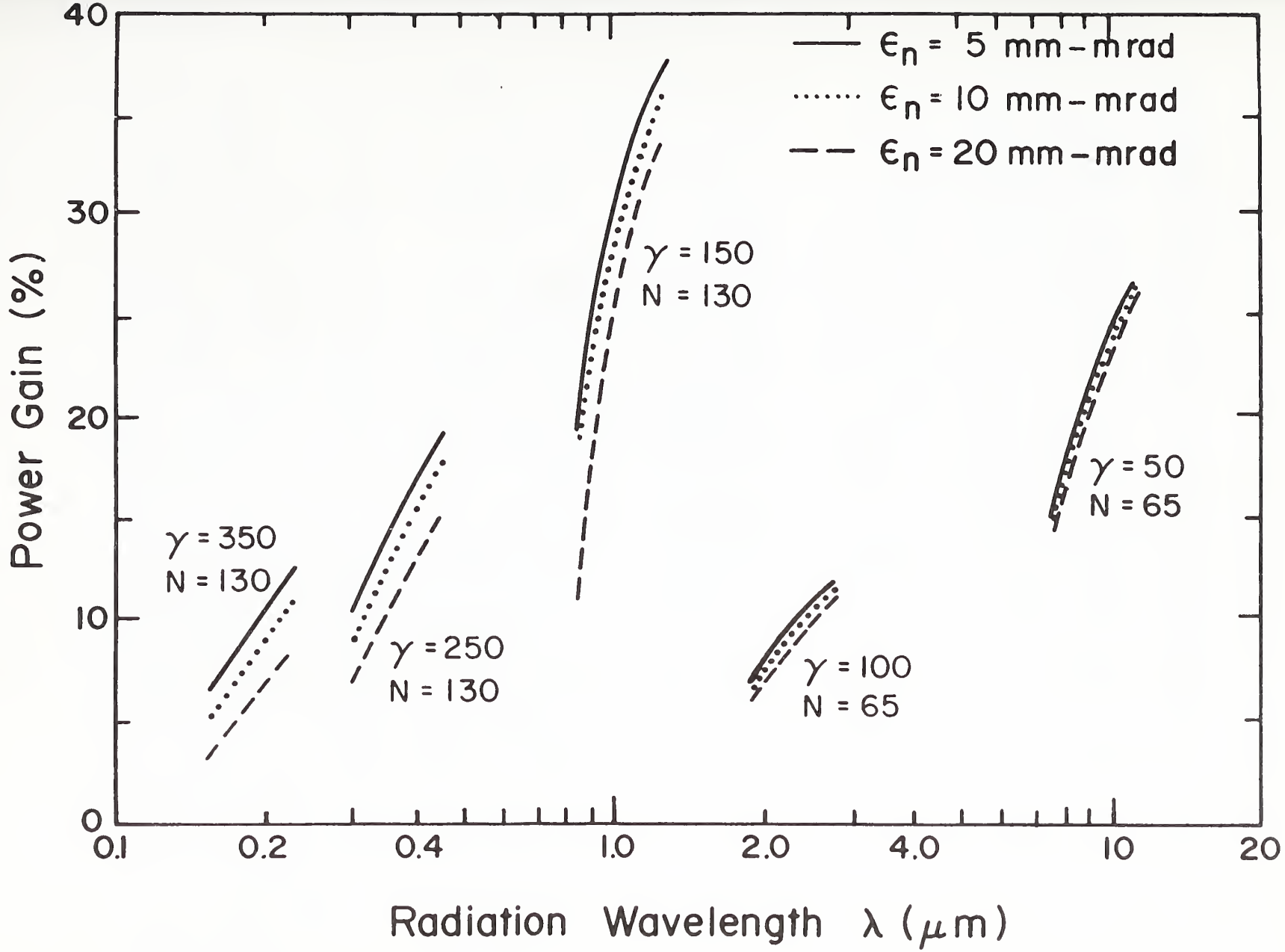

Figure 4. Power gain as a function of radiation wavelength from the 3-D calculations (peak electron current of 2A).

when an electron bunch is present, the FEL behaves as a cw, harmonic-mode-locked laser. The cw nature of the accelerator results in very high average output power for the FEL.

For cavity mirrors, we plan to use multi-layer dielectric (MLD) coatings on transparent substrates. An advantage of MLD coatings is the ability to couple the light out through one mirror by using a partially transmitting/partially reflecting MLD coating. Compared to metal mirrors, the spectral bandwidth, or tuning range, is narrow. However, in the visible and UV, metal mirrors cannot be constructed with the high power reflection coefficients (up to R = 99.9%) that are necessary because ours is a low-gain laser. The cavity mirrors must have high damage thresholds, as we expect the peak irradiance to be 1-2 $GW \cdot cm^{-2}$, and the average power to be 200-400 $kW \cdot cm^{-2}$. As discussed above, the losses from diffraction on the cavity mirrors and the intracavity vacuum chamber apertures will be negligible at ultraviolet and visible wavelengths and small at the infrared wavelengths at which we plan to operate.

The minimum wavelength for lasing can be reduced by lasing on the third harmonic because G_p for the third harmonic exceeds that for the fundamental. This is done by maintaining a high-Q optical cavity at the desired wavelength while decreasing the electron beam energy by the factor $3^{-1/2}$. We may be able to reach 150 nm by this means.

The wiggler will have a peak field of 0.54 T, 130 periods of 2.8 cm for UV and visible operation, and 65 periods for IR operation. Proposals were received from several potential wiggler contractors in October, 1987, and were evaluated by an internal technical committee, with Dr. Brian Kincaid (AT&T Bell Laboratories) acting as an outside consultant. In May, 1988 a contract was signed with Brobeck Division of Maxwell Laboratories to construct the wiggler. The contractor has completed the mechanical and magnetic design and has constructed a one-period, full-scale model magnet which fully meets the specifications.

The room where the wiggler and optical cavity will be located has been cleared of interfering equipment. (The layout in this room is shown in Figure 3.) We have measured ionizing radiation levels in this area during operation of the NIST neutron time-of-flight facility, when a 5 kW electron beam from the NIST 110 MeV linac passes through the FEL area. The measured radiation levels are in the range of 10-100 krad per year, which will give the samarium-cobalt wiggler magnets an estimated useful lifetime of 5000 years. Lifetimes of optical components at this radiation level will be 1-10 years, longer than lifetimes due to optical radiation damage. We have also initiated sound and vibration measurements in the room in order to determine isolation specifications for the optical cavity.

As originally planned, the user facility was to consist of two experimental rooms: an existing room, XA1, adjacent to the FEL and a building addition above ground. XA1 was also to house electron beam lines for high-energy dosimetry and x-ray research. We have recently reassessed these plans. By relocating the dosimetry and x-ray beam lines in another existing experimental room, we can make the full area of XA1 (1700 sq ft) available to FEL users at all times. The revised facility is shown in Figures 5 and 6. We are not planning to construct the above-ground building at this time. XA1 was formerly a measurement room for the NIST 150-MeV Electron Linac; the equipment associated with that use is being removed, and plans are complete for conversion to the FEL user facility.

High-Current RTM Injector Project — Roy Cutler (project leader), E. Lindstrom, and S. Penner (contractor)

The present RTM injector consists of a 100 kV, 5 mA dc, thermionic electron gun followed by a chopper/buncher system and a 5 MeV cw linac. The injector produces beam pulses at 2380 MHz (the rf drive frequency) with a maximum of 0.35 pC per pulse. A peak electron beam current of 2-4 A is required in the FEL to achieve lasing. For a 3.5-ps long beam pulse, this is 7-14 pC per pulse. We have proposed to increase the charge per pulse without increasing the average current in the RTM (limited by the rf power available) by reducing the beam pulse frequency to 74.375 MHz, the 32nd subharmonic of the rf frequency.

The electron beam that drives the FEL must have a longitudinal emittance of 20 keV·degrees or less and a normalized transverse emittance of 5 μm or less. Actual beam measurements made at 5 MeV on the existing injector have exceeded these goals, but achieving them at the required peak current is more difficult. We are evaluating several methods of increasing the current beam with 100 keV injection into the present injector linac. We will retain 100 keV injection primarily for cost considerations. However, this means we must transport a high-current beam from the electron gun to the linac with significant space charge. To calculate space-charge effects, we are using the electron beam transport code PARMELA as an aid to designing the 100 keV transport line.

Two basic technologies have been studied for achieving this higher current beam for the FEL. The first involves the use of a laser-illuminated photocathode. The time structure of the drive laser is designed to produce the time structure desired for the emitted photo-electrons, pulses as short as 30 ps. Pulse-to-pulse amplitude and pulse shape stability of the drive laser are important issues that need to be addressed. Existing, several-watt cw, mode-locked drive lasers require cathode materials with quantum efficiencies of approximately 1% to achieve the required peak current. Materials such as CsSb have the

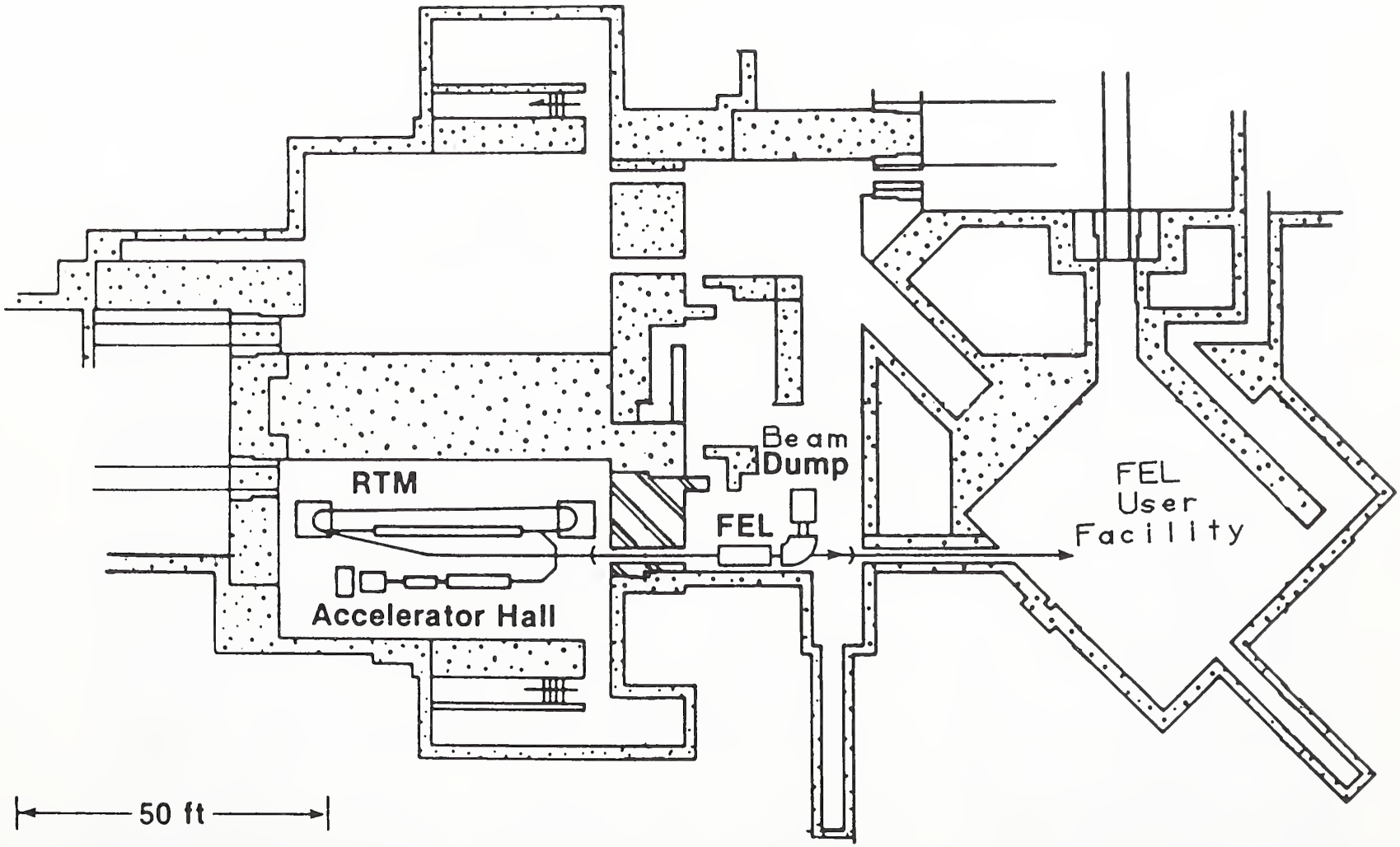

Figure 5. Plan view of the FEL Facility.

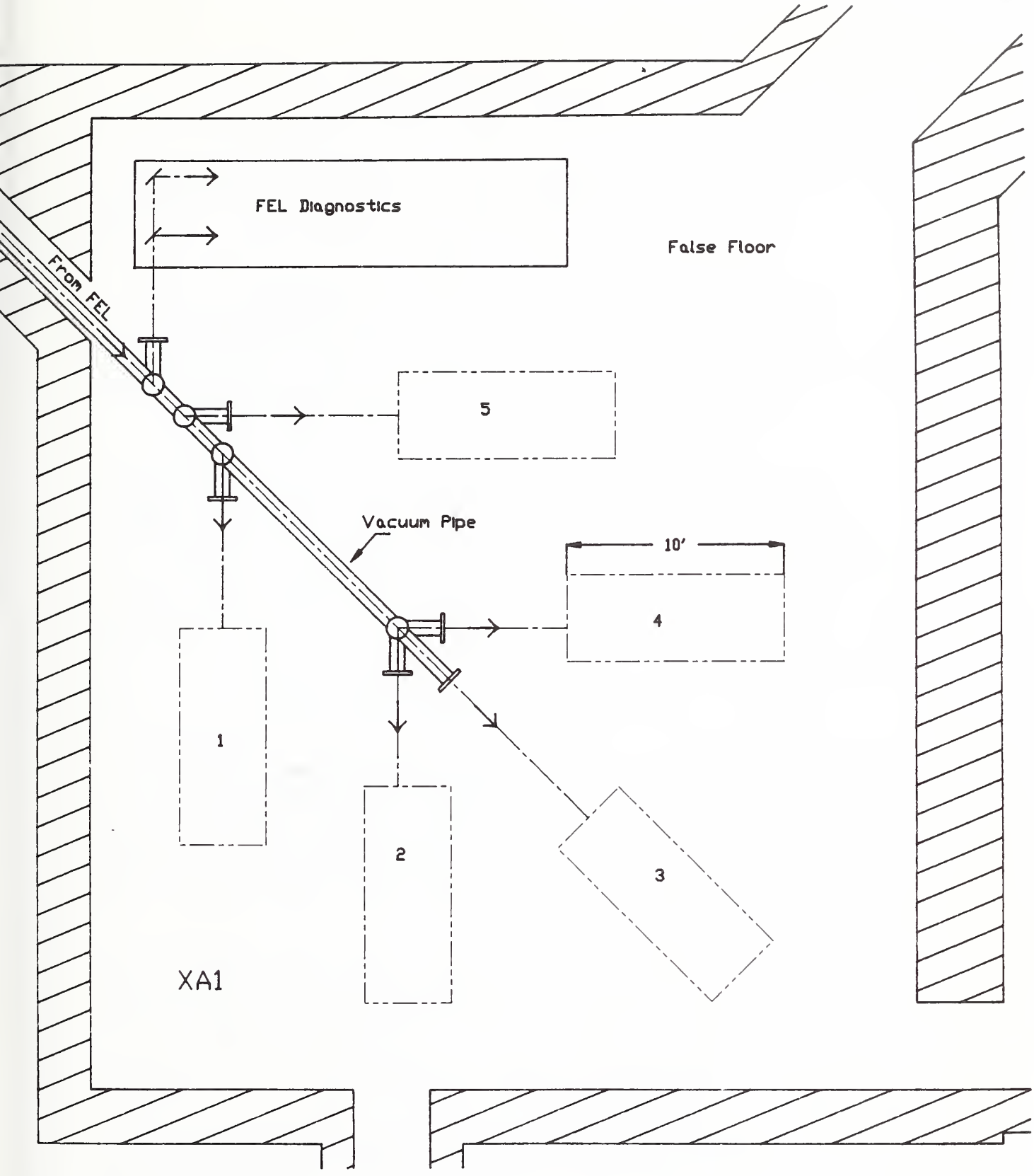

Figure 6. Plan view of user's experimental area. Areas 1 - 5 indicate optical tables.

necessary quantum efficiency but have too short a lifetime due to contamination in a good accelerator vacuum (10^{-9} Torr) to be acceptable for user facility operation. We are collaborating with the AT-7 Group at Los Alamos to develop a suitable photocathode.

The second technology that we are studying is conventional rf chopping and bunching, as in the existing 100 keV RTM injector. In this method, a thermionic electron gun is pulsed at 74.375 MHz, with a pulse length of approximately 2.5 ns, the limit for electron guns at this repetition rate. This pulse is then shortened by sweeping the electron beam over an aperture with rf deflection cavities or deflection plates. The beam is then compressed to 15 ps for injection into the injector linac using one or two bunching cavities. We are simulating three possible 100 keV injection lines with PARMELA, each using a different method of chopping and bunching. The first design uses a 100-200 mA gun current and chops to either 70 or 140 ps-long pulses. These pulses would then be compressed by the existing buncher to 15 ps. The second design uses a 40 mA gun current chopped to 280 ps and bunched by a 1190 MHz cavity and by the existing buncher. The third design uses a 20 mA electron gun, chopped to 600 ps and bunched by a 297.5 MHz rf cavity and by the existing buncher. The best design will be chosen on the basis of feasibility, cost, and beam quality.

Accelerator Operations J. Broberg (project leader), W. Dobbie, T. Hotchkiss, A. Lopez, and J. Pitt

The Division operates and maintains two major electron accelerators in support of Center programs: the Linac and the Racetrack Microtron (RTM). Since each accelerator requires the total installed power and cooling water capacity of approximately 1 MW, they are not operated simultaneously. This year the Linac was operated exclusively to produce neutrons in the time-of-flight facility (TOFF) for neutron cross-section standards measurements and radiography. We supplied 1148 hours of actual Linac beam to TOFF with 30 hours of unscheduled maintenance, for an operational efficiency of 97%.

The operations staff assists in the construction of the RTM and is being trained in RTM operations. This year we assisted in rf-testing the RTM 8-m linac and in one-pass beam tests. We are also responsible for maintaining the RTM and enhancing its reliability as a component of a user facility. Twice this year the variable-transformer stage of the 1-MW klystron power supply failed and was returned to the manufacturer for repairs. At least one and possibly both failures were caused by the use of an undersized gasket at manufacture. As a precaution, we are planning to procure a replacement unit to avoid the problematic sliding contact in oil that is currently used. We have also constructed and installed a new interlock circuit to prevent collisions of wirescanners and viewscreens

and have modified the modular, 30-watt magnet power supplies for improved reliability.

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

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

Some examples of devices designed and constructed this year are: the support mechanism for the RTM end magnet vacuum boxes to allow magnet linear motion while holding boxes in position and maintaining vacuum system integrity; the vacuum system for one-pass RTM operation; RTM return path quadrupoles; and a thin window vacuum/pressure photodetector to be used on the Linac.

It is desirable to use aluminum rather than stainless steel vacuum chambers in RTM magnets to avoid distorting the very precise magnetic fields. We have developed a method of welding a rectangular aluminum tube into an aluminum flange with minimal distortion. This allows us to construct aluminum vacuum chambers with the new, hardened aluminum conflat flanges for high vacuum.

Some examples of major installation and maintenance tasks for this year are: installation and alignment of all dipole and quadrupole magnets and associated vacuum hardware for one-pass RTM operation; repair of a large vacuum chamber on the Linac; rebuilding of Model 12 electron guns for our Linac and for NRL; and rebuilding of vac-ion pumps for the Linac, SURF and other divisions in CRR.

We now have three operational CAD/CAM work stations. These are essential for designing RTM and FEL components in a timely manner. The group staff has been heavily involved in the planning of the FEL program, and the group leader served as the contracting officer's technical representative for the wiggler.

Electronics Instrumentation — J. Whittaker (project leader), A. Marella, J. Owen, L. Shuman, N. Wilkin, and D. Tirosh (guest scientist)

The Division provides consultation, design, construction and maintenance services to CRR staff requiring electronics instrumentation, data acquisition systems and computer systems. With a relatively small staff, we rely heavily on computer-aided design techniques for printed

circuit board production. This year 85 instruments have been constructed and 109 repaired and modified. Repair services are limited to equipment constructed in-house and special items that cannot be repaired commercially.

We designed measurement instruments for pulse radiolysis experiments. Control and data acquisition systems were completed for X-ray standards measurements and high dose dosimetry. Further instrumentation has been provided for the States Regional Calibration Centers as the program expands. Instrumentation provided for the RTM includes control circuits, wire-scanner amplifiers and preliminary examination of possible power supply designs for the small magnet power requirements. A considerable amount of software has been written for GPIB instrument control. We also provided experimental equipment for the Harry Diamond Laboratories fuze instrumentation program.

We have provided consulting services to CRR, other centers, DOC, DOE and HDL. We have installed 30 small 386-based computers together with extensive software support for CRR and Harry Diamond Laboratories. Our Hewlett-Packard 350 computer, which is normally used for electronic CAD, was also used for the detailed mechanical design of a large detector array by a CRR physicist. Software to permit much faster and more automated printed circuit board design is being examined.

Radiation Instrumentation Standards L. Costrell

The Division provides national leadership in the standardization of nuclear instrumentation. The standards work falls into three categories: National Voluntary Standards, Nuclear Instrumentation Module (NIM) Committee Standards, and International Electrotechnical Commission (IEC) Standards.

The Division plays an active role in the development and processing of National Voluntary 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.

The NIM committee oversees development and maintenance of instrument standards, in cooperation with the National Laboratories, primarily for use in nuclear applications. NIST has the management responsibility for this work, with L. Costrell serving as Chairman of the NIM Committee.

Division 535, Technical Activities (cont'd.)

