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Technical Note 92

RESEARCH PROGRAM OF THE RADIATION PHYSICS DIVISION, NATIONAL BUREAU OF STANDARDS

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

THE NATIONAL BUREAU OF STANDARDS

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The functions of the National Bureau of Standards are set forth in the Act of Congress, March 3, 1901, as amended by Congress in Public Law 619, 1950. These include the development and maintenance of the national standards of measurement and the provision of means and methods for making measurements consistent with these standards; the determination of physical constants and properties of materials; the development of methods and instruments for testing materials, devices, and structures; advisory services to government agencies on scientific and technical problems; invention and development of devices to serve special needs of the Government; and the development of standard practices, codes, and specifications. The work includes basic and applied research, development, engineering, instrumentation, testing, evaluation, calibration services, and various consultation and information services. Research projects are also performed for other government agencies when the work relates to and supplements the basic program of the Bureau or when the Bureau's unique competence is required. The scope of activities is suggested by the listing of divisions and sections on the inside of the back cover.

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NATIONAL BUREAU OF STANDARDS

Technical Note

92

MAY 1961

RESEARCH PROGRAM OF THE RADIATION PHYSICS DIVISION, NATIONAL BUREAU OF STANDARDS

W. R. Ney AND L. S. Taylor

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FOREWORD

The Radiation Physics Division had its roots in the old Optics Division, which was one of the original divisions of the National Bureau of Standards established in 1901. In 1947, the Optics Division was reorganized and a new division, the Atomic and Radiation Physics Division, formed from those sections and activities concerning atomic and radiation physics. Because of the natural grouping of some of the activities in the new division, it was decided in 1949 to subdivide the division into two branches or laboratories, the Atomic Physics Laboratory and the Radiation Physics Laboratory. This subdivision was carried further in 1960 when the two laboratories were made the bases of two new divisions, the Atomic Physics Division and the Radiation Physics Division.

The Radiation Physics Division is thus an outgrowth of the X-ray Section, which was established in the Optics Division in 1927. The Scope of the activities of the X-ray Section began to broaden in about 1940 under the pressure of war research. Following the advent of atomic energy, the demands upon the laboratory developed rapidly, particularly in the directions of high-energy-radiation research and radiation instrumentation. By 1949, the program had developed to the point where it seemed desirable to divide the activities of the X-ray Section into five sections, X-ray, Radiation Theory, High Energy Radiation, Radiological Equipment, Nucleonic Instrumentation, and group them together with the Radioactivity Section to form the Radiation Physics Laboratory. In January 1957 the Neutron Physics Section was formed and these seven sections formed the basis for the establishment of the Radiation Physics Division in 1960.

This report sets forth the organizational plan of the Division together with a brief presentation of the activities carried out in the various sections. It covers only programs upon which there has been activity within the past year. However, in some instances brief mention is made of the direction of future work for which plans have already been made

Lauriston S. Taylor, Chief
Radiation Physics Division

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RESEARCH PROGRAM OF THE RADIATION PHYSICS DIVISION, NATIONAL BUREAU OF STANDARDS

Abstract: This report describes the research program of the Radiation Physics Division. It includes a statement of the mission of the division, a list of senior staff members, descriptions of the facilities available to the division staff, and detailed descriptions of the research programs of the various sections of the division.

I. MISSION OF THE RADIATION PHYSICS DIVISION*

The National Bureau of Standards must provide national leadership in accurate and uniform techniques of physical measurement of radiations and their interactions with matter. The radiations considered by the Radiation Physics Division are those available from radionuclides and from particle accelerators with energies between 5 kev and 200 Mev.

Therefore, the mission of the Division is to obtain basic experimental and theoretical data concerning the interactions of radiation with nuclei, atoms, and molecules, as well as with bulk matter; the investigation, development, and improvement of radiation sources and standards; and the development of improved techniques and instruments for the detection and measurement of these radiations.

The Division is concerned with the development and improvement of: flux and dosimetry standards for neutrons, electrons, X-rays and gamma-rays; X-ray and radioactivity standards; nuclear data; radiation protection standards; and definitions of quantities and units. The Division is also concerned with the international correlation of these data. Complementing the provision of radiation standards for physical measurement must be a general measurement and research competence. This competence must especially be developed in those new areas of radiation physics where sufficiently accurate basic data are unavailable.