The NIM system[1,2] has been adopted nearly universally in the U.S. and a continuous coordination effort is required, involving contact with numerous laboratories and manufacturers. Similar management, direction and maintenance services are provided in the U.S. with regard to the international CAMAC (Computer Automated Measurement and Control) system[3] 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.[4,5] 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 Institute for Standards and Technology. The documents are usually issued as Reports of the Department of Energy and then processed as Standards of ANSI,[6] and IEC.[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 consul-

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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 SHO8482, 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," Report DOE/ER-0189, December 1983.

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

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

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

tants.[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.

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 published and others that are to be published. These include documents that are technically identical to the NIM, CAMAC and FASTBUS standards.[1,2,3,6] Similarly, the international standards for semiconductor detectors for charged particles, for amplifiers and preamplifiers used for radiation detection, and several other standards are technically identical to ANSI/IEEE standards developed by the committees referred to above.

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[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.

INVITED TALKS

Division 535, Radiation Source and Instrumentation

Debenham, P.H., "The NBS Free-Electron Laser Facility," George Washington University, Washington DC, February 12, 1988.

Debenham, P.H., "Research Opportunities Below 300 nm at the NBS Free-Electron Laser Facility," Topical Meeting on Free-Electron Laser Applications in the Ultraviolet, Cloudcroft, NM, March 2-5, 1988.

Johnson, B.C., "The NBS Free-Electron Laser Facility," Fourth International Symposium on Resonance Ionization Spectroscopy and Its Applications, Gaithersburg, MD, April 14, 1988.

Johnson, B.C., "The NBS Free-Electron Laser Facility," 19th Annual Meeting of the Division of Atomic, Molecular, and Optical Physics of the American Physical Society, Baltimore, MD, April 18, 1988.

Johnson, B.C., "The NBS-NRL Free Electron Laser Program," 3rd Annual Medical Free-Electron Laser Contractor's Meeting, Univ. of Utah, Salt Lake City, UT, May 16 - 18, 1988.

Penner, S., "NBS Free Electron Laser Facility, University of Maryland, College Park, MD, October 23, 1987.

Penner, S., "NBS Free Electron Laser Facility," JILA, Boulder, CO, February 10, 1988.

Wilson, M.A., "Electron Beam Performance Expectations from the NBS-LANL Racetrack Microtron," Naval Surface Weapons Center, White Oak, Silver Spring, MD, March 30, 1988.

PUBLICATIONS

Division 535, Radiation Source and Instrumentation

Debenham, P.H., Bruce, S.S., Penner, S., and Wilson, M.A., "The Injection Chicane of the NBS-Los Alamos Racetrack Microtron," Proc. of 1987 IEEE Particle Accelerator Conference, 1452, Dec. 1987.

Debenham, P.H. and Johnson, B.C., "Research Opportunities Below 300 nm at the NBS Free Electron Laser Facility," Optical Society of America Technical Digest Series 4 76, March 1988.

Cutler, R.I., Owen, J., and Whittaker J., "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", Proc. of 1987 IEEE Particle Accelerator Conference, 625, Dec. 1987.

Cutler, R.I. and Young, L., "Performance of the High Power RF System of the NBS-Los Alamos Racetrack Microtron," Proc. of 1987 IEEE Particle Accelerator Conference, 1863, Dec. 1987.

Johnson, B.C., Debenham, P.H., Penner, S., Tang, C.-M., and Sprangle, P., "The NBS Free Electron Laser Facility," Bull. Am. Phys. Soc. 33 916, April 1988.

Johnson, B.C., Wang, M.-X., and Weiner, J., "Crossed-beam Studies of Associative Ionisation in Heteronuclear Systems: $NaLi^{+}$ Production from Li^{*} + Na and Na^{*} + Li Collisions," J. Phys. B: At. Mol. Opt. Phys. 21 (1988) 2599.

Penner, S., "RF Linac Based Free Electron Lasers," Proc. of 1987 IEEE Particle Accelerator Conference, 183, Dec. 1987.

Maruyama, X.K., Penner, S., Tang, C.-M., and Sprangle, "Proposal for a Free Electron Laser Driven by the National Bureau of Standards' CW Microtron," Nuclear Instruments and Methods in Physics Research A259 (1987) 259-262, North-Holland, Amsterdam.

Tang, C.-M., Sprangle, P., Penner, S., and Maruyama, X.K., "Analysis of Free Electron Laser Performance Utilizing the National Bureau of Standards' CW Microtron," Proc. of 1987 IEEE Particle Accelerator Conference, Dec. 1987.

Wen, J., Lucatorto, T., Johnson, B.C., and Clark, C., "Two-Photon Transitions in Beryllium," Phys. Rev. A 37 4207, June 1988.

Division 535, Publications (cont'd.)

Wilson, M.A., Ayres, R.L., Cutler, R.I., Debenham, P.H., Lindstrom, E.R., Mohr, D.L., Penner, S., Rose, J., Young, L.M., and Stovall, J., "Performance of the 5 MeV Injector for the NBS-Los Alamos Racetrack Microtron," Proc. of 1987 IEEE Particle Accelerator Conference, 322, Dec. 1987.

Wilson, M.A., Debenham, P.H., Penner, S., and Bruce, S.S., "Orbit Reversing Magnets for the NBS-Los Alamos Racetrack Microtron," Proc. of 1987 IEEE Particle Accelerator Conference, 1469, Dec. 1987.

PUBLICATIONS IN PREPARATION

Division 535, Radiation Source and Instrumentation

Debenham, P.H., Bruce, S.S., Penner, S., and Wilson, M.A.D., "The Injection Chicane of the NBS-Los Alamos Racetrack Microtron," to be published in IEEE Transactions on Nuclear Science.

Penner, S., Ayres, R., Cutler, R., Debenham, P., Johnson, B.C., Lindstrom, E., Mohr, D., Rose, J., Wilson, M., Sprangle, P., and Tang, C.M., "The NBS/NRL Free Electron Laser Facility," to be published in Nuclear Instruments and Methods in Physics Research.

Tang, C.-M., Sprangle, P., Penner, S., and Maruyama, X.K., "Analysis of Free Electron Laser Performance Utilizing the National Bureau of Standards' CW Microtron," to be published in J. of Applied Physics.

Tirosh, D. and Whittaker, J., "A Fast Pulse Amplifier for Pulse Radiolysis Measurements with Digitally Controlled DC Offset," to be published in Nuclear Instruments and Methods.

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 IEEE Transactions on Nuclear Science.

TECHNICAL AND PROFESSIONAL COMMITTEE PARTICIPATION AND LEADERSHIP

Division 535, Radiation Source and Instrumentation

John B. Broberg

Member, Program Committee of the 1988 Linear Accelerator Conference

Louis Costrell

Chairman, NIM (National Instrumentation Methods) Committee

Chairman, American National Standards Institute Committee N42, Radiation Instrumentation

Member, American National Standards Institute Nuclear Standards Board

Member, American National Standards Institute Nuclear Standards Board Planning Committee

Secretary, IEEE Nuclear Instrumentation and Detectors Committee

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

Chairman, IEEE Nuclear and Plasma Sciences Nominating Committee

Chairman, IEEE Nuclear and Plasma Sciences Annual Meetings Committee

Member, Organizing Committee, 1989 IEEE Particle Accelerator Conference

Member, IEEE Nuclear Science Symposium Program Committee

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

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

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

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

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

Philip Debenham

Technical Consultant, DOE Review Committee, CEBAF Semi-Annual Review, Nov. 17-19, 1987.

Reviewed spectrometer design and project management, DOE Technical Advisory Panel on CEBAF High Resolution Spectrometers

Member, Program Committee, 1989 IEEE Particle Accelerator Conference

Eric Lindstrom

Editor, Proceedings of 1987 IEEE Particle Accelerator Conference

Samuel Penner

Member, Organizing Committee, 1989 IEEE Particle Accelerator Conference

Julian Whittaker

Member, ASTM Committee D22 on Sampling and Analysis of Atmospheres

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

Mark Wilson

Member, Program Committee, 1989 IEEE Particle Accelerator Conference

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

MAJOR CONSULTING AND ADVISORY SERVICES

Division 535, Radiation Source and Instrumentation

1. S. Penner and M. Wilson continue to provide Accelerator Technology and Assessment and Oversight for DARPA.

2. 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.

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

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

SPONSORED SEMINARS AND COLLOQUIA

Division 535, Radiation Source and Instrumentation

Thomas M. Baer, Spectra-Physics, Inc., Mountain View California, "Subpicosecond Optical Pulse Generation Using Compression Techniques," October 22, 1987.

Spilios Riyopoulos, Science Applications International Corporation, McLean, Virginia, "Reflection Matrix for Gaussian Light Beams in FEL Oscillators," December 3, 1987.

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 and radioactive materials

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

  - Medicine
  - Industry
  - States
  - Other Federal Agencies

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

Division 536, Technical Activities (cont'd.)

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

The division was restructured in March 1988 to a simpler organizational structure:

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

Office of Radiation Measurement (E. H. Eisenhower)

Radiation Interactions and Dosimetry (B. M. Coursey)

Neutron Interactions and Dosimetry (J. A. Grundl)

Radioactivity (D. D. Hoppes)

Some of the goals in restructuring were: better balance between fundamental research and services, better support for fewer activities, fresh leadership, choice of state-of-the-art research activities, effect economies where possible by combining support services, and to improve other objects levels. Due to an FY 88 funding shortage a staff reduction also took place at the time of the reorganization.

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

Radiation Interactions Research

Chemical mechanisms of biological effects and applications to radiation dosimetry

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

Neutron and high-LET radiation interactions (includes radon)

Dissemination of Measurement Services

Develop national measurement support system for ionizing radiation

Radiation Measurement Science

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

Chemical dosimetry/industrial radiation processing

Dosimetry for radiation protection monitoring

Radon measurement standards

Radionuclide atom counting

Radiology imaging research

I. 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 provide a leadership role and collaborate with members of the Radioactivity group on several projects: upgrading and replacing the primary radon measurement system; continuing the development of the prototype transfer standard for flux density measurements; completing the development and cross calibrations for the new NaI(Tl) secondary measurement system; participating in measurement intercomparisons with the principal U.S. radon measurement laboratories, and planning for a new intercomparison with international metrology laboratories; assembly of a second radon-in water standard generator; and initiating a new project for a primary radon calibration which is independent of a ^{226}Ra standard.

In the past year, significant progress has been made on replacing the old primary radon measurement system which serves as the national standard for radon measurements. The four new pulse ionization chambers, custom-built to our specifications by Reuter-Stokes, were delivered and preliminary performance evaluations were completed. All of the ancillary electronics for power, signal processing, and computer control have been assembled. Testing of the electronic counting systems is ongoing.

Construction of the extensive gas handling and purification manifold was initiated this Spring. It is anticipated that initial testing and calibrations of the completed system will begin in the next six to nine months.

The project to develop a large surface area flux density standard is continuing. A 40-cm diameter prototype has been operational for the past two years. Preliminary calibrations for both the constrained and unconstrained flux density were completed, and were shown to be in agreement with theoretical calculations based on a diffusion model for the standard. These initial successes, however, were offset by a major setback in this development work. Unexpected large evaporation losses by transpiration of water through the polyethylene membrane over the past 26 months resulted in the formation of air gaps at the water-polyethylene interface as well as changes in the initial radium solution concentration. The former result introduces an undesirable permeation component in the operation of the otherwise purely diffusive transport of radon in the standard. The latter changes the radon production rate in the standard. As a result, the prototype had to refilled to make up the evaporation losses. Work is ongoing to establish operating procedures that will either minimize the evaporation losses or simplify the make-up refilling. The final series of calibrations against the primary measurement system was recently initiated in collaboration with a guest worker.

A measurement intercomparison with the five principal laboratories within the U.S. that maintain an independent radon calibration capability was completed in the past year. An unsatisfactorily large, systematic measurement discrepancy of over 7 percent among these laboratories was found despite the fact that all of the laboratories' calibrations were based on similar NIST ^{226}Ra solution standards. We are continuing to work with these laboratories to try to understand and resolve the discrepancy. A new international radon measurement intercomparison among the national metrology laboratories (e.g., PTB and NPL) is also being planned for early 1989.

Work also has been started on an initiative to perform a primary radon calibration which is not based on an indirect or comparative measurement against a ^{226}Ra standard. This primary calibration, expected to have an overall uncertainty of 1 to 2 percent, will be based on liquid scintillation counting techniques using radium-free radon solutions. A radon-in-water standard generator which was successfully developed several years ago will be used to prepare the solutions. A second generator is presently being assembled for this work (the first prototype generator was delivered to EPA). This primary calibration, if successful, will be a significant achievement in providing the first independent confirmation of the radium calibrations used over the past 50 years.

Division 536, Technical Activities (cont'd.)

Measurement Uncertainties (R. Collé)

An international guidance document for the treatment and reporting of measurement uncertainties has been under development for the past 18 months under the chairmanship of a member of the Office. The document is being developed by a joint international working group representing the International Organization for Standards, the International Electrotechnical Commission, the International Bureau of Weights and Measures, and the International Organization of Legal Metrology. The first draft completed last year required substantial changes in content and nearly a complete rewrite. The second draft was completed in September, and presently is being distributed and made available to a wider audience for comment. The U.S. industrial metrology community, which has considerable interest in the topic, has been kept well apprised of the ongoing efforts through an ad hoc advisory group of over 70 members.

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 is being used by the labs in CA, IL, and SC. This code is written in a compiled BASIC with the source code for the menu-driven programs occupying over 800k on the fixed disk. This code includes two instrument-specific calibration procedures, as well as a generic calibration procedure, for the types of instruments most commonly calibrated at state laboratories. For Radcal instruments, there is a procedure for electrically checking the response of the instrument including its linearity. There are options for both x-ray and gamma-ray calibrations. The code also includes quality control procedures for 14 different pieces of the calibration equipment used, and is necessary to demonstrate that the equipment is performing statistically in the same manner as it was during the performance test. There are 15 programs for general data analysis and procedures for making measurements necessary for characterizing the laboratory including a procedure for determining x-ray beam half-value-layer, with the statistical uncertainty associated with the linear regression techniques used in this analysis. There is a program for a nonlinear regression analysis to fit measured exposure rate as a function of distance from a gamma source to a model which includes build-up and attenuation in air and gamma rays scattered from a rear wall. There is also a procedure for electrically calibrating a modified picoampere source and electrometer. In addition to these programs for the state-sector secondary labs, many of which are also necessary for making similar measurement in the Office lab, there are programs for monitoring the equipment and transfer standards used by the Office for performance tests of the secondary-level labs.

Directory of Calibration Laboratories (H. T. Heaton & E. H. Eisenhower)

One of the national needs in ionizing radiation is for a directory listing those companies providing survey instrument calibration services. Thus, the Office, in cooperation with the Radiation Measurements Committee of the Conference of Radiation Control Program Directors, has revised and published the "Directory of Commercial Calibration Services for Ionizing Radiation Survey Instruments". This directory provides detailed information on companies offering alpha, beta, gamma-ray, neutron, and x-ray calibrations together with information on the radiation fields available. The directory was mailed to all of the companies listed and has been sent to all of the state radiation program directors to assist them in answering inquires as to where calibration with a particular radionuclide or exposure rate can be obtained.

Environmental Dosimetry (H. T. Heaton & C. G. Soares)

Environmental dosimeters were irradiated using the NIST cesium and cobalt beams in a joint program with the Environmental Measurements Laboratory (EML) to confirm previously observed differences between participants who use Cs or Co to calibrate their dosimeter readout equipment. The dosimeters have been read out by the participants, the results reported back to EML, and preliminary data analysis made by EML. The previously observed effect is still observable and discussions are under way looking for common elements among the participants showing the strongest effect.

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

The Office is continuing to provide technical assistance to five state sector secondary calibration laboratories (IL, SC, CA, WA, and AR). These labs provide calibrations of instruments used for diagnostic x-ray compliance measurements and for x-ray and gamma-ray radiation protection measurements. Three of these labs were given training in the use of the computer code (see above) for the calibrations performed at their labs and the labs are revising their protocols for routine use of this code. The lab in IL is planning to move to a new facility and they will replace their existing Cs sources with a 40-Ci and 130-mCi dual unit. They are purchasing an additional 10-Ci Cs source for calibrating pocket dosimeters. The x-ray capability will remain the same and they are planning to install a neutron source to be used for constancy checks. They are calibrating instruments for 9 other state radiation control programs. The lab in SC was accredited by the Conference of Radiation Control Program Directors (CRCPD) for x-ray calibrations and they are investigating various options for installing the Cs sources. The lab in WA is only offering gamma-ray calibrations. All three of these labs successfully passed their annual performance test required for accreditation by the CRCPD. The lab in CA has completed the minimum set of measurements necessary to characterize the lab equipment for both x-ray and gamma-ray calibrations. As soon as

their protocol is satisfactory, they will be given the performance test necessary for CRCPD accreditation. The lab in AR has recently acquired several Cs sources and is in the process of installing them. As a result of a performance test at the high-flux neutron facility, an improved model of room return was developed to better account for the large neutron scatter component at that site.

Transfer Standard QC Test Facilities (H. T. Heaton & C. G. Jones)

Two facilities are being developed to monitor the response to radiation of the transfer standards used in performance tests of secondary laboratories. The first incorporates a 3-Ci Cs gamma-ray source and track system to reposition the transfer standard in a precise manner. This system, set up in the Office lab, is presently being used to monitor transfer standards used in gamma-ray performance tests. The second facility is being set up in the Radiation Interactions and Dosimetry Group's industrial x-ray facility and makes use of their 150 kV x-ray unit and an optical bench for instrument positioning. The mounting support system for the x-ray tube is being designed and manufactured, as is the instrument support system.

Private-Sector Calibration Laboratories (E. H. Eisenhower, H. T. Heaton, & C. G. Jones)

The Health Physics Society has begun to accept applications for accreditation of secondary laboratories. The first company to apply (Eberline Instrument Corp.) has been accredited after submitting a satisfactory protocol, an on-site visit, and a successful performance test of calibrating an instrument in their Cs beam. This performance test involved several new features. First, the instrument was calibrated by the Radiation Interactions and Dosimetry Group in the "integrate" mode at a single exposure rate from their Cs source. The performance test was done using the instrument in the "rate" mode and at different exposures than it was calibrated. Thus the Office had to develop procedures to determine the additional uncertainty component of using the transfer standard in different conditions than it was initially calibrated. Part of this involved developing in-house quality control procedures to monitor the response of the transfer standard.

Federally-Owned Calibration Laboratories (E. H. Eisenhower)

Significant progress has been made to develop a program that will lead to formal recognition of the competence of federally-owned calibration laboratories. Performance criteria have been prepared for a broad range of calibrations (i.e., survey instruments, x-ray diagnostic instruments, dosimeter irradiations, reference-class instruments, and source calibrations). These criteria apply to secondary laboratories, but will be expanded to include tertiary laboratories in the future. It has been

decided that accreditation will be provided under the 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 22 individuals from 19 laboratories.

II. Radiation Interactions & Dosimetry Group

In the March 1988 reorganization of programs in the Ionizing Radiation Division, the Radiation Interactions and Dosimetry Group was created which incorporated most of the personnel and programs of the following four groups: Radiation Theory, X-Ray Physics, Dosimetry, and Radiation Chemistry and Chemical Dosimetry. The structure of the new group is still evolving; it presently comprises four projects:

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

The Radiation Sources Project consolidates the operation, maintenance, and updating of the electron, x-ray, and neutron producing sources of the division in a single project. This change encompasses the 300-kV industrial x-ray source, the 500-, 1500-, and 4000-keV electron accelerators and the 3000-keV positive ion accelerator. Operationally, this arrangement will facilitate the servicing and improvements of these sources since more personnel will be available for any particular situations that arise. The sources are available for the physics and chemistry research programs of the Division, as well as to other NIST investigators and to the public.

The Physical Interactions and Dosimetry Project combines the experimental, theoretical and computational research and metrology which was formerly carried out in three separate Groups. Some of the programs for this project are in medical therapy, computational dosimetry, radiological imaging, and personnel protection. Thrusts for the 1990's include: calculation and measurement techniques for ionizing radiation effects on electronics and interfaces of dissimilar materials; dosimetry for medical therapy using high-energy electrons and photons from accelerators; development of real-time inorganic dosimeters for medical and industrial applications; and computation, design and measurement techniques for optimizing radiographic image quality with minimum dose through digital imaging.

The Chemical Interactions and Dosimetry Project has three main elements: radiation chemistry, chemical dosimetry, and post irradiation dosimetry (PID). The aim for these programs is understanding the basic mechanisms of radiation interactions in organic systems and applying this information to problems in the health sciences, industrial applications, and hardness testing of components, as well as personnel radiation protection. The thrusts for the 1990's include: respond to increasing needs of emerging technologies for ionizing radiation measurements in processing and electronics; use electron paramagnetic resonance (EPR) techniques to elucidate free radical processes in irradiated materials; study energy deposition and effects in model systems using GC-MS, HPLC, electrochemical and radioanalytical techniques; develop real-time chemical dosimeters for industrial, medical and research applications.

The Radiation Measurement Services Project combines the calibration services and measurement assurance programs formerly carried out in the X-Ray Physics and Dosimetry Groups. These calibration services include three of the most used services in NML: x- and γ-instrument calibrations, ferrous sulfate dosimetry for medical therapy, and high radiation dose calibration services. The project also includes technical support for the secondary standard dosimetry laboratories (SSDLs) as well as measurement assurance programs in dosimetry and radiographic imaging for other agencies. The thrusts for the 1990's will be to automate and update existing services, to develop new services for emerging industries, and to assist in implementing new measurement assurance programs and secondary laboratory programs which will increase our leverage on ionizing radiation measurements of x- and γ-rays and electrons.

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

A. Radiation Sources (C. E. Dick)

In the past year significant improvements have been made to several of the sources operated in this Project as outlined below.

The experimental room associated with the 300-kV x-ray machine has been improved with the addition of optical benches and a mount for the tube head on these benches. This system will permit accurate repositioning of the source to object and source to detector distances in those measurements where reproducibility of these distances is essential. This machine has been utilized for a number of measurements including the radiography of sections of the oil tank which collapsed in Pittsburgh and in the determination of the resolution and sensitivity of a new class of x-ray imager, the Dynamic Random Access Memory (DRAM) imaging system.

Modifications to the 4-MeV electron Van de Graaff have continued with the addition of a non-dispersive bending magnet system for the

electron beam. This system will facilitate the positioning and reproducibility of the electron beam at either end of the horizontal flight tube. In addition, the design of this system allows additional experimental space for the zero degree high current experimental location. At present, this accelerator is being utilized for the generation of standard electron fields for instrument calibration and for experiments in pulsed radiolysis.

Work has been initiated on the 3 MeV positive ion accelerator which is used to produce neutrons via nuclear interactions. Modifications to the electronics have been initiated and the accelerator is now capable of high voltages up to 3 million volts. Currently, modifications have been undertaken to improve the vacuum in the accelerator tube structure to increase the available beam current, particularly for deuteron beams. In the past year, experiments have been carried out to provide standard fields of 6-7 MeV photon beams for experiments in dosimetry and calibration services.

B. Physical Interactions and Dosimetry Project

Calculational Dosimetry (M. J. Berger & S. M. Seltzer)

A microdosimetry calculation has been completed and published (Phys. Med. Biol. 33, 583 (1988)) pertaining to the distribution of energy deposition events in smaller spherical sites in water (with diameters of 1 micron or smaller in unit density material). The method takes into account energy-loss straggling and the transport of energy by secondary electrons, and goes respect beyond the classical calculations of Caswell and Coyne based on the continuous-slowing down approximation. Results have been obtained for monoenergetic protons between 1 to 20 MeV and for proton beams released in the interactions of 14-MeV and 20-MeV neutrons with hydrogen nuclei.

A Monte Carlo calculation has been completed of the spatial pattern of absorbed dose, and of the spectra of secondary photons and electrons, around cladded ^{60}Co gamma-ray sources used in industrial applications.

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

The NIST general purpose Monte Carlo electron-photon transport program ETRAN has been thoroughly reviewed in six chapters of a book to be published in 1988 or 1989. These chapters cover the input cross sections, the characteristics and limitations of the Monte Carlo model, computational aspects, and various applications. Stimulated by this review, the ETRAN code has been thoroughly revised, including improved cross sections and sampling techniques, and refinements of the Monte Carlo model. As the result of this updating, the code is now easily portable to any computer with a FORTRAN 77 compiler installed, and has been ported to a work station microcomputer. The throughput achieved on

this microcomputer is comparable to that obtained on a mainframe, but at much lower cost.

Cross Sections: Photons (M. J. Berger, S. M. Seltzer, & J. H. Hubbell)

A photon cross section data base XGAM, for use on personal computers, has been supplied to the Office of Standard Reference Data, for sale to the public. This is a further elaboration of the previously published database XCOM.

A compilation of all available, experimental data on total photon cross sections and attenuation coefficients for all elements has been updated and revised, and published in Atomic and Nuclear Data Tables, 38, 1-197 (1988). Software has been developed with which the experimental data base can be accessed using a personal computer. A preliminary analysis of these data, discussed in the Proceeding of SPIE Conference 911 (X-ray and VUV Interaction Databases, January 1988) indicates that between 100 keV and 1 keV (except in the close vicinity of absorption edges) there is satisfactory agreement between experimental values, theoretical results of Scofield, and semi-empirical recommendations of Henke. Between 1 keV and 100 eV the comparison maps out the regions where the available theory becomes inadequate.

Cross Sections: Charged Particles (M. J. Berger & S. M. Seltzer)

A database has been completed pertaining to the elastic scattering of electrons with energies between 1 keV and 1 MeV in all elements. The underlying calculations involved the solution of the Dirac equation for a static screened (Hartree-Fock) Coulomb potential. Progress has been made in extending these calculations above 1 MeV (where partial wave expansions become prohibitively expensive) through the use of a WKB method. A set of model cross sections for inelastic interactions of electrons with water molecules, at energies from 1 MeV to 10 eV has been developed for use in microdosimetric transport calculations.

Preliminary versions have been developed of proton and alpha particle stopping power and range tables, extending from 1000 MeV to 1 keV, taking into account electronic, as well as nuclear stopping powers. These tabulations are based on use of the Bethe theory (with shell corrections) above 1 to 2 MeV, and using critically evaluated experimental stopping powers at lower energies.

Digital Energy Subtraction for Biomaterials (C. E. Dick)

The technique of utilizing digital energy subtraction to investigate materials of biological interest in the human body is continuing. Studies are underway to determine the sensitivity of the method by imaging various thickness water samples embedded in tissue equivalent plastic. At present,

the use of photon beams with average energies of 75- and 150-keV allows the detection of fluid thicknesses of approximately 1 mm in 5 cm thick phantoms. Further experiments are underway to optimize the energies of the photon beams and improve the sensitivity of the method for this and other imaging tasks.

Medical and Industrial Radiography (C. E. Dick)

Several programs are continuing to investigate topics concerned with x-ray imaging for both medical and industrial applications. A collaborative effort is underway to investigate the properties of a new class of x-ray imaging medium, photostimulable storage phosphors. Experiments have been initiated to investigate storage of x-ray image information in deep traps in these materials which can be released on demand by interrogation with an infrared laser. Preliminary results indicate that the process can be successfully modeled by a Monte Carlo calculation of the charge storage and retrieval process. Presently, the calculated and experimentally measured data agree to within 10 percent x-ray excitation energy of 662-keV. Data are also being gathered on the fading of the storage screen and the lifetime of the stored image information.

An experiment has been completed to measure the effect of metallic x-ray intensifying screens used in industrial radiography. The relative photographic effect for aluminum, copper, and lead screens has been measured as a function of the screen thickness and screen location (front or back) for both the front and back emulsion of a typical x-ray double emulsion film. At present the measurements are limited to a photon energy of 662-keV. The process has been modeled by a Monte Carlo calculation based on the ETRAN model which includes geometrical factors. The experimental and calculated data agree to within 5 percent indicate the relative energy deposition in the film emulsion by electrons generated by photon interactions in the metallic foils.

Portable Dental X-Ray Imaging Systems (J. H. Sparrow, M. R. McClelland, & J. W. Motz)

The Radiation Interactions and Dosimetry 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 ruggedized six pound, 70 kV 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 55 kV x-ray source. 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 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 NIST 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.

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 dose. NIST has developed a series of calorimeters as part of a program to develop reliable national measurement standards for absorbed dose. One of these NIST 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 water calorimeters to be operated at room temperature without loss of accuracy because of concerns about convection. A new model of a high-purity water calorimeter has been designed, which is also based on

calculations of the effects of materials other than the high-purity water. Preliminary work has been successfully completed on the fabrication and assembly of micro-bead thermistors within thin glass capillaries, which are to be the temperature sensors. Reports on these works are in press.

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 NIST ^{60}Co beam for comparison of calorimeter and ionization-chamber measurements. A similar comparison will be made at another institution using a beam of 15-MeV neutrons.

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 world-wide. 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. NIST 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 NIST 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 NIST 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 NIST scientists and by providing specific dosimetry services. This effort is needed to support the radiobiological studies at AFRRI because of the relatively frequent (approximately 2-year) turnover of scientific military personnel at AFRRI. It is essential that accurate dosimetry methods support the radiobiological experiments in order to relate this research to similar work at other laboratories.

During the past year we have designed and installed a ^{252}Cf radiation source housed in a specific 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 have 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 NIST and AFRRI scientists.

Personnel Dosimetry (C. Soares & M. Ehrlich)

M. Ehrlich developed a method for estimating the new operational quantity, directional dose equivalent, with existing personnel dosimeters having energy- and angle-response functions different from this operational quantity. The efficacy of the method was demonstrated for one personnel dosimeter for which suitable response data were available. A paper on this subject was presented at a seminar at the Physikalisch-Technische Bundesanstalt in Braunschweig. The full text of the paper will appear in

the Proceedings of this seminar, to be published in Radiation Protection Dosimetry.

Further activities of M. Ehrlich in radiation-protection dosimetry relate to work on two committees of the International Organization for Standards (one dealing with radiation fields for the calibration of radiation-protection instruments and the other with performance characteristics of photographic personnel dosimeters) and work on a committee of the American National Standards Institute, dealing with dosimetry quantities for use in radiation shielding.

Work on revision of ANSI Standard N13.11, "Personnel Dosimetry Performance - Criteria for Testing" continued, with C. Soares attending three meetings of the working group. As part of the proposed testing of angular dependence of dosimeter response, experiments were initiated on the feasibility of such tests utilizing the aid of guest-worker C.-Y. Yu of Taiwan Power (ROC). Comparison of dosimeter response of the Panasonic 802 dosimetry system with the ICRU 39 quantity directional dose equivalent, which is the proposed testing quantity, are being performed as a function of photon energy.

Standard Monoenergetic Electron Beams (C. G. Soares)

NIST has been requested by the radiation protection community to establish standards for and assist in the development of methods of measuring the beta-particle radiation fields that are found in nuclear power installations. Beta-particle detection instrumentation is currently being calibrated using only broad-spectrum radionuclide sources. In order to determine instrument response as a function of energy in detail, NIST has developed a set of accelerator-produced nearly monoenergetic electron beams. The beam monitoring and control system developed in FY 86 has now been tested at the higher electron energies (1-2.5 MeV) and found to perform satisfactorily. A full report on the system as well as results of its use is in preparation.

High-Energy Nearly Monoenergetic Photon Calibration Facility
(C. G. Soares & R. J. Biss)

Work was resumed on development of this facility which supplies a need expressed by the Radiation Protection community for testing instruments used for surveying areas where personnel are exposed to the high-energy photons (~6 MeV) produced by activation of cooling water in power reactors. The NIST facility uses the 3 MV positive ion accelerator to produce 6-7 MeV photons via the $^{19}F(p,\alpha\gamma)^{16}O$ reaction. Source usefulness has been limited previously by low output dose rate (0.2 mGy/h). By raising the incident proton energy from 2 to 2.7 MeV, it has been possible to increase this maximum dose rate by about a factor of five. Maximum beam currents have been limited to about 10 μA; work is now under way to design a

moving target assembly to allow more proton current to be used and improvements to the accelerator are in progress to achieve higher beam currents.

A key focus of the current work has been to compare dose-rate measurements using several different systems. Previously, with the low dose-rate limitation, only thermoluminescence dosimetry (TLD) measurements were possible. With the higher dose rate, ionization chamber measurements have now also been made. Comparisons between these two measurements, and the results of spectral measurements from unfolded NaI pulse height spectra (described elsewhere) are in progress.

Dosimetry of High-Energy Electron Beams (J. C. Humphreys)

Work continued on the development of methods to characterize and calibrate high-intensity electron beams in the energy range of 10-40 MeV. Preliminary designs include an aluminum multi-foil array calorimeter with a high-speed multichannel data analysis system that can measure a complete depth-dose profile from a single pulse (or short pulse train) irradiation. These results will provide information on the integrated total dose, dose rate and electron energy (calculated from the extrapolated range). The data acquisition system and calorimeter will be compact and light so as to be easily transported to an industrial accelerator facility for calibration of its electron beam. These accelerators are becoming more numerous and are being increasingly utilized for medical product sterilization, and radiation hardness and polymer modification testing of electronic devices. At present, dosimetry is performed with passive systems (such as TLDs or dye films) that are calibrated with ^{60}Co gamma rays. Direct calibration of the electron beams with calorimeters would reduce the uncertainties in the dosimetry measurements as well as provide evidence as to whether the response of the passive systems is the same for electrons as for gamma rays.

C. Chemical Interactions and Dosimetry Project

Radiation Chemistry of Aromatic Molecules (M. G. Simic, L. R. Karam, M. Farahani & M. Al-Sheikhly)

Aromatic molecules play a major role in the mechanisms of direct action of radiation on biological targets. Mechanisms of radiation on the ring opening of benzene were unraveled and a new method for discrimination of metabolic (mucondialdehyde) and free radical processes (hydroxymucondialdehye) involving benzene molecule was developed. It was also shown that benzene may induce free radical processes and generate •OH radicals in muscle tissue in the absence of radiation and visible light.

Lipids (M. Al-Sheikhly & M. G. Simic)

Mechanisms of radiation induced autoxidation of lipids are being studied by pulse radiolysis and oxygen uptake experiments, 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.

A novel method based on radiation induced uptake of oxygen was developed which allows discrimination of oxidative mechanisms (e.g., Russell, Bennett).

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

Antioxidants and sulfhydryls act as radioprotectors and anticarcinogens and in both cases the mechanism of action is being studied. The impact of this work is also of significance in food preservation and human physiology. NIST is the only institution in the U.S. dealing with kinetic aspects of antioxidants. The redox potentials of radioprotectors and physiological antioxidants are being investigated.

Deoxyribosephosphate Modification by Ataxia Telangiectasia Cells (L. R. Karam, M. G. Simic, W. Franklin, & T. Lindahl)

Cells from patients with Ataxia Telangiectasia (AT), a disease characterized by an accelerated build-up of damage caused by aging, show extreme sensitivity to ionizing radiation and other free-radical producing agents. Extensive DNA strand breakage, and a failure of these cells to delay DNA replication immediately after irradiation so that DNA damage may be repaired, suggested a study of an enzyme deficiency in this disease as a possible venue in the further study of biomarkers and radiation-induced DNA damage.

The reaction of AT cell lysates with nick translated DNA substrate was observed to alter the deoxyribosephosphate moiety. AT lysates were found to induce an adduct reaction with a free phosphate group (observed by both HPLC and GC-MS), at a DNA strand break as well as in solution, which may present a blocking point to DNA repair. The potential of using this modified phosphate as a biomarker of radiolytic and non-radiolytic (active oxygen) damage has yet to be determined.

Post Irradiation Dosimetry (PID) (L. R. Karam, D. S. Bergtold, & M. 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. PID techniques should also be useful in radiation therapy and in measurements of 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 non-irradiated chicken-breast meat. No measurable (<0.1 ppm) quantities of o-Tyr were found in non-irradiated 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 non-irradiated meat. However, even under those circumstances no o-Tyr was found in the water-insoluble fraction (~75 percent of protein) after water extraction. Currently developing HPLC (liquid chromatography) techniques for the separation and elucidation of modified amino acids (primarily, ortho-tyrosine) by derivatization (Picotag) and non-derivatization methods (UV by reverse-phase HPLC). Gas chromatography-mass spectrometry have been used to measure quantities of o-Tyr in meats exposed to free radicals by radiation and organic solvents which affect O_2 metabolism in the mitochondria. Relative yields of the various isomers of tyrosine formed by the irradiation of phenylalanine in the presence and absence of O_2 are being studied.

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

Radiation chemical kinetics and steady-state radiolysis studies are underway to unravel the response mechanisms of new chemical dosimeters, namely those that show promise for applications at intermediate and high doses. Pulse radiolysis of dichromate dosimeter solutions and radiochromic dosimeter solutions are presently explaining for the first time the intermediate reaction yields of these organic and aqueous solutions and,

in fact, have provided important clues on how to enhance yields of the ultimate chemical products that are used for the dosimetric analyses. Most important of all, the kinetics studies have made it possible to design more precise systems which are devoid of reciprocity failure (no rate dependence) and have well-behaved temperature coefficients. The next direction in these studies is to examine the reaction mechanisms of selected solid-phase chemical dosimeters.

High-Dose Dosimetry Applications (W. L. McLaughlin, M. Desrosiers, M. Farahani, & M. Al-Sheikhly)

Valuable quality-control is provided by dosimetry at high doses of photons and electrons. Areas of application include the sterilization of medical products, food preservation, rubber vulcanization, plastic and electronics manufacturing, treatment of solid, liquid, and gas waste, and the production of wire and cable, plastics, and a wide variety of industrial products. High-resolution dose mapping at interfaces of different materials is a particularly effective application of thin-film dosimeters developed at NIST-CRR. A current cooperative project with the ADA deals with interface dosimetry. Absorbed doses are measured at tissue-teeth, tissue-bone and tissue-metal interfaces where clinical radiation treatment planning involves oral cancers and requires an accurate determination of dose to lesions as well as to healthy tissues. Similar treatment planning applications are envisaged for the irradiation of heterogeneous anatomical tissues, where radiation-treatable laryngeal, cranial, ocular, and bone and bone-marrow tumors occur. Improved quality control is also achieved by such dosimetry in the radiation sterilization of complex medical devices (e.g., iv sets, syringes, and prosthetics).

Optical Waveguide Dosimetry (W. L. McLaughlin, M. G. Simic, B. Radak, & W. Warasawas)

The concept of optical waveguides combined with radiochromic dyes was applied to spectrophotometry and to pulse radiolysis, in order to enhance the sensitivity of these analytical techniques. New approaches involving kinetic spectroscopy were developed in collaboration with the Boris Kidric Institute in Yugoslavia and allow pulse radiolysis examination of radiation-induced reactions in solutions using low doses of flash x-rays in single or multiple short pulses (<1 ns). A broad range chemical dosimeter for real-time steady-state or pulsed fields of electrons, photons or neutrons was developed to measure doses as low as 0.005 Gy, and this innovation was honored as one of five R&D (IR-100) awards to NIST in 1988.

Reference Chemical Dosimeters (W. L. McLaughlin, B. M. Coursey, M. Farahani, M. Al-Sheikhly, J. C. Humphreys, D. Hocken, M. Hussmann, L. Sheahen, & S. Monaco)

Aqueous and organic chemical dosimeters were introduced, both as standard reference materials and as reference standards for calibration of radiation sources of industrial and national laboratories. A major paper was published on the radiation chemical yields of a potassium-silver dichromate dosimeter which, by means of appropriate chemical additives, was sensitized eight-fold, in order to overlap the classic Fricke dosimeter. This work thus extends the dose range of aqueous reference dosimetry by dichromate from 0.3 to 50 kGy. The response mechanisms of this new dosimeter were investigated and are explained in a publication in preparation. In addition, a new class of reference radiochromic organic solutions were introduced as SRMs and are in the final test stages. These systems are presently being reported on in the scientific literature and cover an exceptionally wide dose range (0.5 to 10^6 Gy), for use in industry, medicine, agriculture, and radiation protection.

New Dosimeter Film Developments (W. L. McLaughlin, M. Al-Sheikhly, & A. Miller)

Several new types of radiochromic films have been added to the stable of thin-film detectors, which can be used conveniently for measuring high-resolution dose distributions over wide dose and dose-rate ranges. Such films are useful especially in electron-beam dose mapping in industrial and clinical applications. The new films include the following: dyed cellulose diacetate (10^4 - 10^6 Gy); high-density polyethylene ($5x10^4$ - $5x10^6$ Gy); dyed polyvinylbutyral ($5x10^3$ - $5x10^5$ Gy); green cellophane ($5x10^3$ - $5x10^4$ Gy); a propriety film coating from GAF Corp. ($2x10^1$ - $5x10^3$ Gy). Papers have been published or are in preparation describing all five of these systems and their utilities in providing radiation diagnostics and quality control. Four of them are now beginning to be marketed successfully by private enterprise for specialty purposes, and the last one is especially promising because it is unique in its sensitivity and versatility.

D. Radiation Measurement Services Project

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 continue at an increased rate. The number of TLD badge irradiations has increased again this fiscal year. The documentation of the NIST calibration procedures for x-ray and gamma-ray measuring instruments, NBS SP250-16, has been published. The documentation of the NIST calibration procedures, equipment, standards and history for the brachytherapy sources, is in the

final stages of revision. Final publication will be in the NBS Special Publication 250 series.

The Hewlett-Packard data-acquisition system used with the x-ray instrument calibration ranges is obsolete and no longer supported by HP, and a breakdown would interrupt the x-ray calibration services. As a result, work continues in an effort 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 would then be used to control essentially all aspects of the instrument calibration.

All three NIST free-air standards were compared with each other in their overlapping energy ranges. Agreement was between 0.5 percent and 1.0 percent.

An experimental technique for measuring the air attenuation correction as a function of x-ray energy was designed. Data for the higher energy x-ray beams (those used with the 300 kV x-ray range) have been taken and analyzed. The experiment continues for the lower energy x-ray beams (100 kV x-ray range). These new data will be the basis for the corrections to be applied to the NIST free-air standards.

Additional assistance in the use of the ^{60}Co and ^{137}Cs gamma-ray ranges continues to be provided to other agencies and industry. Assistance was also provided to Group physicists for their continuing study of the intensifying effects of metallic screens in industrial radiography.

High-Dose Radiation Calibration Services (J. C. Humphreys & D. Hocken)

Documentation of these services has been developed as NBS Special Publication 250-11: "Dosimetry for High Dose Applications". This report describes in detail the various services available for the standardization of high absorbed dose measurements of ionizing radiation (photons and electrons only). It describes the various irradiation facilities employed, the dosimeter handling and analysis procedures and assignment of uncertainties to all aspects of the services. The report is available for general public distribution and has been sent to over 450 interested persons so far. During the past year about 300 calibration irradiations and measurement services were performed for industrial radiation processing facilities, national laboratories, universities, other government agencies, and other users at NIST. Steamlining of these services and improved statistical analysis of calibration data have enhanced the efficiency and reproducibility of the services and have reduced the "turn around" time for calibration requests.

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, NIST offers a measurement assurance service that involves mailing to the users passive dosimeters to be irradiated in a prescribed geometry and returned to NIST for evaluation of the absorbed dose delivered. For this service, ferrous-ferric (Fricke) dosimeters are used at present. There were three mailings of Fricke dosimeters in FY 88, involving 50 sets of participants, and a total of 182 dose interpretations. Two batches of dosimeters were prepared. In order to conserve time, and thus cost to the participants, the tests are administered simultaneously to as many participants as the batch size permits. To help in preparing summary reports and identifying trends, the test results from the entire twenty-year history of the service have been entered into a data base.

Documentation on the NIST procedures for the Fricke measurement assurance service is complete and has been published. It was distributed to all present and past participants of the study and will be part of the package sent to prospective new users.

Beta-particle Source Calibration and Associated Measurement-Assurance Services (J. S. Pruitt)

The NIST 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 NIST applicator SN0258.

The PTW extrapolation chamber has been transported to the Battelle Pacific Northwest Laboratories, in Richland, WA, to calibrate two strontium beta-particle sources purchased by the National Voluntary Laboratory Accreditation Program (NVLAP) for use in that laboratory. The PTW chamber has also been used for several measurements in this laboratory, including mapping the two NIST strontium sources, with and without a flattening filter and measuring the perturbation introduced into current measurements by a ring used to hold filters added to the chamber face to simulate skin depth.