Examples of research areas included in this statement are: radiation dosimetry and protection; radiation penetration; electron, atomic, and nuclear cross sections.

* This statement represents the present thinking of the Division but is still under development and hence should not be considered conclusive.

II. ORGANIZATION OF THE RADIATION PHYSICS DIVISION

The Radiation Physics Division of the National Bureau of Standards is divided into seven sections. The division organization is as follows:

RADIATION PHYSICS DIVISION,	Lauriston S. Taylor, Chief
1. X-ray Section	H. O. Wyckoff, Chief
2. Radioactivity Section	W. B. Mann, Chief
3. Radiation Theory Section	L. V. Spencer, Acting Chief
4. High Energy Radiation Section	H. W. Koch, Chief
5. Radiological Equipment Section	S. W. Smith, Chief
6. Nucleonic Instrumentation Section	L. Costrell, Chief
7. Neutron Physics Section	R. S. Caswell, Chief

III. Staff of the Radiation Physics Division

The senior professional staff members of the Radiation Physics Division are listed below. In addition, there are 8 junior professional and 17 subprofessional personnel together with 14 administrative employees.

BAY, Zoltan L. (NBS 1955)
PhD. University of Budapest, 1926, mathematics and astronomy.
University of Budapest, 1923-26, assistant professor; Physikalisch Technische Reichsanstalt, Berlin, 1926-30, research; University of Szeged, Hungary, 1930-36, professor; Research Laboratory of Tungsram, Budapest, 1936-48, Chief of Laboratory; Technical University of Budapest, 1938-48, professor; George Washington University, Washington, D.C., 1948-55, research professor.
Present: X-ray Section; measurement of W; fast coincidence experiments.

BERGER, Martin J. (NBS 1952)
PhD. University of Chicago, 1951, scattering in photographic emulsions; University of Chicago, 1951-52, Post-doctoral Fellow in statistics.
Present: Radiation Theory Section; transport theory for gamma rays, neutrons and charged particles; radiological physics; development of Monte Carlo methods.

BEVERLY, William B. (NBS 1959)
PhD. University of Virginia, 1959, neutron polarization.
Present: Neutron Physics Section; neutron polarization, neutron spectroscopy.

BRUECKMANN, Robert E. (NBS 1948)
M.S.E. Princeton University, 1950, research in microwave radio.
Manhattan Project, 1944-46; Princeton University, 1946-48, laboratory instructor; NBS Radiological Equipment Section, 1948-57, applicational engineering of X-ray equipment.
Present: Nucleonic Instrumentation Section; development and design of instrumentation for nuclear physics research.

CASWELL, Randall S. (NBS 1952)
PhD. Massachusetts Institute of Technology, 1951, average energy of beta-ray spectra.
M.I.T., 1947-50, teaching and research assistant; University of Kentucky, 1950-52, Associate Professor of Physics; The American University, 1955 to present, Adjunct Professor of Physics.
Present: Chief, Neutron Physics Section; experimental neutron physics, neutron cross section calculations.

CAVALLO, Lucy M. (NBS 1947)
B.A. Hunter College, 1947, work in biochemical analysis; course in Radioisotope Techniques at ORINS.
Present: Radioactivity Section; radioisotope standardization.

CHIN, Jack (NBS 1954)
B.S. St. Mary's University, 1951, physics.
Present: Neutron Physics Section; neutron sources and detectors.

COSTRELL, Louis (NBS 1946)
M.S. University of Maryland, 1949, electrical engineering; B.S. University of Maine, 1939, electrical engineering.
Westinghouse, 1939-41, generator design; Navy Dept. BuShips, 1941-46, Electrical Section; NBS Radioactivity Section, 1946-49, radioactivity measurements and instrumentation.
Present: Chief, Nucleonic Instrumentation Section; telemetering systems, electronic instrumentation development.

COYNE, J. Joseph (NBS 1960)
B.S. Loyola College, Baltimore, 1950, physics.
Catholic University, 1955-60, graduate student, teaching assistant and then research assistant, nuclear structure.
Present: Radiation Theory Section; nuclear cross sections and penetration.