The parallel plate ionization chamber purchased for dissemination of NIST beta-particle calibration (PTW#2047) has been shown to be erratic and not trustworthy for that purpose. The reason for this erratic behavior has not yet been determined, but a second PTW extrapolation chamber has been used in its place for long-distance comparisons between NIST strontium and thallium sources and similar sources at the Idaho National Laboratory in Idaho Falls.

Performance Evaluations of DOD Radiological Inspection Systems (20 keV to 16 MeV) (J. H. Sparrow)

At the request of the Department of the Navy, this program carries out the following tasks:

1) measure and calibrate, every 12 to 18 months, the x-ray outputs of approximately seven 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;

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.

Department of the Navy Dosimetry Calibration Program
(J. T. Weaver & E. L. Bright)

The Navy thermoluminescence dosimetry (TLD) measurement-assurance program, sponsored by the Naval Sea Systems Command, continues. NIST 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 facilities for readout, and the results are returned to NIST for analysis and comparison to NIST exposures. The results are sent to the sponsoring agency, and they schedule a retest or recalibration for any TLD-readout instruments that indicate exposures differing from the NIST exposure by more than 13 percent. About 312 boxes, containing 3744 exposed dosimeters, were dispatched during FY 88. Also included on this project is exposure of an estimated 144 badges for the Naval Medical Command and completing a calibration of an AN/UDM1A calibrator. Several Victoreen R-meters and associated chambers were also calibrated under this project.

III. NEUTRON INTERACTIONS AND DOSIMETRY GROUP

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

Accomplishments for FY 88 are outlined below in titled paragraphs under the five projects that define the group's activities. Major participants and a scope statement are included for each project.

DOSIMETRY FOR MATERIAL PERFORMANCE ASSESSMENT (E. D. McGarry, D. Gilliam, C. Eisenhauer, & G. Lamaze)

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

1. Neutron fluence standards. These unique artifact standards are neutron sensors (activation foils generally) in which a radioactive species relevant for dosimetry is induced by irradiation in a standard neutron field. NIST maintains a variety of standard neutron fields to supply such neutron fluence standards to customers under NBS SP 250 Calibration Services and to the Nuclear Regulatory Commission under a general consultation contract. These fluence standards provide benchmark referencing for dosimetry measurement methods used in the nuclear industry.

Of particular interest is the production of 30-year ^{137}Cs in fissionable foils of ^{238}U and ^{237}Np, and the production of 5.7-year ^{60}Co in copper by 30-day irradiations in the NIST ^{235}U Cavity Fission Source at the NIST reactor. Although long half lives make these radioactive species difficult to produce in standard neutron fields, irradiations are carried out at some expense because long half-lives are especially appropriate for long-term neutron fluence monitoring in power reactors.

2. NBS-Westinghouse cooperative agreement. In a move to improve Quality Assurance (QA) methods associated with dosimetry procedures at commercial power reactors, NIST and Westinghouse have begun negotiating a cooperative agreement. Under this agreement, NIST will review the measurement techniques for reactor neutron dosimetry at Westinghouse to insure that direct measurement links exist with standard neutron fields

at NIST. Westinghouse and NIST personnel have met and agreed upon important elements of a written agreement. Efforts are already underway to investigate some measurement discrepancies in power reactor data obtained with paired uranium detectors (PUD) for neutron fluence furnished by NIST.

3. Dosimetry benchmarking for the heavy section steel testing (HSST)-program. NIST is helping the NRC benchmark fast neutron dosimetry for an HSST steel testing program carried out by the Materials Engineering Associates (MEA) Corporation at the University of Buffalo's Pulstar Reactor. The focus of this activity is radioactive counting procedures at the Idaho Nuclear Engineering Laboratory (INEL) where analysis of all dosimetry involved in the MEA tests are performed. Comparisons of experimental dosimetry with neutron transport calculations were presented by NIST at the 14th ASTM-E10 Radiation Effects on Materials Symposium, in Andover, MA in June 1988.

4. Fission spectrum cross section of ^{93}Nb(n,n')^{93m}Nb. Because of its long half life (16 years) and a low energy threshold (1 MeV), the Nb(n,n') reaction is a candidate for long term neutron fluence monitoring. One drawback has been the lack of adequate cross section information. Now, in cooperation with the universities of Illinois and Arkansas, the spectrum averaged cross sections of the niobium reaction have been measured in the ^{235}U and ^{252}Cf standard fission neutron fields at NIST. Free-field neutron fluences at both irradiation facilities were established by neutron source emission-rate calibrations at the NIST $MnSO_4$ Bath Facility.

5. Benchmark measurements in commercial power reactors. Efforts continue to benchmark reference neutron dosimetry associated with fast neutron exposures of critical structures at nuclear power plants. The benchmark work focuses on both measurement of neutron exposures that cause embrittlement of steel and on the characterization of test reactor neutron environments used to study embrittlement models.

NIST is assisting the Babcock & Wilcox (B&W) Owner's Group conduct a full power cycle benchmark designed to check a variety of dosimetry methods, e.g., conventional foil activation versus solid-state track fission-event recorders. Paired uranium detectors (PUDs), and lithium fluoride chips gamma sensors, both developed at NIST, are also included in this comprehensive dosimetry technique comparison.

6. Power reactor mockups. Because of the complexity of the radioactive environments in and near the core of commercial nuclear power reactors, and because of the apathy that utilities have toward "other than mandatory" measurements in operating power plants, it is necessary to develop and use mockups of power reactors structures to ensure materials integrity. For the most part, this effort is aimed at improving the agreement between measurements and neutron transport calculations. NIST has been involved

with two such international power reactor benchmarks: VENUS at a laboratory in Belgium and NESDIP in Great Britain.

VENUS is core loading benchmark that was constructed to study neutron leakage in the vicinity of the fuel corners of PWR reactor cores. NIST assists in the characterization work itself as well as with QA of dosimetry measurements. NESDIP is a reactor mock up of various ex-vessel reactor cavities. Again, NIST is involved with benchmark referencing of inter-laboratory dosimetry measurements.

7. Dosimetry calibration for White Sands pulsed reactors. Fast-burst, Godiva-type reactors are used for electronic materials irradiation damage studies. A visit was made to White Sands Proving Grounds, New Mexico, by NIST personnel in January to arrange for NIST fission chamber measurements in the leakage spectrum from the White Sands Pulsed Reactor. These arrangements were later postponed because of licensing problems with on-site fissionable materials at White Sands. Rescheduling is expected early in FY 89. In the meantime preparations for these in situ measurements continue including detector response calculations and design of acceptable fission chamber mountings.

PERSONNEL DOSIMETRY (R. Schwartz, C. Eisenhauer, J. Coyne, & E. Boswell)

Standard neutron fields are developed and applied for calibration of radiation protection instrumentation and for the investigation and testing of new types of dose measuring techniques. Substantial responsibilities in national and international dosimetry methods research focuses on tissue dose modeling and tissue equivalent proportional counter measurements.

1. Calibration service. Approximately 40 neutron radiation protection instruments were calibrated this year, the majority of them for nuclear power plants. The remotely operated detector positioner continues to operate well, minimizing exposure to personnel, speeding up data taking, and improving accuracy.

2. Performance tests of radiation protection instrumentation. In a joint project involving Harwell and the National Physical Laboratory in England, and the Naval Surface Warfare Center and Naval Research Laboratory in the U. S., the properties of the new Chalk River "Bubble Damage Detector" were investigated. The results of this work were sufficiently promising that this collaboration will continue under the auspices of the Naval Medical Command.

In an effort to understand the cause of the persistent slow drift in the 9" remmeters commonly used for neutron radiation protection measurements, a detailed study was made of the behavior of the ^{3}BF proportional counters used as neutron detectors in these instruments. It was discovered that the drift is caused by an unfortunate combination of the somewhat unstable

electronics in the remmeter instrument package, and the abysmal performance of the proportional counter. A good counter (readily available from other manufacturers) would eliminate the problem.

3. Calibration intercomparison. The international intercomparison of remmeter calibrations among NIST, NPL (Great Britain), PTB (Germany), and CEA (France) has been completed. Calibrations with bare and moderated californium involved a conventional spherical remmeter and a totally new, unique neutron survey meter (the Dineutron). Each laboratory determined a calibration factor for these instruments using their own californium sources and their own preferred calibration techniques. The results were consistent with the assigned uncertainties. The NIST values for the Harwell monitor were within about 2 percent of the mean of the other three values. For the Dineutron, the NIST values differed from the mean by 6 percent, with an uncertainty of 6 percent. (The latter instrument is very difficult to calibrate properly). The results of this intercomparison are to be presented at the Conference on Radiation Protection and Dosimetry in Florida, in November 1988.

4. Tissue equivalent proportional counter (TEPC) studies. In a joint program with PTB and the University of Saarlands, a detailed study was made of the behavior of various configurations of TEPC's in the NIST filtered neutron beams. The purpose of this investigation was to learn how to improve the response of TEPC-based remmeters in the keV-to-100 keV neutron energy range. These types of remmeters are under active development at several laboratories in the U. S. and in Europe. It is recognized, however, that their performance needs to be improved in the energy region made accessible by our filtered beams. An immediate result of this study showed that the neutron dose due to contaminants in the beams as measured by the TEPC was in agreement with the predictions based on NIST ^{3}He and proton recoil spectroscopy. This work also demonstrated that the NIST filtered beams are, by a very significant margin, purer and of higher intensity than those available elsewhere.

5. International standards writing. The ISO Draft Standard Proposal, "Procedures for Calibrating and Determining the Energy Response of Neutron Measuring Devices Used for Radiation Protection," has been completely rewritten although further changes will have to be made. A draft of the chapter on calibrations, for the forthcoming ICRU publication "Determining of Dose Equivalents from External Radiation Sources - Part 3," has also been completed.

6. Radiation protection policy committee work. C. Eisenhauer serves as chairman of a sub-panel of the Science Panel of the Committee on Interagency Radiation Research and Policy Coordination (CIRRPC). This sub-panel is responsible for producing a report on the desirability of planning for research on human health effects in the event of a nuclear accident. J. Coyne serves on the High-LET subcommittee for CIRRPC. This

subcommittee is writing a report which will outline a general research program for all government agencies on the radiobiological effectiveness of neutrons. A first draft of the report will be ready in September and will be submitted for informal review to concerned American and European scientists.

7. Room scattered neutrons. A series of Monte Carlo calculations have been performed to check out the simple model developed at NIST for estimating room-return background. Calculated room configurations were varied from a spherical cavity, for which the model is rigorous, to a cubical cavity, a rectangular parallelepiped cavity, and, finally, to a parallelepiped with an open ceiling corresponding to the configuration of the NIST calibration room. The simple expression for the fluence $\Phi r^2 = A+Br^2$ where r is the source detector distance, works well for a cubical room, but correction term proportional to r^4 has to be added for the configuration of the NIST room. Recent experimental results at NIST tend to confirm this prediction, although the coefficient of the r^4 term is so small that more careful measurements will be required. An invited paper on this subject was given at the annual meeting of the American Nuclear Society.

8. Air-scattered neutrons. Although the correction for air scattering is estimated to be only a few percent in a typical NIST calibration of neutron personnel instruments, larger corrections have been observed in calibrations at other institutions. A definitive series of Monte Carlo calculations of the fluence and spectrum of air scattered neutrons verified earlier estimate of a 1 percent fluence correction at 1 meter for the NIST Cf sources and 4 percent at 1 meter for the moderated Cf sources. A paper describing these calculations was published in Radiation Protection Dosimetry.

9. Microdosimetry of radon and radon daughters. There is much interest at present in understanding how cancer in the lung and bronchial epithelium are produced by radon and radon daughters. We are studying the physics of this process through microdosimetry. A new computer code, "RADONA" (radon-analytic), has been constructed from our "analytic method" code for neutrons. This code involves calculating an alpha-particle slowing-down spectrum at the basal cell location based on an assumed distribution of alpha-particle sources and anatomical geometry. From this microdosimetric spectra and parameters are calculated. Calculations have been carried out for a surface uniformly covered with ^{218}Po and ^{214}Po, with cells at depths such as 22 μm. In addition, we are able to calculate microdosimetric spectra and parameters for uniformly distributed alpha sources in an organ.

10. New standard field for testing radiation protection instruments. Calculations of neutron fluence spectra in spherical cavities with various materials and neutron sources have begun as a first step in

generating a calibration spectrum which is close to that observed in maintenance areas of nuclear power plants. We are seeking a spectrum which minimizes the dose-equivalent for neutrons above about 500 keV. Our present Cf and moderated Cf sources give 75 percent and 50 percent above 500 keV, respectively. This provides encouragement that use of the moderated Cf source in a cavity with some combination of Fe and CH_2 will give an acceptably low component of dose equivalent response above 500 keV.

NUCLEAR INTERACTION MEASUREMENTS (A. Wasson, R. Schrack, R. Johnson, K. Duvall, & A. Carlson)

Jointly supported by DoE and NIST, this project pursues on a long term basis accurate measurement and evaluation of standard neutron cross sections for nuclear technology. The major experimental work including detector development is carried out at neutron time-of-flight facilities associated with electron linacs at NIST and elsewhere, and at the NIST 3 MV positive-ion accelerator. This project coordinates all standard cross section evaluation efforts in the U.S.

1. U-235(n,f) fission cross section from thermal to 1 keV. The measurements of the neutron induced fission cross section for ^{235}U from .02 to 1000 electron volts using the NIST electron LINAC facility have been completed. This cross section, especially the integrals from 7.8-to 11-eV and from 100 to 1000-eV, is widely used as a standard to normalize shape experiments. The present relative measurements were normalized at the thermal neutron energy region. The cross sections agree within 3 percent with other recent measurements and show an important deviation from the ENDF/B-V evaluation.

2. The standards evaluation for ENDF/B-VI. The standard cross sections to be used in the ENDF/B-VI evaluations are now available. These standards, accepted by the Cross Section Evaluators Working Group in May 1988, are the result of evaluations performed in a more thorough and consistent manner than in earlier ENDF/B versions. The primary effort focused on a simultaneous evaluation using generalized least squares, R-matrix evaluations, and a separate procedure for combining the results. This evaluation effort turned out to be more substantial than anticipated. Under consideration are proposals for establishing meaningful uncertainties in these evaluations.

3. Fifty years with nuclear fission, a conference. Preparations for the NIST and American Nuclear Society to co-sponsor a conference to celebrate the golden anniversary of the discovery of nuclear fission from April 26-28, 1989 are progressing smoothly. General topics for the conference have been selected by the program committee and approved by the American Nuclear Society. The roster of invited speakers is nearly complete, and the call for contributed papers has been issued.

4. U-235 fission cross section from 3-to 30-Mev. In an effort to improve the accuracy of the $^{235}U(n,f)$ cross section, measurements were initiated at the new target 4 facility at the Los Alamos National Laboratory (LANL) 800-MeV proton accelerator two years ago. The fission reaction rate is determined with a fast parallel plate ionization chamber designed at LANL while the neutron fluence is being measured with an annular proton recoil telescope whose properties were studied earlier at NIST. Experimental tests, diagnostic studies, and preliminary cross section determinations have been completed this year.

5. Response of the dual-thin scintillation neutron detector. The Dual Thin Scintillator (DTS) is a unique neutron detector that is being developed for improved neutron fluence and spectrum measurement. Current attention has been directed towards understanding some details of the detector response. A Monte Carlo code has been used to calculate the sum coincidence pulse-height response and detector efficiency in the 1 to 15 MeV energy region. The results indicate that the sum coincidence mode of operation is superior for certain applications.

6. A 2.5-MeV neutron source for fission cross section measurements. A 2.5-MeV neutron source has been established at the 100-kV, 0.5-mA ion accelerator. Neutrons are produced by the D(d,n)He reaction with a yield of about $3x10^6 s^{-1}$. The time-correlated associated particle method (TCAP) is utilized for the neutron fluence determination and for neutron background elimination. A fission chamber containing six UF_4 deposits has been designed for use in the $^{235}U(n,f)$ cross section measurement at 2.5-MeV.

7. Measurement of the He-3(n,p) cross section from 1 eV to 750 keV. The $^3He/Xe$ gas scintillation counter has been used during the past year to measure the $^3He(n,p)^3H$ cross section in the neutron energy region from 1 eV to 750-keV using the NIST linac pulsed neutron source. These first measurements used the $^{10}B(n,\alpha)$ reaction as the reference standard. Although the contribution from neutrons scattered from the thick walls of the counter into the gas is large, it is believed that the cross section can still be measured to within the desired 3 percent uncertainty for this important standard cross section.

8. Bulk material elemental assay with 2.5-MeV neutrons. A new application of 2.5-MeV neutrons to measure the elemental composition of bulk materials has been explored. The new technique uses the timing from associated particles to detect prompt γ rays as signatures of elemental content. The aim of the research is to develop portable nuclear probes for nondestructive identification.

9. Dosimetry for a 6- to 7-MeV photon source. Dosimetry measurements of a nearly monoenergetic 6- to 7-MeV photon source developed at NIST for radiation protection instrument calibration has been carried out by means of NaI scintillation spectrometry. Spectrum-unfolding results indicate a

total air contribution of approximately 12 percent kerma from a continuous distribution of low-energy photons extending up to 4.5 MeV.

10. Data acquisition systems. The three Datacraft computers used for data acquisition at the linac and the 3-MV positive-ion accelerator for the past 13 years have been replaced. The new system consists of a Charles River Data System UV2403FT computer, MIZAR MZ9400 computer, and AST Research Inc. Premium/286 computer connected by a high speed local area network. The system is operational but will require some additional programming efforts.

RESEARCH AND TECHNOLOGY ASSISTANCE (all group members)

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

1. Benchmark measurement for criticality safety calculations. An interlaboratory program aimed at resolving discrepancies between calculations and measurements in nuclear criticality safety has been undertaken with DoE sponsorship and NIST leadership. NIST will make measurements of fission detector responses in the leakage spectra from spherical aqueous moderators driven by ^{252}Cf neutron sources while LANL and ORNL will make detailed calculations of these systems. Associated calculations at NIST so far have included reaction rates for ^{239}Pu, ^{235}U, ^{238}U, and ^{237}Np at four distances from a bare Cf source and from a source at the center of 4-inch and 6-inch diameter spheres of water. These benchmark measurements and calculations will help assure the validity in the future of calculations that establish safe configurations of nuclear materials during processing and storage.

2. Neutron lifetime measurement. In collaboration with scientists of the Quantum Metrology Division, the University of Sussex, and the Central Bureau for Nuclear Measurements, an ambitious experimental program has been undertaken to improve previous measurements of the free neutron lifetime. The half-life for this most fundamental example of nuclidic disintegration is known to an accuracy of only ± 2.5 percent, while the half-lives of less stable particles such as the pion and the muon are known as much as 1400 times more accurately. The first lifetime data from this collaboration are expected between late August and early December, 1988 from measurements at the Institut Laue-Langevin cold neutron guidehall in Grenoble, France. The experiment will next move to the new cold neutron guidehall at NIST for more exhaustive measurements. The group so far has carried out the absolute efficiency calibration of the ^{10}B neutron density monitor and will improve this calibration by means of a total

absorption detector and an alpha-gamma coincidence calibration scheme. Group personnel also have participated in the Grenoble measurements.

3. Capture cross section measurement in ISNF. Spectrum-averaged cross sections for six reactions of interest in reactor physics have been measured in the Intermediate Energy Standard Neutron Field (ISNF). The ISNF neutron energy spectrum resembles a fast reactor spectrum, but with much less complexity. The ISNF neutron fluence is determined by fluence transfer from a calibrated ^{252}Cf fission source. The following spectrum-averaged cross sections were reported this year: $^{23}Na(n,\gamma) = 1.57 \pm .10$ mb, $^{45}Sc(n,\gamma) = 24.4 \pm 0.8$ mb, $^{59}Co(n,\gamma) = 36.3 \pm 1.5$ mb, $^{109}Ag(n,\gamma) = 23.8 \pm 0.9$ mb, $^{115}In(n,n') = 97.0 \pm 2.5$ mb, and $^{197}Au(n,\gamma) = 11$ mb.

4. Fission chamber monitors at AFRRI. Neutron dosimetry at the Armed Forces Radiobiological Research Institute's reactor exposure room was put on a more stable basis by the installation and testing of two fission chamber monitors. The AFRRI staff has learned to operate these monitors confidently and have found them useful in resolving conflicting readings among other dosimetry systems. Linearity tests of reactor instrumentation, vs. NIST absolute fission chambers and tissue-equivalent ionization chambers were carried out over the full range of reactor power for the three most commonly used irradiation configurations.

5. Neutron spectrum characterizations for AFRRI. At the request of the Armed Forces Radiobiology Research Institute (AFRRI), a spectrum directory has been compiled that summarized calculated and experimental neutron spectra and energy-deposition distributions ("y-spectra") for AFRRI exposure fields. In addition, we have advised them on the adequacy of information on neutron and gamma-ray kerma in other fields for which animal exposures have indicated an anomalously high relative biological effectiveness.

6. Neutron penetration in slabs. In order to help the U. S. Navy estimate shielding requirements for personnel on submarines carrying nuclear missiles, Monte Carlo calculations of neutron transmission through slabs of iron have been performed. These calculations demonstrate that the neutron penetration is insensitive to the position of a slab between a localized source and detector. A scaling parameter was found that relates the relative contribution to the lateral dimensions of the slab.

7. Reactor beam calibrations. Absolute fission chambers and fissionable isotope mass standards were employed to determine absolute neutron fluence rates and improvement in the "capture flux" resulting from installation of the Cold Source at the NIST Research Reactor. These results influenced plans for further upgrading of the Cold Source.

8. Public knowledge and radiation emergencies. The NCRP Committee on Radiation Exposure in a Nuclear Emergency created a task group last

year to develop guidelines for improving public knowledge about radiation exposure in order to enhance public response during a major radiation emergency. The NIST representative on this task group prepared material for the final report that identifies and briefly evaluates the pathways by which the public receives information and forms a point regarding the hazard of nuclear radiation before and during such an emergency. The breadth of representation on this task group has also led to consideration of a possible Radiation Index for the general public similar in concept and application to the Air Quality Index developed by EPA. The effort is to develop a compass and envelope of purpose for the index that will be acceptable to various levels of radiation protection authorities and endorsable by responsible federal agencies. This is a large order.

9. Mass assay of ultra-light fissionable deposits. Westinghouse Research Center, Pittsburgh is working cooperatively with NIST to establish mass scales for ultra-light fissionable deposits. These deposits, with masses in the picogram or sub-picogram range, are used with mica Solid Track Recorders (SSTR's) and represent a significant new dosimetry measurement technique. Currently achieved accuracy is better than five percent; The goal is three percent or better.

10. Paired uranium detectors (PUDs). In 1984, PUDs were provided to Westinghouse Nuclear Technology Systems Division as backup dosimetry for ultra-lightweight SSTR neutron dosimeters (see, item 9 above). These dosimeters have been recovered and analyzed after an 18-month exposure in the Diablo Canyon power reactor. The results show a presently unexplained 15 percent discrepancy between the PUDs and SSTRs. NIST will now re-irradiate several of the PUD/SSTR pairs in a carefully controlled experiment in the NIST ^{235}U standard neutron field in an attempt to resolve the discrepancy.

11. LiF chip development and application. A lithium fluoride crystal dosimeter package was returned to NIST after irradiation through a full fuel cycle in the cavity surrounding the reactor vessel at the Oconee 2 nuclear power plant. The sample retained virtually perfect optical quality, despite the heat and humidity of the environment. The gamma dose recorded was comfortably within the accurately readable range. This gamma dose data will be employed by the operating utility to confirm calculations of gamma and neutron dose as they affect the reactor vessel embrittlement and safe operating lifetime.

12. Rhodium dosimetry detector. Rhodium is an attractive neutron fluence monitor because of the close correspondence of its neutron response to the kerma muscle response function. In support of its use as a neutron monitor, the spectrum averaged cross section has been measured at the NIST Cf Fission Neutron Irradiation Facility. The results of five separate irradiations yielded a cross section value of 768 ± 23 millibarns. This

measured result disagrees with the calculated value by nearly 10 percent. A paper for Nuclear Science & Engineering has been accepted for publication.

IRRADIATION AND CALIBRATION FACILITIES (E. D. McGarry, J. Grundl, C. Eisenhauer, & E. Boswell)

Well-characterized neutron fields are built and maintained as permanent irradiation facilities providing certified fluences of pure fission neutrons, sub-MeV distributions, monoenergetic keV beams, and thermal neutrons. Passive and active detectors of all kinds are exposed in these neutron fields for response calibrations, for cross section measurements, and for the investigation of new measurement techniques. A high intensity, neutron-driven gamma field operates for special purpose measurements.

A multi-purpose fission rate measurement capability is centered around the NIST "go anywhere" double fission chambers and the NIST set of fissionable isotope mass standards (FIMS). The Manganous Sulfate Bath is the primary neutron source strength calibration facility for the U. S. Absolute neutron fluences for all fission-neutron-driven standard neutron fields at NIST are derived from source strength calibrations at this facility.

1. Neutron source emission rate calibrations. NIST continues to provide neutron source-strength calibrations at a quoted absolute accuracy level of nominally 1.5 percent. For sources of strengths less than 1 x 10^9 n/s, international intercomparisons have validated this claim. The latest such comparison was published in Metrologia in 1988. For sources of larger strength, a "limited participation" comparison was accomplished this fiscal year with National Physical Laboratory in Great Britain. Final results will be reported in FY 89.

2. Cavity fission source operations. Efforts to improve cavity fission source operations and calibration base documentation are continuing. A new general purpose shield cave for high and intermediate level radioactive components has been designed and shop work on the shield walls has begun. When complete, this shield cave will greatly simplify irradiation operations at the reactor thermal column. New documentation describing the complicated path by which absolute fission neutron fluence rates are established are in final draft stage.

3. Scattering corrections in the cavity fission source. Corrections for neutron scattering in the hardware and irradiation samples of the cavity fission source are under review. Existing corrections are based on Monte Carlo calculations made by LANL for an earlier configuration of the cavity fission source with a different Cd box and Al enclosure. Furthermore, recent calibrations of solid state track recorders (SSTR's) involve a significantly different irradiation sample assembly. Recalculation of neutron scattering with the MCNP Monte Carlo code has yielded corrections

for scattering in SSTR's that differ from the one calculated by LANL. We, therefore, recalculated scattering corrections with the MCNP Monte Carlo code. Corrections for scattering for SSTR's vary from - .006 for the Ni reaction to + .018 for ^{235}U fissionable deposits.

4. $MNSO_4$ bath facility upgrade. Upgrade of the $MnSO_4$ facility continues. Current efforts aim at better gain stabilization of the system at high counting rates by replacing one of the sodium iodide crystals with a germanium-lithium (GeLi) detector. The GeLi detector has been purchased and checked out and is in the process of being installed. Temporarily, the system will have three rather than two sensors until sufficient experience with the new detector has been acquired. The current system is capable, with extensive monitoring of electronic gain shifts, of long-term reproducibility with a systematic uncertainty level of 0.35 percent (1σ). The upgraded system should do as well but with considerably less effort.

5. Thermal neutron density standard. This NIST calibration service was discontinued in FY 88 because it has been under utilized and because the same calibrations can be better accomplished at the thermal column of the NIST reactor.

IV. Radioactivity Group

Introduction

During the past year the Group has accommodated several perturbations of staff and facilities while attempting (1) to maintain interactions with diverse U.S. radioactivity-measurement communities, (2) demonstrate Group competence internationally and assist in the convergence of the standards of all nations for all pertinent radionuclides, (3) develop improved measurement techniques and create national standards for newly significant radionuclides, and (4) issue unique Standard Reference Materials (SRMs). Selected examples are described briefly in the following sections.

Propagation of National Radioactivity Standards (J. M. Calhoun, L. L. Lucas, and remainder of Group)

For over a decade the concept of demonstrated traceability for radioactivity measurements, in the sense of measurers presenting their values for sources before the official values are revealed, has been accepted by the U.S. regulatory agencies concerned, and most other organizations, as an important element of quality assurance programs.

This demonstration requires that a national standard exists for the radionuclide in question and that some mechanism exists for making a comparison, directly or indirectly, with it.

Although in principle it is not required that a source shown to be related to a national standard has been used to calibrate the measurer's instrument, it is in practice usually desired. This implies that suitable NIST Standard Reference Materials (SRMS) or equivalents from other suppliers should be available. Towards this goal, the following actions took place between August 1, 1987 and July 31, 1988:

Total radioactivity SRMs distributed	747
Short-lived SRMs supplied under the USCEA program for nuclear medicine	232
Scheduled calibrations	21
Special measurements	19
Traceability tests for FDA, NRC, and commercial firms	233

While the total number of SRMs has not declined appreciably this year, a revised mode of operation requires that future productions concentrate on reference materials which are unique to NIST and for which there is at least moderate demand. Scheduled calibrations provide a way of certifying existing alpha sources or short-lived radionuclides not available as SRMs; special measurements offer even greater flexibility in terms of activity level, impurities, or source configuration, and this is reflected in their cost.

The programs with the U.S. Council for Energy Awareness (USCEA), carried out with the assistance of two very able research associates, have grown in significance. The stable program for nuclear medicine offers a self-supporting mechanism for supplying radionuclides judged significant by the major radiopharmaceutical companies to the entire medical community. The increasingly ambitious testing program for nuclear power now has 14 participants from that industry, in addition to a major measurement service organization and the three companies supplying most of the commercial calibration sources. Test samples this year, which accounted for much of the marked increase in traceability exercises, included realistic gas samples and uniformly spiked air filters.

The long-standing testing programs with the quality control laboratories of the Nuclear Regulatory Commission (NRC) and the Food and Drug Administration continued effectively, and plans have been made to reactivate the lapsed program with the Environmental Protection Agency.

^{228}Ra Standardization (D. D. Hoppes & L. L. Lucas)

In experiments spanning five years previous discrepancies between two activity-measurement methods for ^{228}Ra have been resolved and SRMs prepared. These reference materials are important for accurate monitoring of natural environmental radioactivity, for in some regions of the U.S. ^{228}Ra from the thorium decay series is more significant than ^{226}Ra from the uranium series.

Activity measurements of 5.75-year half-life ^{228}Ra are difficult because of the low beta-particle energies (average of about 10 keV) and the high-energy contribution from daughter 6.13-h ^{228}Ac and subsequent progeny. Rapid and simple chemical separations are complicated by the presence of 3.6-da ^{224}Ra later in the chain.

Moreover, if one attempts to separate the ^{228}Ac, measure its activity with high-efficiency liquid scintillators and its gamma-ray emission rates with germanium spectrometers, and then compare gamma-ray rates for an equilibrium ^{228}Ra - ^{228}Ac source, there are two problems. Completely clear separations are difficult and confusion can arise in interpreting the liquid-scintillation measurements. As always, some fraction of the lower-energy portion of the spectrum is masked by system noise. Usually some estimate of counts lost in this region is added, or an extrapolation to zero energy is made. In the ^{228}Ac decay almost every beta decay is followed by conversion electrons or Auger electrons that add 50 keV or more to the equivalent beta-particle pulse. If this shift in the energy-pulse-height intercept is not appreciated in the extrapolation through the region masked by noise, an error of several percent can occur.

In 1983, ^{228}Ra was extracted from 25-year-old purified thorium oxide and repeatedly separated over a period of four months until the relative activity of any progeny was 0.1 percent or less. Liquid scintillation counting was used for early measurements, but the definitive calibration came from gamma-ray measurements of progeny in growth over five years with an efficiency-calibrated spectrometry system. The gamma-ray probabilities per decay used were those measured at the Physikalisch-Technische Bundesanstalt, FR, using comparable spectrometry systems viewing known masses of the (1.405×10^{10})-year ^{232}Th parent in equilibrium with ^{228}Ra.

Quantitative samples of calibrated solution, with an overall uncertainty of less than 3 percent, have been prepared as SRM 4339 and will be available for distribution shortly.

Development of the NIST ^{10}Be/^{9}Be Isotopic SRM (K. G. W. Inn, B. M. Coursey, & J. D. Fassett)

NIST, in conjunction with the Oak Ridge National Laboratory and the Accelerator Mass Spectrometry Community, is in the process of developing

a beryllium isotopic SRM. The SRM is being developed to serve the Accelerator Mass Spectrometry community as a reference for geochronological studies being done in laboratories around the world. The final $^{10}Be/^{9}Be$ isotopic composition is approximately 3×10^{-11}. The material will be released when differences between NIST and ORNL mass spectrometric measurements are satisfactorily resolved.

Isotopic-Fractionation-Free Method for the Mass Analysis of Beryllium Isotopes (K. G. W. Inn & J. D. Fassett)

NIST has developed a method which results in an isotopic-fractionation-free method of determining the $^{9}Be/^{10}Be$ isotopic composition. In the absence of reliable standards and because beryllium has only one stable isotope, the quantitative determination of beryllium isotopic composition was not previously considered possible. The method developed utilized a combination of isotope dilution mass spectrometry for the isotopic information, and inductively coupled plasma atomic emission for the total beryllium content. The algebraic manipulation of the data results in an analysis which is independent of isotopic fractionation effects.

International Laboratory Intercomparison of Actinides in Human Tissue (K. G. W. Inn & W. S. Liggett, Jr.)

An intercomparison exercise for $^{239}Pu + ^{240}Pu$ in SRM 4351 (Human Lung) and 4352 (Human Liver) included scientists from the United Kingdom, United States, and Japan. The conclusions of the study were: 1) there were no significant performance differences among the participants, 2) the data generated during the exercise was consistent with the data used to certify the SRMs, and 3) combining the previous and new data sets resulted in significant improvements in the precision and accuracy of the certified values.

Methods Development for Radiochemical Analyses in Powdered Milk (K. G. W. Inn & T. Gills)

Since the Chernobyl incident there has been increased interest in the content of radioactivity in foodstuffs. To address the quality assurance needs within the U.S. and around the world, NIST will begin to develop radioactivity-in-foodstuffs SRMs in the near future. In preparation for the certification analyses, the Office of Standard Reference Materials supported the development of radiochemical methods for actinides and gamma-ray emitters. The most important feature of the procedures is the complete and quantitative combustion of the samples by dry ashing, wet ashing with combination of strong acids, and final ashing in teflon jars with microwaves.

Gamma-ray Measurements of Natural-Matrix Ocean Sediment (K. G. W. Inn & F. J. Schima)

NIST is in the process of preparing an ocean sediment as an environmental-level radioactivity natural-matrix SRM to address the oceanographic community's quality assurance needs. Bottles of the prepared sediment have been measured for photon-emitting radionuclides, with a total counting time of 24 weeks. The data is being critically evaluated for interferences and background effects and will be the first NIST efforts to determine ^{210}Pb and ^{241}Am by non-destructive photon spectroscopy.

Large Area X-Ray Source Measurements (J. M. R. Hutchinson, P. A. Hodge, & M. P. Unterweger)

Measurements were made with large-area ^{238}Pu sources to characterize the response of the x-ray measuring and calibration system. Measurements were made with a rectangular source 5-in x 8-in and a circular source 3-in in diameter. The activity of the sources were determined by means of $2\pi\alpha$ particle counting and then x-ray counting efficiencies were determined for source-to-detector distances from roughly 2cm to 35cm. A curve was fitted through the efficiency points for each type source, based on a modification of the analytic expression for a point source. Agreement between fitted and experimental points was within one percent in all cases.

Radon Intercomparison of Basic Calibration Laboratories in the U.S. (J. M. R. Hutchinson & R. Collé)

Reports of discrepancies in the basic calibrations of radon in major radon quality-control laboratories prompted NIST to initiate an intercomparison with four radon-measurement laboratories. A special ampoule was designed which could be inserted into a 5-in NaI(Tl) well detector and the response relative to other ampoules determined. Ampoules were filled, intercompared in the NaI(Tl) detector, and assayed by the four laboratories and NIST. Results agreed for four of the five laboratories to approximately two percent, but the value of one laboratory differed from the mean value by seven percent.

Isotopic Fractionation Anomalies in Resonance Ionization Spectrometry Observed in Molybdenum and Tin (J. M. R. Hutchinson & W. F. Fairbank, Jr.)

Studies aimed at determining the validity of the isotope dilution procedure in resonance ionization spectrometry (RIS) resulted in the observation of anomalous isotopic ratios in samples of metallic molybdenum and tin. Since the actual ratio was known, the result was puzzling at first and brought into question the accuracy of RIS to measure isotopic ratios. The effect appears to be at least partially due to the selective ionization of odd isotopes in the laser steps when the transition is

unsaturated. Both theoretical and experimental work aimed at resolving this problem are being pursued.

International Comparison of ^{125}I Activity Measurements (D. D. Hoppes)

The ability of laboratories in about 20 countries to produce equivalent national activity standards of ^{125}I was tested in a 1988 comparison organized under the auspices of the Bureau International des Poids et Mésures (BIPM). This radionuclide is important for nuclear medicine, but has photon radiations too low in energy for reliable comparison of national calibrations with the ionization chambers of the present International Reference System (SIR) at BIPM.

Aliquots of known mass were prepared at the Országos Mérésügyi Hivatal, Hungary, from material supplied by NIST, and ampoules containing these samples were distributed to participants by the Laboratoire de Métrologie des Rayonnements Ionisants, France. Measurements at each participating laboratory were performed on about June 15 in order to minimize comparison errors due to present uncertainties in the half life.

The technique used at NIST was sum-peak counting, in which a peak due to two cascade radiations detected simultaneously is compared with the peak due to each detected singly in order to calculate the counting efficiency.

A visiting scientist from the Studiecentrum Voor Kernenergie, Belgium, used a high-efficiency NaI(Tl) well detector for the measurement, and prepared a detailed report comparing calculated and measured efficiencies. Daniel Golas and Donald Gray, research associates from the U. S. Council for Energy Awareness, measured sources with the same two-thin-crystal system used annually for the calibration of SRMs.

The two NIST results differed by 0.49 percent, slightly more than the combined uncertainty (approximating one standard deviation) of either measurement. Data from other countries, including measurements by at least three other methods, are now being evaluated at BIPM.

Reliability of Radioactivity Calibration Sources (D. D. Hoppes, J. M. R. Hutchinson, & F. J. Schima)

Ideally, a radioactivity source or solution obtained from a commercial supplier or any other nation's standardizing laboratory should give an instrument efficiency calibration equivalent to material from NIST, with a possible error consistent with the uncertainty assessed by the producer. Three Group actions have addressed this point.

For several years, the SIR at BIPM has served as a comparative repository for many national standards of gamma-ray-emitting radionuclides.

INVITED TALKS

Division 536, Ionizing Radiation

Berger, M. J., "Multiple Scattering Angular Deflections and Energy-Loss Straggling in Electron Transport Calculations," 8th Course: Monte Carlo Transport of Electrons and Photons Below 50 MeV," International School of Radiation Damage and Protection, Ettore Majorana Centre for Scientific Culture, Erice, Sicily, Italy, September 24-October 3, 1987.

Berger, M. J., "Electron Stopping Powers for Transport Calculations," 8th Course: Monte Carlo Transport of Electrons and Photons Below 50 MeV," International School of Radiation Damage and Protection, Ettore Majorana Centre for Scientific Culture, Erice, Sicily, Italy, September 24-October 3, 1987.

Berger, M. J., "Cross Sections for Bremsstrahlung Production and Electron-Impact Ionization," 8th Course: Monte Carlo Transport of Electrons and Photons Below 50 MeV, International School of Radiation Damage and Protection, Ettore Majorana Centre for Scientific Culture, Erice, Sicily, Italy, September 24-October 3, 1987.

Bergtold, D. S., "Urinary Biomarkers of DNA Damage and Repair," University of Pennsylvania, Fox Chase Cancer Center, Philadelphia, PA, June 16, 1988.

Bergtold, D. S., "Free-Radical-and Radiation-induced Damage to DNA"; "Measurements of Biomarkers for DNA Damage and Repair," Exclusive International Symposium (only 30 top experts invited), Max Planck Institute, Mulheim, West Germany, September 25, 1988.

Calhoun, J. M., "Radioactivity and Its Uses," Office for Special Services and State Affairs, District of Columbia Public Schools, Washington, DC, April 30, 1988.

Carlson, Allan D., "Thermal Constants and Recommended Average Values," Meeting at Oak Ridge National Laboratory on Constraints on the ^{235}U Resonance Prescription, Oak Ridge, TN, February 24-25, 1988.

Carlson, Allan D., "Status of the ENDF/VI Standards," Cross Section Evaluators Working Group (CSEWG), Brookhaven National Laboratory, NY, May 10, 1988.

Caswell, Randall S., "Basic Data Necessary for Neutron Dosimetry," Sixth Symposium on Neutron Dosimetry, Munich, West Germany, October 13, 1988.

Collé, R. "Measurement Uncertainties in the Past, Present, and Future," 1988 NCSL Annual Meeting, Washington, DC, August 15, 1988.

Division 536, Invited Talks (cont'd.)

Coyne, J., "Applications of Nuclear Physics to Radiation Dosimetry and Neutron Radiation Biology," 8th International Summer School on Nuclear Physics Neutron Physics, and Nuclear Energy, Varna, Bulgaria, October 19-27, 1987.

Domen, S. R., "The Role of Water Parity, Convection, and Heat Conduction in a New Calorimeter Design," National Research Council, Ottawa, Canada, June 6-7, 1988.

Ehrlich, M., "Evaluating the Indication of Currently Available Personnel and Environmental Dosimeters in Terms of Directional Dose Equivalent," Seminar on "Implementation of Dose-Equivalent Operational Quantities into Radiation Protection Practice," Physikalisch-Technische Bundesanstalt, Braunschweig, West Germany, June 7-9, 1988.

Eisenhauer, C. M., and Schwartz, R. B., "Review of Scattering Corrections for Calibration of Neutron Instruments," American Nuclear Society, Los Angeles, CA, November 18, 1987.

Eisenhower, E. H., "The Status of National Measurement Quality Assurance Programs," School of Public Health, Harvard University, Boston, MA, May 13, 1988.

Eisenhower, E. H., "National Measurement Quality Assurance Programs," Health Physics Society Continuing Education Course, Boston, MA, July 5, 1988.

Eisenhower, E. H., "The National Quality Assurance Program for Personnel Radiation Dosimetry: A Case History," Workshop and Symposium of the National Conference of Standards Laboratories, Washington, DC, August 16, 1988.

Hutchinson, J. M. R. (with K. G.W. Inn, and S. J. Bright), "Low-level Radioactivity Standards at the National Bureau of Standards," First International Summer School, La Rabida, Huelva, Spain, September 28-October 9, 1987.

Hutchinson, J. M. R. (with R. Collé), "Radon Measurements and Calibration Standards," First International Summer School, La Rabida, Huelva, Spain, September 28-October 9, 1987.

Hutchinson, J. M. R. (with W. F. Fairbank, Jr., K. G.W. Inn, J. E. Parks, M. T. Spaar, and J. C. Huneke), "Workshop on Advanced Laser Technology for Chemical Measurement," National Institute of Standards and Technology, November 4-6, 1987.

Division 536, Invited Talks (cont'd.)

Hutchinson, J. M. R., "Traceability of Alpha-Particle and X-Ray Measurement," Conference to draft "Criterion for the Operation of Secondary Calibration Laboratories for Health Physics Instrumentation," National Institute of Standards and Technology, February 9-11, 1988.

Hutchinson, J. M. R., "Direct Analysis of Radioactivity in Solids," Department of Chemistry, University of Maryland, College Park, MD, April 1, 1988.

Hutchinson, J. M. R. (with W. F. Fairbank, Jr., J. E. Parks, M. J. Spaar, and John C. Huneke), "Investigation of Systematic Effects in SIRIS: Matrix Effects and Anomalous Isotopic Ratios," Resonance Ionization Spectroscopy and Its Applications, National Institute of Standards and Technology, April 10-15, 1988.

Inn, Kenneth G. W., "Closed-vessel-microwave Dissolution," 334th Annual Conference on Bioassay, Analytical and Environmental Radiochemistry, Berkeley, CA, October 4-9, 1987.