DANOS, Michael (NBS1954)
PhD. University of Heidelberg, 1950, physics, theory of photonuclear reactions, physics of metal surfaces; M.S. Techn. Univ. of Hannover, 1948, electrical engineering.
Columbia University, 1952-54, Res. Assoc., microwave physics and theory of radiation; Guggenheim Fellow, 1959, Univ. of Heidelberg, Germany.
Present: Theoretical studies of photonuclear reactions. Validity of sum rule calculations. Effects of long and short range correlations on the nuclear photoeffect.

DeLaVERGNE, LeRoy (NBS 1953)
B.S. Queens College, City of New York, 1943, physics.
Naval Research Laboratory, 1943-46, Sound Division; graduate studies - University of Rochester, 1946-52.
Present: Radiological Equipment Section, radiation instrument studies and calibration.

DOMEN, Steve (NBS 1951)
B.A. State Teachers College, Indiana, Pa., 1949, mathematics and physics; M.S. University of Maryland, 1958, physics.
Present: Development of methods for absolute determination of high energy X-ray intensities.

EHRLICH, Margarete (NBS 1948)
PhD. Catholic University, 1955, X-ray scintillation spectrometry; University of Vienna, 1934-38; Grady Memorial Hospital and Emory University, 1940-48, medical laboratory and X-ray technology.
Present: Radiological Equipment Section; photographic sensitometry and dosimetry.

EISENHAUER, Charles M. (NBS 1958)
B.S. Queens College, 1951, mathematics; Columbia University, 1955-56.
Armed Forces Special Weapons Project, 1953-54; Brookhaven National Laboratory, 1952-57, experimental work in cold neutron scattering.
Present: Radiation Theory Section; calculation of gamma ray and neutron penetration through matter.

FULLER, Everett G. (NBS 1950)
PhD. University of Illinois, 1950, photodisintegration of deuterium by the continuous X-ray spectrum from a betatron; B.A. Amherst College, 1942, physics; M.S. University of Illinois, 1947, physics.
University of Illinois, 1949-50, Res. Assoc., preliminary experiments on the photodisintegration of He^4 and the high energy effect in the deuteron.
Present: High Energy Radiation Section; precision measurements of photoneutron production cross sections. Studies of the scattering and absorption of photons by deformed nuclei. Study of the nuclear photoeffect in oriented nuclei.

GARFINKEL, Samuel B. (NBS 1949)
M.S. University of Michigan, 1948, physics.
NBS Electron Physics Section, 1949-51, tracer micrography and mapping magnetic fields; NBS Mechanical Instruments Section, 1951-57, development of carbon dioxide hypsometer, research on thin film hygrometer elements, and development of a logarithmic meter for use in weather balloon soundings.
Present: Radioactivity Section; in charge of development and preparation of beta-ray and gamma-ray standards of radioactivity.

GERSTENBERG, Henry M. (NBS 1957)
B.E.E. University of Delaware, 1957, electrical engineering.
Present: High Energy Radiation Section; Development of experimental equipment for use with 50 Mev betatron. Measurement of neutron yield curves.

HAYWARD, Evans V. (NBS 1950)
PhD. University of California, 1947, cloud-chamber studies of cosmic rays; M.A. University of California, 1945, physics; B.A. Smith College, 1942, physics.
University of California Radiation Laboratory, 1947-50, cloud-chamber studies of synchrotron and cyclotron radiation.
Present: High Energy Radiation Section; precision measurements of photoneutron production cross sections; studies of the scattering and absorption of photons by deformed nuclei; and study of the nuclear photoeffect in oriented nuclei.

HAYWARD, Raymond W. (NBS 1950)
PhD. University of California, 1950, studies of beta and gamma-ray spectroscopy; B.S. Iowa State College, 1943.
Naval Research Laboratory, 1943-45, electronic engineer; University of California, 1946-48, teaching assistant; University of California, 1948-50, AEC Pre-doctoral Fellow; Fellow, American Physical Society.
Present: Radioactivity Section; beta decay, spontaneous nuclear transitions.

HILL, Owen H. (NBS 1956)
B.S. U.S. Naval Academy, Annapolis, Md., 1926, engineering.
Commissioned officer, U.S. Navy and U.S. Navy Reserve, 19 years.
Civilian experience, 1929-1940, engineering technology in the mechanical, electrical and structural branches; and design and analysis of systems for land and shipboard applications.
Present: Radiation Theory Section; general engineering services in support of research in structure shielding against radioactive fallout; civil defense radiological measuring instruments, decontamination processes, disposal of radioactive wastes, etc.

HIRSHFELD, Alan T. (NBS 1960)
PhD. Columbia University, 1961, heat capacities of niobium in normal and superconducting states.
Present: Radioactivity Section; cryogenic aspects of nuclear polarization experiments.

HOBBS, Thomas G. (NBS 1959)
B.S. Lincoln Memorial University, 1958, mathematics.
Vanderbilt University and Oak Ridge National Laboratory, 1958-59, A.E.C. Fellow in Radiological Physics.
Present: Radiation Physics Division, Health Physics Group.

HOPPES, Dale D. (NBS 1950)
PhD. Catholic University, anticipated 1961, beta particle emission from oriented nuclei; M.S. Catholic University, 1956; B.S. Purdue University 1950.
Present: Radioactivity Section; nuclear spectroscopy.

HUBBELL, John H. (NBS 1950)
M.S. University of Michigan, 1950, physics.
NBS Constitution and Microstructure Section, 1950-51, X-ray diffraction analysis standards; NBS Thermodynamics Section, 1951, properties of steam.
Present: Radiation Theory Section; geometrical radiation problems, X-ray attenuation coefficients, supporting work in gamma-ray diffusion and bremsstrahlung theoretical calculations, experimental work on measurement of diffused gamma rays.

HUTCHINSON, J.M.R. (NBS 1958)
M.S. University of Washington, 1957, physics.
Present: Radioactivity Section; radioactivity standards.

KOCH, H. William (NBS 1949)
PhD. University of Illinois, 1944, photofission thresholds and betatron X-ray ionization distributions; M.S. University of Illinois, 1942, physics; B.S. Queens College, 1941, physics.
Clinton Labs., Oak Ridge, Tenn., 1945-46, physicist; Univ. of Illinois, 1944-49, Asst. Professor, betatron design and nuclear physics research.
Present: Chief, High Energy Radiation Section; precision measurements of X-ray absorption coefficients in the energy range 10-100 Mev. Direct determination of photonuclear absorption cross sections. Planning new facilities for the Gaithersburg laboratory.

LAMPERTI, Paul J. (NBS 1959)
B.S. Manhattan College, 1958, physics.
General Atomic (Division of General Dynamics), 1958-59, Fusion Program.
Present: X-ray Section; X-ray standards.

LEISS, James E. (NBS 1954)
PhD. University of Illinois, 1954, photomeson production and bremsstrahlung cross section analysis; M.S. University of Illinois, 1951, physics; B.S. Case Institute of Technology, 1946, physics.
University of Paris, Nov. 1959-July 1960, study of design and operation of electron accelerators.
Present: High Energy Radiation Section; neutral photomeson production from hydrogen and other elements; the study of (γ,p) and (γ,np) reactions; analyzing data on inelastic electron scattering data taken at the University of Paris; designing experimental equipment to be used with the new linear accelerator.

LOFTUS, Thomas P. (NBS 1949)
B.S. University of Scranton, 1959, physics.
U.S. Navy, 1943-46; NBS Central Radio Propagation Laboratory, 1949-51, prediction of radio frequencies; NBS Radiological Equipment Section, 1951-54, calibration and performance studies of radiological instruments.
Present: Radiological Equipment Section; in charge of Gamma Ray Laboratory.

MANN, Wilfrid B. (NBS 1951)
PhD. University of London, 1934, exchange of energy between a platinum surface and gas molecules; D.Sc. University of London, 1951.
Imperial College, London, 1929-1936, thermal conductivities and electron diffraction; University of California, Berkeley, 1936-38, cyclotron and artificial radioactivity; Imperial College, London, 1938-46, electrostatic generators; Canadian N.R.C., 1946-48, Radioactive Standards Laboratory; British Embassy, Washington, D.C., 1948-51; Alternate delegate and scientific advisor UNAEC, 1946-51.
Present: Chief, Radioactivity Section; radioactivity standardization, nuclear decay schemes, microcalorimetry, low-level and gas counting.