Inn, Kenneth G. W., "Quality Assurance Check list for Radiochemistry laboratories," American Chemical Society Southwest Regional Meeting, Little Rock, AR, December 1-4, 1987.

Inn, Kenneth G. W., "Interlaboratory Comparison of Actinides in Human Tissues," Second International Conference on Low-Level Measurements of Actinides and Long-Lived Radionuclides in Biological and Environmental Samples, Akita, Japan, May 17, 1988.

Loevinger, R., "The Role of the Water Calorimeter in High-Energy Medical Radiation Dosimetry," Workshop on Water Calorimetry, National Research Council, Ottawa, Canada, June 6, 1988.

McGarry, E. D., "Californium-252 Sources Used for Standard Neutron Fields at NBS," ^{252}Cf Workshop, sponsored by Oak Ridge National Laboratory, Garden Plaza Hotel, Oak Ridge, TN, April 13-14, 1988.

McLaughlin, W. L., "Dosimetry for Industrial Radiation," Winter Meeting of American Nuclear Society, on receiving ANS Radiation Science and Technology Award, Westin Bonaventure Hotel, Los Angeles, CA, November 16, 1987.

McLaughlin, W. L., "Role of Dosimetry in Quality Assurance," Engineering Foundation Conference on Advancing Food Technology With the Irradiation Process, Sheraton Hotel, Santa Barbara, CA, November 20, 1987.

McLaughlin, W. L., "Quality Control in Industrial Radiation Processing," Office of Atomic Energy for Peace of Thailand Colloquium, Bangkok, Thailand, March 11, 1988.

Division 536, Invited Talks (cont'd.)

McLaughlin, W. L., "Dosimetry in Agricultural Applications of Ionizing Radiation," Thailand Department of Agriculture Seminar, Chaing-Mai, Thailand, March 18, 1988.

McLaughlin, W. L., "Sterility Control in Medical Supplies Sterilized by Ionizing Radiation," Thailand Food and Drug Agency Seminar, Bangkok, Thailand, March 25, 1988.

McLaughlin, W. L., "Development of Radiochromic Personnel Dosimeter," Federal Emergency Management Agency Test Facility, Berryville, VA, August 30, 1988.

McLaughlin, W. L., "NBS Developments for Quality Control in Food Irradiation by Means of Dosimetry, Calibration and Testing are Described," Department of Energy Meeting on Food Irradiation Technology, Forrestal Building, Department of Energy, Washington, DC, September 7, 1988.

Seltzer, S. M., "Cross Sections for Bremsstrahlung Production and for Electron-Impact Ionization," 8th Course: Monte Carlo Transport of Electrons and Photons Below 50 MeV, International School of Radiation Damage and Protection, Ettore Majorana Centre for Scientific Culture, Erice, Sicily, Italy, September 24-October 3, 1987.

Seltzer, S. M., "An Overview of ETRAN Monte Carlo Methods for Coupled Electron/Photon Transport Calculations," 8th Course: Monte Carlo Transport of Electrons and Photons Below 50 MeV, International School of Radiation Damage and Protection, Ettore Majorana Centre for Scientific Culture, Erice, Sicily (Italy) September 24-October 3, 1987.

Seltzer, S. M., " Applications of ETRAN Monte Carlo Codes to Some Radiation-Transport Problems," 8th Course: Monte Carlo Transport of Electrons and Photons Below 50 MeV, International School of Radiation Damage and Protection, Ettore Majorana Centre for Scientific Culture, Erice, Sicily, Italy, September 24-October 3, 1987.

Seltzer, S. M., "Bremsstrahlung Production by Electrons: Cross Sections and Electron-Photon Transport Calculations," Conference on High Energy Radiation Background in Space, Sanibel Island, FL, November 3-5, 1987.

Simic, M. G., "Exactly What Radiation Does to Food Molecules," Advances in Food Technology Engineering Foundation Conferences, Santa Barbara, California, November 15-20, 1987.

Simic, M. G., "Electron and Charge-transfer Processes in Macromolecules," Gordon Conference-Radiation and Macromolecules, Oxnard, CA, March 7-11, 1988.

Division 536, Invited Talks (cont'd.)

Simic, M. G., "Mechanisms of Free Radical Chemistry and Biochemistry of Benzene," International Symposium on Benzene Metabolism, Toxicity and Carcinogenesis, Chapel Hill, NC, March 14-16, 1988.

Simic, M. G., "Superoxide Radical Elimination From Peroxyls," Fast Excitation Processes Conference, Tokyo, Japan, March 22-25, 1988.

Simic, M. G., "Kinetics and Mechanisms of Physiological Antioxidants," Medical, Biochemical, and Chemical Aspects of Free Radicals Conference, Kyoto, Japan, April 9-13, 1988.

Simic, M. G., "Mechanisms of Oxygen Radical Reactions in Biosystems FASEB," Las Vegas, NV, May 1-5, 1988.

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

Sparrow, Julian H., "High Energy NDT Work at NBS," D5 Propulsion, NDT Program Review, Lockheed Missile and Space Co.,, Sunnyvale, CA, April 20, 1988.

Wasson, Oren A., "Neutron Facilities at NBS," Institute of Atomic Energy, Beijing, People's Republic of China, June 6, 1988.

Wasson, Oren A., "Neutron Standard Cross Section Measurements at NBS," Institute of Atomic Energy, Beijing, People's Republic of China, June 7, 1988.

Wasson, Oren A., "Neutron Reaction Studies at NBS," Beijing University, Beijing, People's Republic of China, June 8, 1988.

Wasson, Oren A., "Neutron Detector Development," Research Institute of Xian Petroleum Exploration Instrument Complex, Xian, People's Republic of China, June 14, 1988.

Wasson, Oren, A., "Neutron and Gamma-ray Measurement Methods," Chinese National Analytical Center, Guangzhou, People's Republic of China, June 14, 1988.

Wasson, Oren A., "Studies of the Effect of the Properties of Neutron-Producing Targets on Neutron Cross Section Measurements, IAEA/International Nuclear Target Development Society Conference, Gessellschaft fςr Schwerionen Forschung, Darmstadt, West Germany, September 6, 1988.

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Seltzer, S. M., Cross Sections for Bremsstrahlung Production and for Electron Impact Ionization, Monte Carlo Calculations of Electron and Photon Transport, eds. T. A. Jenkins, W. R. Nelson and A. Rindi, Plenum, NY (in press).

Seltzer, S. M., Bremsstrahlung Production by Electrons: Cross Sections and Electron-photon Transport Calculations, Proc. of the Conference on High Energy Radiation Background in Space, Sanibel Island, FL, Nov. 3-5, 1987, AIP Conf. Proceedings (in press).

Simic, M. G., Al-Sheikhly, M., and Jovanovic, S. V., Inhibition of Free Radical Processes by Antioxidants--Tryptophan and 5-Hydroxy-Tryptophan, Eds. H. R. Mueller, J. C. Somogyi, Karger Press (in press).

Simic, M. G., Mechanisms of Inhibition of Free Radical Processes in Mutagenesis and Carcinogenesis, Mutation Res. (in press).

Williams, J., Cogburn, C., Hodgson, L., Apple, S., McGarry, E. D., Lamaze, G., Gilliam, D., Grundl, J., Coursey, F. Schima, Rogers, J. W., Gherke, R., Baker, J. D., and Wheeler, F. J., Measurement of Fission Spectrum Averaged Cross Sections for the $^{93}Nb(n,n')^{93m}Nb$ Reaction, ASTM Special Tech. Pub. 1001 (in press).

Williamson, T. G., and Lamaze, G. P., Photon Excitation of ^{93m}Nb, Proc. of 7th International Conference on Radiation Shielding, Bournemouth, England, September 1988 (in press).

Williamson, T. G., Lamaze, G. P., Gilliam, D. M., and Eisenhauer, C. M., Iron and Cadmium Capture Gamma Ray Photofission Measurements, ANS Topical Conference on Theory and Practices in Radiation Protection and Shielding, Knoxville, TN, April 22-24, 1987 (in press).

Williamson, T. G., Lamaze, G. P., and Gilliam, D. M., Calibration of a Neutron Driven Gamma Ray Source, ASTM Special Tech. Pub. 1001 (in press).

Williamson, T. G., Ayers, T. A., Hammerson, W. L., and Lamaze, G. P., $^{93}Nb(n,n')$ Cross Section Measurement in a Fission Spectrum, ASTM Special Tech. Pub. 1001 (in press).

Yin, Lo I, Trombka, J. I., and Seltzer, S. M., Pattern Recognition Approach in XRF Analysis, Nucl. Instrum. Methods (submitted).

Division 536, Publications in Preparation (cont'd.)

Yin, Lo, Trombka, J. I., and Seltzer, S.M., Possible Use of Pattern Recognitition for the Analysis of Mars-Rover XRF Spectra, submitted to J. of Geophys. Res.

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 NIST (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, NIST, 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 NIST (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.

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

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

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

Member, Commission of the European Communities (CEC) Program Committee, Sixth Symposium on Neutron Dosimetry.

Member, CEC Program Committee, Seminar on Implementation of Dose-Equivalent Operational Quantities into Radiation Protection Practice.

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 Clinical Dosimetry for Neutrons (Physics).

Division 536, Technical and Professional Committee Participation and Leadership (cont'd.)

Ronald Collé

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.

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

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 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 in Research and Industry.

Member, Editorial Board, Industrial Metrology.

Charles M. Eisenhauer

Member, CIRRPC Science Panel; Chairman, Subpanel on Predisaster Planning.

Division 536, Technical and Professional Committee Participation and Leadership (cont'd.)

Charles M. Eisenhauer (cont'd.)

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

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

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.

Alternate 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.

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.

Member, Operations Group for the Accreditation of Instrument Calibratior Laboratories, Health Physics Society.

Member, CIRRPC Ad Hoc Working Group on Transuranics in the Environment (Identification of issues related to guidance).

Division 536, Technical and Professional Committee Participation and Leadership (cont'd.)

James A. Grundl

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

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

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

Member, International Committee of Weights and Measures (CIPM), 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.

Division 536, Technical and Professional Committee Participation and Leadership (cont'd.)

John H. Hubbell (cont'd.)

Members, ANS Isotopes and Radiation Division Industrial Radiation Measurement Applications Committee; Organizer and Chairman of sponsored session: "Atomic and Radiation Data and Applications", for November 15-19, 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 5-8, 1988. Also chaired a session.

Executive Councilor, International Radiation Physics Society; Member Nominating Committee for 1988 elections. Also member, International Advisory Board for the 4th International Symposium on Radiation Physics, Sao Paulo, Brazil, October 3-7, 1988. Also chaired a session.

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

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

Jimmy C. Humphreys

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

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

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

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

J. M. Robin Hutchinson

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

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

Division 536, Technical and Professional Committee Participation and Leadership (cont'd.)

J. M. Robin Hutchinson (cont'd.)

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

Kenneth G. W. Inn

Member, ANSI N42.02, Quality Assurance for Radioassay of Environmental Samples.

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

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

George P. Lamaze

Secretary, ASTM Committee E10, Nuclear Radiation Metrology.

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.

Consultant, American Association of Physicists in Medicine (AAPM) Radiation Therapy Committee.

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

Wilfrid B. Mann

Consultant, ICRU.

Division 536, Technical and Professional Committee Participation and Leadership (cont'd.)

Wilfrid B. Mann (cont'd.)

Member, ANSI-INMM Working Group INMM 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 8th ASTM-EURATOM Symposium on Reactor Dosimetry.

William L. McLaughlin

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

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

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

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

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

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

Science and Technology Consultant, CIRRPC.

Division 536, Technical and Professional Committee Participation and Leadership (cont'd.)

William L. McLaughlin (cont'd.)

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

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

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

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

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

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

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.

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.

Division 536, Technical and Professional Committee Participation and Leadership (cont'd.)

Robert B. Schwartz (cont'd.)

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

Michael G. Simic

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

Secretary General of the Oxygen Society.

Member of the Advisory Board Critical Reviews of Sulfhydryl Chemistry.

Christopher G. Soares

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

Michael P. Unterwerger

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

Oren A. Wasson

Member, Department of Energy Nuclear Data Committee.

Executive Chairman, for conference entitled "Fifty Years with Nuclear Fission" to be held at the NIST (April, 1989).

MAJOR CONSULTING AND ADVISORY SERVICES

Division 536, Ionizing Radiation

1. 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.

2. C. E. Dick consulted with Don Snyder, Eglin Air Force Base, on the new imaging methodologies in NDE for armament evaluation.

3. C. E. Dick consulted with John Cox, General Imaging Co., on evaluation of RAM imagers for real-time radiography.

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

5. C. E. Dick consulted with R. Shives, Metallurgy, NIST, on radiography of steel plates from Pittsburgh oil tank collapse.

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

7. David M. Gilliam advised and assisted Babcock and Wilcox (B&W) in preparation and read-out of high-level gamma dosimeters, which are employed in mixed gamma and neutron radiation fields at the Oconee 2 and Davis Besse 1 nuclear power reactors. This novel measurement technique, employing LiF single crystals, is proving highly successful for assessment of radiation dose in power plant environments, aiding operating utilities in safety assurance, power plant life extension, and reduction of personnel dose.

8. David M. Gilliam assisted the dosimetry staff at the Armed Forces Radiobiological Research (AFRRI) reactor in making reliable measurements of neutron dose. The fission chamber monitor system installed under NIST guidance is proving extremely useful in resolving discrepancies between other less-direct instrumentation systems. Accurate dosimetry is essential for AFRRI experiments which are aimed at understanding biological effects of radiation and advancing radiation therapy techniques.

9. H. T. Heaton, II consulted with the Illinois Department of Nuclear Safety on designing a new calibration facility and computer code for instrument calibration and quality control procedures.

Division 536, Major Consulting and Advisory Services (cont'd.)

10. H. T. Heaton, II consulted with the South Carolina Department of Health and Environmental Control on the use of a computer code for instrument calibration and quality control procedures.

11. H. T. Heaton, II consulted with the California Office of Emergency Services on the use of a computer code for instrumentation and quality control procedures.

12. J. H. Hubbell responded to 303 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, 10/01/87 to 06/30/88.

13. J. C. Humphreys provided advice and irradiation services on various gamma-ray and x-ray facilities in the testing of a new phosphor crystal-filter optic radiation detector system for Quantex Corporation of Rockville, MD.

14. J. C. Humphreys provided advice and design ideas for construction of a graphite calorimeter to be used in the electron beam of a 10 MeV research linear accelerator to the Atomic Energy of Canada, Ltd., Pinawa, Manitoba, Canada..

15. J. C. Humphreys and W. L. McLaughlin provided advice on appropriate methods for dosimetry data analysis and statistical quality control techniques to the Department of Food and Agriculture, State of California (Joseph Rothleder). A joint paper will be published on that subject.

16. L. R. Karam consulted in chemical and biochemical procedures, Imperial Cancer Research Fund, London.

17. 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 cm^2 range.

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

19. W. L. McLaughlin consulted with Lew Devigli and Michael Hyman, Science Applications International Corp., San Diego, CA, on the design and testing of field-operational optical waveguide dosimeters for DoD, solving technical problems to permit meeting military specifications.

Division 536, Major Consulting and Advisory Services (cont'd.)

20. W. L. McLaughlin met with Dr. S. Kronenberg, Electronics and Radiation Command, U.S. Army, Fort Monmouth, NJ, regarding design and testing of a neutron and gamma ray personnel dosimeter for dose and dose rate measurements over wide ranges.

21. W. L. McLaughlin assisted C. R. Siebentritt and B. Thompson, Federal Emergency Management Agency, Mount Weather Testing Facility, Berryville, VA, in the design and testing of two types of emergency dosimeters: one for low personnel doses (based on quartz-fiber technique); and the other for emergency doses (based on optical waveguide technique).

22. W. L. McLaughlin worked with K. C. Humphreys and W. Wilde, Far West Technology, Inc., Goleta, CA, on the design and testing of new radiochromic and optical waveguide dosimeters and densitometers, which are tailored for medical, industrial and agricultural applications.

23. W. L. McLaughlin, together with Dr. W. J. Chappas and Dr. M. Al-Sheikhly, Applied Technology Corporation, New Carrollton, MD, worked on the invention of a new visually-read optical waveguide dosimeter for personnel dosimeter (patent application made).

24. W. L. McLaughlin consulted with Dr. T. Prusik, Allied Corp., New Venture Group, Morristown, NJ, and went through extensive testing of new "Lifelines" dosimeters based on bar-coded radiochromic labels which are designed for food irradiation dosimetry.

25. W. L. McLaughlin, with J. M. Foley, Dr. David Lewis, and J. C. Shiloff, GAF Corp., Wayne, NJ, discovered and extensively tested a new thin-film radiochromic dosimeter, which is now marketed by AECL, Ltd., Canada, as GafChromic.

26. W. L. McLaughlin, J. C. Humphreys and D. Hocken consulted with Geraldine Barrett, Neutron Products, Inc., on devising quality control methods for radiation sterilization of medical devices and radiation processing of plastics, which included trouble-shooting radiation processing commissioning, using radiochromic film dosimeters.

27. W. L. McLaughlin provided Ken Roth, NASA-ARAC, Indianapolis, IN, detailed information and methods for food irradiation dosimetry for quality control.

28. W. L. McLaughlin provided R. Schuler, Rockbestos Co., East Granby, CT, calculations and measurements of electron beam depth-doses at 0.55, 1 and 3 MeV in order to determine beam energy.

Division 536, Major Consulting and Advisory Services (cont'd.)

29. W. L. McLaughlin worked with G. Pageau and S. Kruger, Iotech, Inc., Northglenn, CO, on making dose distribution measurements in medical device packages being sterilized by 10 MCi ^{137}Cs source, for QA at Iotech.

30. W. L. McLaughlin provided Dr. Arne Miller, Risø National Laboratory, Roskilde, Denmark, design and intercomparison measurements at Risø and at NPL using NIST graphite calorimeters as means of calibrating the response of chemical dosimeters in high-energy electron beams.

31. W. L. McLaughlin consulted with J. W. Nam, Dosimetry Section, International Atomic Energy Agency, Vienna, Austria, including chairing an IAEA Advisory Group writing a Technical Report on guidelines on dosimetry for industrial radiation processing.

32. W. L. McLaughlin consulted with Dr. Athorn Patumasootra, Office of Atomic Energy for Peace, Bangkok, Thailand, and set up a secondary standards laboratory for high-dose radiation measurement (industrial, agricultural, and medical applications).

33. W. L. McLaughlin worked with Dr. Fred Eichmiller, American Dental Associates, NIST, providing advice and participating in dose distribution measurements in tissue phantoms, for cancer treatment planning involving gamma ray irradiation of oral tumors next to teeth and tooth restorations.

34. Robert B. Schwartz tested and evaluated neutron detectors for the N. Wood Counter Laboratory.

35. Robert B. Schwartz worked with representatives of the Physikalisch - Technische Bundesanstalt and the University of Saarlands (Federal German Republic) to evaluate use of tissue equivalent proportional counters for low energy neutron dosimetry.

36. Robert B. Schwartz participated in an intercomparison of neutron remmeters with National Physical Laboratory (U.K.); Commissariat a L'Energie Atomique (France); and Physikalisch - Technische Bundesanstalt (FRG).

37. Stephen M. Seltzer did a series of transport calculations for bremsstrahlung production from low-and high-energy electron beams in various targets for members of the Radiation Physics Group at the Stanford Linear Accelerator Center, Stanford, CA.

38. Stephen M. Seltzer assembled an extensive suite of codes and cross-section databases, and instructions on their installation and use, which were provided, to scientists requesting the tools for electron and photon transport calculations. The requests came from members of: the X-Ray Astrophysics Group, Department of Physics, The University of New South Wales, Australia; the Radiation Division, Varian Corporation, Palo Alto, CA; and the Computational Physics Division, Lawrence Livermore National Laboratory, Livermore, CA.

39. Stephen M. Seltzer prepared and extensively tested new algorithms for the sampling of energy-loss fluctuations in electron transport for members of the Simulation Theory Division, Sandia National Laboratory, Sandia, NM.

40. Stephen M. Seltzer, in response to a formal request to NIST for assistance in methods of energy calibration for high-power industrial accelerators used in radiation processing, performed a series of state-of-the-art Monte Carlo calculations of the distribution of absorbed dose by electrons in a number of materials. Extensive analysis was performed to relate penetration depth to electron energy, and to compare present results to previous methods. Results were supplied to Radiation Dynamics, Inc., Melville, Long Island, NY and to Becton-Dickinson, North Canaan, CT.

41. Stephen M. Seltzer prepared extensive tables of the bremsstrahlung yield of electrons and photons for use in the calculation of photon mass-energy transfer and absorption coefficients being done by members of the Department of Radiation Therapy, Cleveland Clinic Foundation, Cleveland, OH.

42. Stephen M. Seltzer collaborated with scientists at NASA's Goddard Space Flight Center on the development of (a) a pattern-recognition analysis of XRF spectra for the compositional classification of geological samples (with application to the Mars Rover Mission) and of alloy samples; and (b) a new method of deconvoluting multiple-pinhole x-ray images for emission tomography.

43. Julian Sparrow consulted with Lynn Spence, Lockheed Missile and Space Corp., and Maynard Grove, Atlantic Research Corp., on penetrameters to identify high and low density inclusion in rubber.

44. Julian Sparrow consulted with Lockheed and Atlantic Research Corporation personnel on radiographic procedures to be used to inspect missile motor components.

Division 536, Major Consulting and Advisory Services (cont'd.)

45. Julian Sparrow 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 Shaffer and Gary Barrett, Hercules, Bacchus, Division, Magna, UT; and Kent Robertson, Morton-Thiokol Inc., Brigham City, UT.

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

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 in Chief, North America, International Journal of Radiation Applications and Instrumentation, Part A. Applied Radiation and Isotopes (succeeded Dr. W. B. Mann).

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

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

TRIPS SPONSORED BY OTHERS

Division 536, Ionizing Radiation

Martin J. Berger and Stephen M. Seltzer traveled to Erice, Sicily to be instructors at the 8th Course: Monte Carlo Transport of Electrons and Photons Below 50 MeV, International School of Radiation Damage and Protection, Ettore Majorana Center for Scientific Culture. All expenses were paid by the host organization (Sept. 24 - Oct. 3, 1987).

Randall S. Caswell traveled to Munich, West Germany to present an invited paper and chair a session at the Sixth Symposium on Neutron Dosimetry; and to attend a Workshop on Fast Neutron Radiotherapy. The Commission of the European Communities provided partial subsistence and registration fee (October 12-16, 1987).

Randall S. Caswell traveled to Helsinki, Finland to attend the Annual Meeting of the International Commission on Radiation Units and Measurements (ICRU). All expenses were paid for by the ICRU (August 14-21, 1988).

E. H. Eisenhower lectured at the Harvard course on Radiation Protection Instrumentation in Boston, MA. All expenses were paid by Harvard University (May 1988).

E. H. Eisenhower participated in on-site assessments of two Eberline Instrument Corporation calibration laboratories, one in Santa Fe, NM, and one in Columbia, SC. All expenses were paid by the Health Physics Society (June 1988).

E. H. Eisenhower participated in a preliminary assessment of health physics quality assurance program needs for the Oak Ridge National Laboratory. Travel expenses were paid by ORNL (August 1988).

David M. Gilliam travelled to Brighton, England for the purpose of preparing a proton trap and neutron counter at the University of Sussex and to carry out calibrations of boron and lithium isotopic targets at the BR-1 reactor. All expenses were paid by a N.A.T.O. grant (January, 1988).

H. T. Heaton, II, traveled to Columbia, South Carolina sponsored by South Carolina Department of Health and Environmental Control for training state personnel in computer procedures for instrument calibrations (October 13, 1987).

Kenneth G.W. Inn presented an invited seminar: Development of low-level natural-matrix Radioactive Standards - Lung and Liver, and discussed the interlaboratory data from assays of SRM 4351 and 4352 at the Los Alamos National Laboratory, Los Alamos, New Mexico. All expenses were paid by the Los Alamos National Laboratory (September 21-23, 1987).

Division 536, Trips Sponsored by Others (cont'd.)

Lisa R. Karam traveled to l'Institut Jacques Monod - Paris for a fellowship under Dr. Miroslav Radman for the study of plasmid manipulations and creation of deletion mutants. The l'Institut Jacques Monod paid for lodging and subsistence (July 7 - October 6, 1987).

Lisa R. Karam traveled to London for a fellowship under Dr. Tomas Lindahl for the study of the biochemistry of Ataxia Telangiectasia and the elucidation of the AT phosphate modification, and purification of the enzyme deoxyribophosphodiesterase. The Imperial Cancer Research Fund paid for lodging and subsistence (December 16, 1987 - March 15, 1988 and April 15-29, 1988).

R. Loevinger and J.T. Weaver traveled to Nashville, TN to take part in a site visit to K & S Associates, who were seeking accreditation by the AAPM as a brachytherapy calibration laboratory. The travel expenses were paid by K & S Associates (October 4-5, 1987).

R. Loevinger traveled to San Francisco, CA and Boston, MA to take part in meetings of the MIRD Committee of the Society of Nuclear Medicine. The trips were paid for by the Society of Nuclear Medicine (November 19-20, 1987 and March 17-18, 1988).

R. Loevinger traveled to Ottawa, Canada, to give an invited talk at the National Research Council Workshop on Water Calorimetry. Travel expenses were paid by the National Research Council (June 6-8, 1988).

W. L. McLaughlin traveled to Risø National Laboratory to begin rewriting a Report (formerly an ICRU Report Draft) on Dosimetry for Radiation Processing and also to present an invited Colloquium on the subject of this books. Risø National Laboratory paid for all expenses (October 26-31, 1987).

W. L. McLaughlin traveled to Santa Barbara, CA to present colloquium on "The Role of Dosimetry in Quality Assurance" at the International Conference on Advancing Food Technology with the Irradiation Process. All expenses were paid by Engineering Foundation Conferences (November 18-20, 1987).

W. L. McLaughlin traveled to Thailand to set up and calibrate a secondary standards High-Dose Dosimetry Laboratory in the Office of Atomic Energy for Peace (OAEP). The travel expenses, lodging and subsistence were paid by the International Atomic Energy Agency (March 6-April 1, 1988).

W. L. McLaughlin traveled to Brussels at the Biology Division of the European Economic Community to work on a C.E.C. report on industrial radiation measurements and quality control. Lodging and subsistence expenses were paid by the C.E.C. (May 26-29, 1988).

Division 536, Trips Sponsored by Others (cont'd.)

W. L. McLaughlin traveled to Vienna to write a Protocol for Industrial Radiation processing dosimetry for the International Atomic Energy Agency, Vienna. The travel expenses, lodging and subsistence were paid by the Risø National Laboratory, Roskilde, Denmark (May 30-June 1, 1988).

W. L. McLaughlin traveled to Oxford, UK to attend an Editors' meeting at Pergamon Press, on Editorial Staff of the Journal, Applied Radiation and Isotopes. Two days' subsistence were paid by Pergamon Press (June 6, 1988).

Robert B. Schwartz traveled to Munich, FRG, in October, 1987, and to Braunschweig, FRG, in June, 1988 to participate in meetings of the ICRU Working Group on Practical Determination of Dose Equivalent. All expenses for both trips were paid for by the ICRU (September 27-October 17, 1987 and May 28-June 8, 1988).

Oren A. Wasson traveled to Beijing, People's Republic of China, to lecture and visit the following laboratories: Institute of Atomic Energy, Beijing; National Institute of Metrology, Beijing; Research Institute of Xian Petroleum Exploration Instrument Complex, Xian; Zhongshan University, Guangzhou; Chinese National Analytical Center, Guangzhou. The IAE, Beijing, partially sponsored and paid his expenses while in PRC (June 5-20, 1988).

Division 536, Ionizing Radiation

Radioactivity Group Standards Issued - 1 August 1987 through 31 July 1988

SRM	Radionuclide	Principal Calibration Use
4417L-F	Indium-111	Activity measurements of radiopharmaceuticals
4410H-L	Technetium-99m	"
4406I	Phosphorus 32	"
4407M	Iodine-25	"
4401L-N	Iodine-131	"
4412L-M	Molybdenum-99	"
4415L-L	Xenon-133	"
4416-I	Gallium-67	"
4404L-K	Thallium-201	"
4400L-J	Chromium-51	"
4339	Radium-228, Solution Source	Natural environmental radioactivity monitoring
4919F	Strontium-90 Solution Source	Detectors and radiochemical separations of radiostrontium
4369	Gadolinium-153 Solution Source	Irradiators for osteoporosis measurements
4275C	Long-Lived Mixed Radionuclide Point Source	Germanium spectrometer systems in the energy range from 27 to 1596 keV
4276C	Long-Lived Mixed Radionuclide Solution Source	Germanium spectrometer systems in the energy range from 27 to 1596 keV with custom sources

CALIBRATION SERVICES PERFORMED

Division 536, Ionizing Radiation Division

I. Radiation Interactions and Dosimetry Group

High-Dose Calibrations, FY-1988

Customer Classification	Type of Service	No. of Customers	No. of Tests Performed	Service Fee Income
Industrial:	A	25	163	41,712.00
medical product	B	3	6	3,747.00
sterilization	C	7	7	57.50
Industrial:	A	5	34	8,788.00
electronic	B	10	33	14,787.00
hardness testing	C	3	4	1,469.00
Industrial:	A	0	0	0
polymer	B	0	0	0
modification	C	0	0	0
National Laboratory:	A	0	0	0
electronic	B	1	34	8,500.00
hardness testing	C	0	0	0
Dept. of Defense:	A	1	11	2,827.00
electronic	B	1	4	1,845.00
hardness testing	C	0	0	0
Secondary	A	0	0	0
Calibration	B	1	1	951.00
Laboratory	C	0	0	0
University:	A	0	0	0
research	B	1	1	965.00
	C	0	0	0
Subtotals:	A	30	197	50,500.00
	B	16	79	30,795.00
	C	10	11	2,326.50
Grand Totals:	XXX	57	297	86,448.50

Service Code	Type of Service	SP-250 Number
A	Irradiate Dosimeters	49010C
B	Supply Transfer Dosimeters	49020C & 49030C
C	Special Measurements	49040S & 49050S

Division 536, Calibration Services Performed (cont'd.)

Type of Service	Customer Type*	SP-250 Item No.	Number of Tests	Income
Calibration of x-ray and γ-ray measuring instruments, and irradiation of TL dosimeters	1-8	46010-50	361	$157 k
Calibration of γ-ray and β-particle sources	2-6	47010-40	19	16 k
Chemical dosimetry measurement assurance service for electron beam	2	48010-20	146	29 k
Irradiation of TLDs and preparation of units for shipboard measurements	Navy	N.A.	312	100 k
Instrument calibration	8	N.A.	1	20 k

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

Division 536, Calibration Services Performed (cont'd.)

II. Neutron Interactions & Dosimetry Group

Type of Service	Customer	SP-250	No. of Tests
Neutron Protection Instrumentation	NRC	44060C	1
	Calvert Cliffs	44060C	17
	Carolina P&L	44060C	1
	Omaha Public Power	44060C	3
	U. S. Army	44060C	2
	Illinois Power	44060C	4
	WPPS	44060C	2
	Barlett Nuclear Corp.	44060C	3
	Eberline Instr. Corp.	44060C	1
	Penn. Power & Light	44060C	2
	Univ. Hospital, Tampa	44060C	1
		Total	37
Neutron Source Calibration	Oak Ridge National Lab	44010C	2
	Westinghouse/Bettis	44010C	1
	Lawrence Livermore National Lab	44010C	1
	U.S. Air Force	44010C	2
		Sub Total	6
	In-house (NBS) Sources	N/A	7
		Total	13

Division 536, Calibration Services Performed (cont'd)

III. Radioactivity Group

August 1, 1987 to August 1, 1988

Category	Scheduled Calibrations* Number of Sources	Scheduled Calibrations* Total Fee $k	Non-scheduled Tests Number of Sources	Non-scheduled Tests Total Fee $k
Alpha-particle Sources SP-250 Nos. 43030C, 43040C, & 43050C	16	11.5	8	16.5
Beta-Particle Solutions and Gases (^{85}Kr)	--	--	2	7.7
Gamma-ray Solutions, Point Sources, and Xe Isotopes SP-250 Nos. 43010C & 43020C	1	1.0	7	4.1
	17	12.5	17	28.3

*SP-250 numbers refer to scheduled calibrations

SPONSORED SEMINARS AND COLLOQUIA

Division 536, Ionizing Radiation

Ken Zasadny, University of Michigan, Michigan, "Neutron Induced Activation Studies at the University of Michigan," January 5, 1988.

Carl Ross, National Research Council, Ottawa, Canada, "Water Calorimetry, with Emphasis on the Heat Defect," January 7, 1988.

R. J. Schultz, Yale University School of Medicine, New Haven, Connecticut, "Absorbed Dose Measurements with a Water Calorimeter," January 7, 1988.

John R. J. Soreson, University of Arkansas for Medical Sciences, Little Rock, Arkansas, "Copper Complexes Offer a Physiological Approach to "Radiation Protection," April 15, 1988.

Steven D. Miller, Battelle Pacific Northwest Labs, Richland, Washington, "Optically-Stimulated Luminescence in CaF_2:Mn," May 4, 1988.

Marlon L. Walker, Georgia Institute of Technology, Atlanta, Georgia, "Effects of UV Photons on Isolated Lens Proteins," May 18, 1988.

David T. Burns, National Physical Laboratory, Teddington, Middlesex, England, "The NPL High-Dose Graphite Calorimeter," June 9, 1988.

M. Roos, Physikalisch-Technische Bundesanstalt, West Germany, "Water Calorimetry at the Physikalisch-Technische Bundesanstalt," June 13, 1988.

Hans G. Menzel, University of Saarlands, Homburg/Saarlands, West Germany, "Proportional Counter Measurements in Low Energy Neutron Beams," June 27, 1988.

Bill Franklin, Imperial Cancer Research Fund, London, England, "DNA Deoxyribophosphodiesterase," July 1, 1988.

Frantisek Becvar, Charles University, Prague, Czechoslovakia, "Capture Gamma-Ray Studies of Deformed Nuclei," July 5, 1988.

Hans Roehrig, University of Arizona, Tucson, Arizona, "Large Area X-Ray Imaging with Storage Phosphors and Fiber Optic," July 12, 1988.

Mingyu Ye, University of Notre Dame, Notre Dame, Indiana, "A Radiolytic Study of Oxidation of Aromatic Compounds by Pulse Radiolysis, Ion Chromatography, and HPLC," July 28, 1988.

Division 536, Sponsored Seminars and Colloquia (cont'd.)

Helmut Schuhmacher, Physikalisch - Technische Bundesanstalt, Braunschweig, West Germany, "Implications of Tissue-Equivalent Proportional Counter Measurements in Neutron Dosimetry," August 11, 1988.

Augustin Grau Malonda, C.I.E.M.A.T., Madrid, Spain, "The NBS/CIEMAT (Spain) Collaborative Program in Radionuclide Metrology Using Liquid Scintillation Detectors," August 15, 1988.

N. J. Parks, University of California, Davis, California, "Radiation Chemistry and Physics Problems in the Cellular, Subcellular and Molecular Dosimetry of in vivo Radionuclides," August 16, 1988.

Johnny Hansen, Risø National Laboratory, Roskilde, Denmark, "Low- and High-LET Particle Dosimetry by ESR Spectrometry of Amino Acids," August 18, 1988.

Colin Mailer, University of New Brunswick, Canada, "Dental Enamel as an In Vivo Dosimeter," September 30, 1988.

Leopold Zuppiroli, Laboratoire des Solides Irradiés, CEA, France, "Gamma-ray Dosimetry in the Megagray Range Using Organic and Inorganic Detectors," September 30, 1988.

TECHNICAL ACTIVITIES

Division 530.1 - Nuclear Physics Group

Experimental Activities. Experimental electro- and photo-nuclear physics activities of the Nuclear Physics Group are now being carried out exclusively in the user mode. We currently have active experiments at the Bates linac, the Saskatchewan cw pulse stretcher ring, the Nuclear Physics at Stanford Linear Accelerator Center (NPAS) facility, and the Berkeley 88" Cyclotron.

We are analyzing data from an MIT Bates ^{233,238}U(e,e'f) experiment performed in the quasifree and delta resonance regions at momentum transfers near 2 fm^{-1}. Preliminary results for ^{238}U indicate a reduced fission branch (roughly 1/3)in the quasifree region compared to the delta region, where the fission branch is nearly 100 percent. The reduced branching ratio indicates low residual energy in the daughter system following nucleon knockout. This is difficult to reconcile with apparent nuclear binding effects based on position of the quasifree nucleon knockout peak relative to that for the free nucleon. Contrasting this with results for ^{233}U, we find that the fission branch is nearer to 100 percent. We are attempting to correlate these observations to known fission branching ratios for real photon absorption at low energies. (NIST Spokesperson; W.R. Dodge, J.W. Lightbody Jr., J.S. O'Connell and collaborators at Lund, MIT, and UNH)

We are currently planning a new experiment at Bates making use of the new polarized beam capability. This experiment has received PAC approval. We will attempt to measure the d(e,e'p)n cross section in an out-of-plane geometry. Asymmetry measurements should yield the first observation of the fifth structure function, which results from interference of charge and magnetic scattering. This measurement should be sensitive to details of the NN potential relating to spin degrees of freedom. For this experiment we are constructing a special purpose out-of-plane spectrometer for detecting protons and a new beam polarization monitor. (NIST Spokesperson: W.R. Dodge, J.W. Lightbody Jr., and J.S. O'Connell and collaborators at MIT)

Recently the University of Saskatchewan at Saskatoon has successfully produced a 300 MeV cw electron beam from their new linac/pulse stretcher ring. The laboratory and PAC approved our proposal to measure the ^{3}He(gamma,2p) cross section looking for evidence of 3-body forces. This experiment is the first to run at the new Saskatchewan facility and is now in progress. We are using scintillator telescopes for detectors, which provide energy, angle and particle ID information. A high pressure gas cell is being used for a target. The kinematic completeness of this reaction permits us to use the high flux provided by

a bremsstrahlung beam. Theoretical guidance is provided by calculations of Laget. (NIST Spokesperson; W.R. Dodge, J.W. Lightbody Jr., J.S. O'Connell and collaborators at UMD, Univ. of Saskatchewan)

Our group is also participating in the first (e,e'p) measurement at SLAC/NPAS. NE16 was proposed to study the reaction ^{4}He(e,e'p) in quasifree kinematics. The goal of this measurement is to address the question of modifications to nucleon electromagnetic structure functions in nuclear matter. The experiment was approved by the PAC and work is proceeding to develop new detectors required for the two spectrometers (1.6 and 8 GeV/c). This experiment will be a collaboration of several universities and labs: CEBAF, UVA, W&M, Stanford, and NIST. Our group is constructing a new segmented scintillator hodoscope for the 8 GeV/c spectrometer to reduce pile-up problems caused by the low duty factor at SLAC. (W.R. Dodge, J.W. Lightbody Jr., J.S. O'Connell and collaborators at CEBAF, UVA, W&M, Stanford)

In other work, we are participating in deuteron-deuteron capture reaction studies at Berkeley. The goal of this work is to extract the d-wave component, or deformation, of the alpha particle ground state. This experiment requires use of a polarized deuteron beam from the 88" cyclotron and a cryogenic target. Photons are detected in large NaI detectors in coincidence with associated alphas. Angular distributions have been taken at several energies. This work is still in progress. (W.R. Dodge, E. Hayward, and collaborators at Duke University)

Polarizability of the nucleon remains a quantity of fundamental importance relating to basic predictions of QCD, and plans are continuing 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 and collaborators)

Finally, we are heavily involved in preparing proposals for CEBAF. The $400M CEBAF project is the highest priority new construction project in US Nuclear Science at this time, reflecting the preeminence of electromagnetic nuclear physics, and is expected to be complete in 1994. Letters of intent are being submitted relating to electron coincidence reaction studies, (e,e'pi) and (e'e'2p), which will address the questions

of pion content in nuclei and the nature of short range NN correlations in nuclear matter.(W.R. Dodge, E. Hayward, J.W. Lightbody Jr., L.C. Maximon, and J.S. O'Connell)

Theory Activities. Theory activities of our group include: (1) elementary particle physics work relating to searches for glueballs, hybrids, etc., mass spectra of composite systems, mass mixing matrices and the quark mass spectrum, formation of quark gluon plasmas, and quantum field theory; (2) calculation of three-body bound state and continuum wave functions using a separable potential expansion of the NN interaction; (3) wide angle bremsstrahlung theory, polarization phenomena in off-axis bremsstrahlung and tagging, and radiative corrections to positron and electron scattering; (4) modeling electron, proton, neutron, and pion yields from electron and photon induced reactions; (5) study of binding effects in quasielastic electron scattering; (6) muon catalyzed fusion studies; and (7) calculation of backgrounds to neutrino cross section measurements relating to solar neutrino studies.

Elementary particle theory [item (1) above] focusses on spectroscopic issues, such as those relating to the existence of composites of gluons, which are mediators of the strong interaction as described by the highly successful quantum chromodynamical (QCD) theory of strong interactions. Predicted on very fundamental grounds, these composites have so far eluded detection. Work has continued on glueball and hadron spectroscopy, showing that earlier meson spectroscopic calculations have been verified by J/psi radiative decay measurements at SLAC and Orsay. Recently a new description of quark and lepton masses using Bardeen, Cooper, Shrieffer (BCS) mass matrices was formulated which has provoked a great deal of interest in the elementary particle community. (S. Meshkov and collaborators)

In a related area, nucleons and mesons are predicted to make a phase transition to a quark-gluon plasma at sufficiently high temperatures. Search for signatures of this transition in related high energy experimental data and for the so called ignition point temperature are under study. (M. Danos and collaborators)

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 in 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 long-range part of the interaction, that part where the microscopic structure of the vertex is unimportant, is being investigated from the standpoint of a relativistic many-body system involving pion and nucleon derees of freedom. A program based on these models is underway. (M. Danos and collaborators)

In addition, work is continuing on understanding the confinement problem. It is widely believed that the confinement in QCD, in analogy with superconductivity, results from the existence of a physical vacuum which is removed from the remainder of the spectrum by an energy 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. (M. Danos and collaborators)

Continuum calculations [item(2)] will be necessary to ultimately describe any ^{3}He or ^{3}H break-up processes, and are therefore of intrinsic fundamental interest. Solution of the three-body problem in nuclear physics is only now becoming tractable, and on the outcome of such studies rests any conclusions regarding the existence of 3-body forces. This work has particular relevance to our group since our experimental efforts are focussing on electro- and photo-disintegration experiments on few nucleon systems. (L.C. Maximon in collaboration with GWU)

Radiation theory calculations [item(3)] in support of experimental programs at CEBAF, Saclay, and Saskatchewan are being carried out. The wide angle bremsstrahlung work has been particularly interesting because of its relation to luminosity limitations on the CEBAF Large Acceptance Spectrometer, which is being built at a cost of $10-15M. The theory of off-axis tagging is essential to polarized photon beam experiments at a number of new facilities. Such experiments are amongst the most interesting of the possibilities provided by these new facilities. The e^{+},e^{-} work addresses the subject of dispersive corrections (essentially two-step mechanisms) to the fundamental electron scattering process. (L.C. Maximon collaboration with Illinois, Montreal, Saskatchewan, and Saclay.)

Nuclear reaction yield modeling for electro- and photo-induced reactions is very important to design of experiments. Item (4) represents development of a computer code now widely used to predict background and accidentals in coincidence reactions at the new generation cw electron accelerators. This type of information is vital to the design of the CEBAF experimental program. Development of this code was driven by needs within our research program. (J.W. Lightbody Jr. and J.S. O'Connell)

Item (5). A result of earlier experimental studies, including some by our group, was observation of a q-dependence of the separation energy inferred from single-arm electron scattering in the quasi-free region. This q-dependence can be understood on the basis of momentum dependent optical potentials experienced by both nucleons and deltas within the nucleus. (J.S. O'Connell in collaboration with the University of Lund.)

Muon catalyzed fusion research [item(6)] has recently gained prominence with the observation of muons recycling and inducing as many as 100-200 dt fusions per muon. Theoretical research is being conducted to understand the nature of this effect, and potential use as an alternative energy source. This research involves elements of molecular and nuclear physics. A small grant from DOE helps support this activity. (M. Danos)

Understanding the solar neutrino flux remains one of the enigmas of nuclear astrophysics. Interest in neutrino induced reactions prompted a study of backgrounds which limit the precision of neutrino detectors. Muons from cosmic rays can induce activities which mimic and mask the signature for several planned neutrino detectors. Calculations have been performed to get a quantitative measure of this effect. This and other work has prompted a close interaction with some of the large US groups interested in the solar neutrino detection problem. (J.S. O'Connell)

Within the Nuclear Physics group 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.

INVITED TALKS

Division 530.01, Nuclear Physics Group

Danos, M., "Theory of Muon Catalyzed Fusion," Muon Catalyzed Fusion Workshop, Sanibel Island, FL, June 1, 1988.

Danos, M., "Quantum Field Theory Anomalies," Center for Nuclear Research, Dubna, USSR, July 5, 1988.

Danos, M., "Muon Catalyzed Fusion," University of Paris, Orsay, July 26, 1988.

Danos, M., "Theory of Muon Sticking in d-t-muon Fusion Incorporating Nuclear Effects, "Muon Catalyzed Fusion Conference, Moscow, USSR, Dec. 7, 1987.

Dodge, W.R, "Moller Polarimeters for CEBAF Hall A," CEBAF Hall A Workshop, University of Maryland, Dec 11, 1988.

Dodge, W.R. "Polarimeters at Bates," CEBAF Workshop, Newport News, VA, March 12, 1988.

Hayward, E., "Nuclear Electromagnetic Interactions (16 Week Graduate Course)," Duke University, Durham, NC, Fall 1987.

Hayward,E., "Polarizability of the Proton," University of Saskatchewan Nuclear Seminar, Saskatoon, Canada, Sept. 16, 1988.

Lightbody, Jr., J.W., "The Study of Three-Body Forces with the ^{3}He(gamma,2p) Reaction," University of Maryland Nuclear Physics Seminar, University of MD, College Park, MD, Sept. 29, 1987.

Lightbody, Jr., J.W., "Science Funding in the US," University of Saskatchewan, Nov. 1987.

Lightbody Jr., J.W., "Requirements for an (e,e'2N) Program at CEBAF," CEBAF Hall C Spectrometer Workshop, Newport News, VA, Feb. 1988.

Lightbody, Jr., J.W., "Experimental Equipment Requirements for (e,e'2N) Reaction Studies at CEBAF," CEBAF Summer Workshop, June 23, 1988.

Lightbody, Jr., J.W., "Physics Motivation for (e,e'2N) Reaction Studies," CEBAF Summer Workshop, Newport News, VA, June 24, 1988.

Division 530.01, Invited Talks (cont'd)

Maximon, L.C., "Bremsstrahlung in Nuclear Physics: Why and How Charged Particles Radiate," Triangle University Laboratory, Duke University, Durham, NC, Nov. 5, 1987.

Maximon, L.C., "Tagged Photons - Using Photons to Probe Nuclear Structure," George Washington U., Washington DC, Feb. 26, 1988

Maximon, L.C., "Theoretical Aspects of Polarized Tagged Gammas," CEBAF Workshop on Tagged Photons, CEBAF, Newport News, VA, March 24, 1988.

Maximon, L.C., "Wide-Angle Bremsstrahlung Background to Electron Scattering,"CEBAF LAS Workshop, CEBAF, Newport News, VA, March 26, 1988.

Maximon, L.C., "Analysis of Wide-Angle Bremsstrahlung Measurements at the University of Illinois," CEBAF LAS Workshop, CEBAF, Newport News, VA, May 20, 1988.

Meshkov, S., "A New Quark Mass Matrix," Aspen Winter Physics Conf., Aspen CO, Jan. 1988.

Meshkov, S., "A New Quark Mass Matrix," California Institute of Technology, Pasadena, CA, March 1988.

Meshkov, S., "BCS Quark Mass Matrix," UCLA High Energy Physics Phenomenology Seminar, UCLA, March 1988.

Meshkov, S., "BCS Quark Mass Matrix," UC Irvine High Energy Physics Seminar, UC Irvine, Irvine, CA, April 1988.

Meshkov, S., "BCS Quark Mass Matrix," UC Riverside High Energy Physics Seminar, UC Riverside, Riverside, CA, May 1988.

Meshkov, S., "Meshkov, Glueball and Meson Spectroscopy," 3rd Conference on the Intersection of Particle and Nuclear Physics, Rockport, ME, May 1988.

Meshkov, S., "BCS Quark Mass Matrix," University of Arizona High Energy Physics Seminar," University of Arizona, Tucson, Arizona, June 1988.

Meshkov, S., "BCS Quark Mass Matrix," University of Munich, Germany, July 1988.

Meshkov, S., "BCS Quark Mass Matrix," Aspen Center for Physics, Aspen, CO, July 1988.

Meshkov, S., "Glueballs: Advances, Problems, and Mysteries," Brookhaven National Laboratory, August 1988.

Division 530.01, Invited Talks (cont'd)

Meshkov, S., "BCS Quark Mass Matrix," CERN, Geneva, Switzerland, August 1988.

O'Connell, J.S., "Progress with Out-of-Plane Spectrometers," MIT Bates Laboratory, Middleton, MA, Jan. 15, 1988.

O'Connell, J.S., "Quasi-free Pion Knockout," CEBAF, Newport News, VA, Feb. 27, 1988.

O'Connell, J.S., "Electromagnetic Excitation of the Delta Resonance in Nuclei," University of Lund, Lund, Sweden, June 8, 1988.

PUBLICATIONS

Division 530.01, Nuclear Physics Group

Asai, J., Caplan, H.S., del Bianco, W., Maximon, L.C., and Skopik, M.; Cross Section and Linear Polarization of Tagged Photons; accepted for publication in Canadian Journal of Physics.

Danos, M., The QCD Vacuum, Maratea Summer School, W. Greiner, Ed., Plenum Press (1987).

Danos, M., and Biedenharn, L.C., Anomalies in Lagrangian Field Theory, Phys. Rev. D36, 3069 (1987).

Danos, M., Biedenharn, L.C., Stahlofen, A.A., and Rafelski, J., Theory of Muon Sticking in d-t-muon Fusion Incorporating Nuclear Effects, Proc. Conference on Muon Catalyzed Fusion, Moscow, USSR, Dec. 7-11, 1987.

Dow, K., Beck, D., Dodge, W.R, Lightbody Jr., J.W., Maruyama, X.K., et al.; Longitudinal Response Functions and Sum Rules for Quasielastic Electron Scattering from ^{3}H and ^{3}He; submitted to Physical Review Letters.

Friar, J., Lehman, D., and Maximon, L.C.; Coulomb Effects in Asymptotic Normalization Constants: a Soluble Model; Phys. Rev. C37, 336(1988).

Heddle, D. and Maximon, L.C.; Landau Straggling of Positrons and Electrons; submitted for publication Phys. Rev. C.

Jandel, M.,Danos, M., and Rafelski, J., Active Target Production of Muons for Muon Catalyzed Fusion, Phys. Rev. C37, 403 (1988).

Kaus, P., and Meshkov, S.; BCS Quark Mass Matrix; accepted for publication in Physics Letters A.

Lightbody, Jr., J.W. and O'Connell, J.S.; Modeling Single Arm Electron Scattering and Nucleon Knockout by GeV Electrons; Computers in Physics, Pg.57, May/June 1988.

Meshkov S.; Glueballs and Hadron Spectroscopy; Proceedings of 3rd Conference on the Intersection of Particle and Nuclear Physics, Rockport, ME, May 1988.

Meshkov, S., Glueballs: Advances, Problems, and Mysteries, Proceedings, BNL Conference on Glueballs, Hybrids, and Exotic Hadrons, Brookhaven National Laboratory, Upton LI, NY, August 1988.

Division 530.01, Publications (cont'd)

O'Connell, J.S. and Schima, F.; Muon Induced Radioactivity in Underground Detectors, accepted for publication in Phys. Rev. D

O'Connell, J.S. and Schroder, B.; Quasifree Electron Scattering on Nucleons in a Momentum Dependent Potential, submitted to Phys. Rev. C.

Rafelski, J. and Danos, M., Possible Signature for Early Hadronization Mechanisms of Quark-Gluon Plasma, Phys. Letters B192, 432 (1987).

Weller, H., Whitton, R.M., Langenbrunner, J., Hayward, E., Dodge, W.R., Kuhn, S., and Tilley, W.R.; The Energy Dependence of Polarization Observables in the $^{2}H(d,gamma)^{4}He$ Reaction; submitted to Physics Letters B.

TECHNICAL & PROFESSIONAL COMMITTEE PARTICIPATION & LEADERSHIP

Division 530.01, Nuclear Physics

Danos, M.

Member Organizing Committee, Conference on Future Directions and Applications of Muon Catalyzed Fusion, University of Arizona, Tuscon, Arizona, Oct. 1988.

Delegate, US-USSR Exchange Program on Muon Catalyzed Fusion.

Hayward, E.

APS Executive Board, Division of Nuclear Physics.

Board of Directors, Southeastern University Research Association (SURA).

Chairman, APS DNP Program Committee for Spring APS Meeting.

Lightbody, Jr., J.W.

Program Director, NSF Intermediate Energy Nuclear Physics Program.

Chairman & Board of Directors, CEBAF Users Group.

Program Advisory Committee, CEBAF.

National Advisory Board, CEBAF.

Program Advisory Committee, University of Saskatchewan Accelerator Laboratory.

Maximon, L.C.

Vice-Chairman Elect, 1990 Gordon Research Conference on Photonuclear Reactions.

Meshkov, S.

Advisory Board, Aspen Center for Physics.

Chairman Organizing Committee, Aspen Winter Conference on Elementary Particle Physics.

Meshkov, S.

Member, Interagency Seminar Series Organizing Committee.

O'Connell, J.S.

Editorial Board, Physical Review C.

Program Advisory Committee, University of Saskatchewan Accelerator Laboratory.

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M. Danos, Consultant to DoE, Basic Energy Sciences Division, Muon Catalyzed Fusion Program.

J.W. Lightbody Jr., Temporary Assignment, Program Director, NSF Intermediate Energy Nuclear Physics Program.

TRIPS SPONSORED BY OTHERS

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Danos, M., Paris, France, to continue collaboration with V. Gillet and Dr. Gogny at Saclay, by CEN, Paris.

Danos, M., numerous trips to U. Texas, U. Fla., elsewhere, for Muon Catalyzed Fusion research and oversight, by DoE.

Danos, M., JINR, Dubna and the Kurchatov Institute of Nuclear Science, Moscow, USSR, partially funded by the Kurchatov Institute of Nuclear Science, Moscow, USSR.

Hayward, E. , Duke University to teach graduate course Fall Semester 1987, by Duke University.

Hayward E., University of California, Berkeley 88" Cyclotron Lab, Jan. & March 1988, by Duke University.

Hayward E., University of Saskatchewan, Saskatoon, Canada, Sept. 16, 1988, by the University of Saskatchewan.

Lightbody Jr., J.W., CEBAF Program Advisory Committee meeting, CEBAF, Newport News, VA, Oct. 1988, by CEBAF.

Lightbody Jr., J.W., numerous trips to university labs, conferences, and meetings, for NSF Intermediate Energy Nuclear Physics Program oversight, under auspices of NSF.

Meshkov, S., Aspen Center for Physics Winter Conference, Jan. 1988, by California Institute of Technology.

Meshkov, S., Conference on the Intersections of Particle and Nuclear Physics, Rockport, ME, May 1988, by Cal.Tech.

Meshkov, S., University of Arizona, Seminar, June 1988, by University of Arizona.

Meshkov, S., Brookhaven Workshop on Glueballs, Hybrids, and Exotic Hadrons, August 1988, by Brookhaven National Laboratory.

O'Connell, J.S., University of Saskatchewan Accelerator Laboratory Program Advisory Committee, August 15, 1988, by Saskatchewan.

O'Connell, J.S.,University of Lund, Sweden, for work on collaborative research, by University of Lund

JOURNAL EDITORSHIPS

Division 530.01, Nuclear Physics Group

J.S. O'Connell, Physical Review C Editorial Board

SPONSORED SEMINARS AND COLLOQUIA

Division 530.01, Nuclear Physics Group

R. Eramzhyan, Institute for Nuclear Research, Moscow, USSR, Cluster Effects in the Photodisintegration of Light Nuclei, August 16, 1988.

Boris Tulupov, Institute for Nuclear Research, Moscow, USSR, Damping of Single Particle States in Medium-Heavy Spherical Nuclei, August 16, 1988.

Brad Filipone, CalTech, Pasadena, CA, CalTech SLAC Experiments, July 22, 1988.

H. Arenhovel, Institut fur Kernphysik, Johannes Gutenberg Universitat, Mainz, West Germany, Determination of the Neutron Electric Form Factor with Polarized Beam and/or Target, August 2, 1988.

Jurgen Arends, Physikalisches Institut, Universitat Bonn, West Germany, ELSA: Status and Plans, March 22, 1988.

Jurgen Ahrens, Max Planck Institut fur Chemie, Mainz, West Germany, MAMI: Status and Plans, March 22, 1988.

W. Greiner, Institute for Theoretical Physics, Frankfurt, West Germany, Nuclear Shock Waves and the Equation of State, March 3, 1988.

LIST OF ACRONYMS

AAMI	Association for the Advancement of Medical Instrumentation
AAPM	American Association of Physicists in Medicine
AFRRI	Armed Forces Radiobiology Research Institute
AMS	Accelerator mass spectrometry
ANL	Argonne National Laboratory
ANS	American Nuclear Society
ANSI	American National Standards Institute
APRES	Angle Resolved Photoelectron Spectroscopy
APS	American Physical Society
ASSI	Airglow Solar Spectrometer Instrument
ASTM	American Society for Testing and Materials
AT	Ataxia Telangiectasia
BCS	Bandeen-Cooper-Schneifer
BIPM	Bureau International des Poids et Mesures (International Bureau of Weights and Measures)
BNL	Brookhaven National Laboratory
BSDF	Bidirectional Scattering Distribution Function
CAD	Computer-aided Design
CAM	Computer-aided Mechanical
CAMAC	Computer Automated Measurement and Control
CCEMRI	Consultative Committee for Ionizing Radiations (to CIPM)
CCPR	Consultative Committee on Photometry and Radiometry
CEA	(French) Atomic Energy
CEA	(U.S.) Council for Energy Awareness; also USCEA
CEBAF	Continuous Electron Beam Accelerator Facility
CEC	Commission of the European Communities
CEN	Center for Nuclear Research (France)
CFR	Center for Fire Research
CIEMAT	Centro de Investigaciones Energeticas Medioambientales y Technologicas
CIPM	Comité International des Poids et Mesures
CIRRPC	Committee on Interagency Radiation Research and Policy Coordination, OSTP
CORM	Council for Optical Radiation Measurements
CRCPD	Conference of Radiation Control Program Directors
CRR	Center for Radiation Research
CSEWG	Cross Section Evaluation Working Group
DAMOP	Division of Atomic Molecular Optical Physics
DNA	Defense Nuclear Agency
DNA	Deoxyribose nucleic acid
DNP	Division of Nuclear Physics
DoC	Department of Commerce
DOD	Department of Defense
DOE	Department of Energy

DOELAP	Department of Energy Laboratory Accreditation Program
DRAM	Dynamic random access memory
DRp-ase	deoxyribosphosphodiesterase
DRTIP	Detector Response Transfer and Intercomparison Program
DTS	Dual thin scintillator
DWBA	Distorted Wave Born Approximation
ECR	Electrically Calibrated Radiometer
EML	Environmental Measurements Laboratory
ENDF	Evaluated Nuclear Data File
ENSDF	Evaluated Nuclear Structure Data File
EPA	Environmental Protection Agency
ESONE	European Standards on Nuclear Electronics
ESR	Electron spin resonance
ETL	Electro-Technical Laboratory (Japan)
ETRAN	Electron/photon Monte Carlo transport code
EURADOS	European Community Dosimetry Committee
EURATOM	European nuclear energy organization
FAA	Federal Aviation Administration
FASCAL	Facility for Automatic Spectroradiometric Calibrations
FASEB	Federation of American Societies for Experimental Biology
FDA	Food and Drug Administration
FEMA	Federal Emergency Management Agency
FEL	Free Electron Laser
FIMS	Fissionable Isotope Mass Standards
FOS	Faint Object Spectrograph
FRG	Federal Republic of Germany
FT	Fourier Transform
FTIR	Fourier Transfor Infrared
FY	Fiscal Year
GB	Great Britain
GC/MS	Gas chromatography/mass spectrometry
GPIB	General Purpose Instrumentation Bus
H	Hungary
HDL	Harry Diamond Laboratories
HPLC	High performance liquid chromatography
HP	Hewlett Packard
HPS	Health Physics Society
HSST	Heavy section steel testing
HVL	Half-value layer
IAE	Institute of Atomic Energy (Beijing, China)
IAEA	International Atomic Energy Agency (Vienna)
IAU	International Astronomical Union
ICRM	International Committee for Radionuclide Metrology

ACRONYMS (Continued)

ICRU	International Commission on Radiation Units and Measurements
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IES	Illuminating Engineering Society
IMEKO	International Measurement Confederation
IMFP	Inelastic Mean Free Path
INEL	Idaho National Engineering Laboratory
INMM	Institute for Nuclear Materials Management
IPTS	International Practical Temperature Scale
IR	Infrared
ISNF	Intermediate Energy Standard Neutron Field
ISO	International Organization for Standards
JAERI	Japan Atomic Energy Research Institute
JET	Joint European Torus
LANL	Los Alamos National Laboratory
LAS	Lange Apentune Spectrometer
LBIR	Low Background Infrared
LEED	Low Energy Electron Diffraction
LET	Linear Energy Transfer
LINAC	Linear Accelerator
LLNL	Lawrence Livermore National Laboratory
LMRI	Laboratoire de Metrologie des Rayonnesments Ionisants (France)
LTEC	Lamp Testing Engineer's Conference
MAMI	Mainz Microtron
MAP	Measurement Assurance Program
MCNP	(computer code)
MEA	Materials Engineering Associates
MIRD	Medical Internal Radiation Dose (committee)
MIT	Massachusetts Institute of Technology
MLD	Multi-layer Dielectric
MQA	Measurement quality assurance
MRG	Materials Research Group
NASA	National Aeronautical and Space Administration
NAS-NRC	National Academy of Sciences-National Research Council
NIST	National Institute of Standards and Technology
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
NESDIP	reactor pressure vessel mock-up experiment
NIM	Nuclear Instrumentation Module
nm	Nanometer

NML	National Measurements Laboratory
NPAS	Nuclear Physics at Stanford Linear Accelerator Center
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
NVIS	Night Vision Imaging System
NVLAP	National Voluntary Laboratory Accreditation Program
OAEP	Office of Atomic Energy for Peach (Thailand)
OIML	Office of International Legal Metrology
OMH	Office of Measures (Hungary)
ONR	Office of Naval Research
ORNL	Oak Ridge National Laboratory
OSA	Optical Society of America
OMEGA	24 Beam Laser Facility at Rochester
PAC	Program Advisory Committee
PEP	Pauli Exclusion Principle
PID	Post irradiation dosimetry
PRC	People's Republic of China
PSD	Photon Stimulated Desorption
PTB	Physikalisch-Technische Bundesanstalt (West Germany)
PTFE	Polytetrafluoroethylene
PTW	Physikalisch-Technische Werkstätten
PUD	Paired uranium detectors
PWR	Pressurized water reactor
QA	Quality assurance
QCD	Quantum Chromodyanimcs
QED	Quantum Efficient Device
QED	Quantum electrodynamics
RF	Radio Frequency
RIMS	Resonance Ionization Mass Spectrometry
RIS	Resonance Ionization Spectroscopy
RIT	Rochester Institute of Technology
ROC	Republic of China
RTM	Racetrack Microton
SCK-CEN	Studiecentrum voor Kernenergie-Centre d'Etude de l'Energie Nucleaire (Belgium)
SDC	Strategic Defense Command
SEM	Scanning Electron Microscope
SEMPA	Scanning Electron Microscopy with Polarization Analysis

SI	Systeme International
SIR	International Reference System for activity measurements
SIRIS	Sputter Initiated Resonance Ionization Mass Spectrometry
SLAC	Stanford Linear Accelerator Center
SOLSPEC	Solar Spectrometer
SOLSTICE	Solar Stellar Irradiance Comparison Experiment
SPIE	The International Society for Optical Engineering
SPIPES	Spin Polarized Inverse Photoemission
SRM	Standard Reference Material
SRS	Synchrotron Radiation Source
SSBUV	Shuttle Solar Backscatter Ultraviolet Radiometer
SSDL	Secondary standard dosimetry laboratory
SSTR	Solid State Track Recorder
STM	Scanning Tunneling Microscope
STOS	Space Telescope Optical Simulator
SURA	Southeastern Universities Research Association
SURF	Synchrotron Ultraviolet Radiation Facility
SUSIM	Solar Ultraviolet Spectral Irradiance Monitor
TCAP	Time-correlated associated Particle
TEPC	Tissue Equivalent Proportional Counter
TEXT	Texas Experimental Tokamak
TLD	Thermoluminescent Detector
TN	Technical Note
TUO	TEXT Users Organization
UMD	University of Maryland
UNH	University of New Hampshire
UPS	Ultraviolet Photoemission Spectroscopy
URPs	Unique radiolytic products
UV	Ultraviolet
UVA	University of Virginia
VENUS	research reactor in Belgium
VIAS	(computer code)
VIS	Visible
VME	(computer bus system)
VUV	Vacuum Ultraviolet
WKB	Wentzel-Kramers-Brillouin
W&M	William and Mary
WNR-PSR	Weapons Neutron Source-Proton Storage Ring (Los Alamos)
XCON	Photon cross section database
XGAM	Photon cross section database
XRF	X-ray fluorescence
XUV	Soft X-Ray and Ultraviolet Wavelength Range, 4-50 nm

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