MARLOW, William F. (NBS 1957)
B.S. George Washington University, 1941, chemistry.
E.I. duPont de Nemours, Inc., 1941-44 and 1946-50, chemist; Office of Synthetic Rubber, 1951-53, chemist; U.S. Army Research and Development Laboratories, 1953-57, chemist.
Present: Radioactivity Section; radiochemistry, carbon-14 and tritium standards; carbon-14 half-life; measurement of and preparation of standards of very low levels of radioactivity.

MAXIMON, Leonard C. (NBS 1958)
PhD. Cornell University, 1952, bremsstrahlung and pair production theory.
Graduate Division of Applied Mathematics, Brown University, 1952-56, assistant professor; Norwegian Technical University, Trondheim, Norway, 1956-57; University of Manchester, Manchester, England, 1957-58, Turner and Newall Fellow.
Present: Radiation Theory Section; scattering theory.

McLAUGHLIN, William L. (NBS 1951)
B.S. (summa cum laude) Hampden-Sydney College, 1949, physics; Graduate studies, Duke University, 1949-50; Rotary International Foundation Fellowship-University of Tübingen, Germany, 1950-51; Graduate studies, George Washington University, 1956- .
Evans Signal Laboratory (U.S. Army), 1954-56.
Present: Radiological Equipment Section; photographic sensitivity and dosimetry.

McLERNON, Franklin D. (NBS 1955)
B.S. George Washington University, 1952, physics; George Washington University, 1952-55.
Present: X-ray Section; delayed coincidence experiments.

MEDLOCK, Robert W. (NBS 1952)
B.S. West Virginia State College, 1949, mathematics.
Walter Reed Army Hospital, 1949-52, hospital attendant.
Present: Radioactivity Section; radiochemistry, carbon-14 and tritium standards.

MOSBURG, Earl, Jr. (NBS 1956)
PhD. Yale University, 1956, nuclear interactions and unstable particles produced by protons from the cosmotron; B.S. Yale University, 1952, physics; Sloane-Silliman Fellowship, 1952-53; DuPont Fellowship, 1955-56.
Present: Neutron Physics Section; neutron standards, neutron elastic and inelastic scattering.

MOTZ, Joseph W. (NBS 1949)
PhD. Indiana University, 1949, low-energy beta-ray spectra; M.S. Cornell University, 1942, hysteresis loss of high polymers.
Signal Corps Radar Laboratory, 1942-43, UHF triode generators; Armour Research Foundation, 1943-46, elastic properties of high polymers and magnetic records.
Present: X-ray Section; X-ray spectrometry and polarization.

NEY, Wilbert R. (NBS 1956)
B.S. Yale University, 1957, physics; Rochester University, 1957-58.
NBS Engineering Metrology Section, 1956-60, development of metrology for determination of stability of gaging materials.
Present: Scientific Assistant to Chief, Radiation Physics Division.

NOYCE, Ralph H. (NBS 1960)
B.A. Grinnell College, 1955, physics. Graduate Assistant, Georgetown University, 1956-58.
Bendix Radio, 1955-56, digital logic design; NBS Electron Devices Section, 1958-60, optical properties of mica.
Present: Neutron Physics Section; measurement of neutron source emission rate.

PENNER, Samuel (NBS 1957)
PhD. University of Illinois, 1956; M.S. University of Illinois, 1954, physics; B.A. University of Buffalo, 1952, physics.
N.S.F. Postdoctoral Fellow, 1956-57; University of Maryland-NBS Graduate School, 1959- , Instructor. Stanford University, summer 1960.
Present: High Energy Radiation Section; neutral photomeson production from hydrogen and other elements, study of (γ,p) and (γ,pn) reactions; design of magnetic analyzing and deflecting systems for the new linear accelerator.

PETREE, Ben (NBS 1951)
PhD. University of Wisconsin, 1951, scattering and absorption of fast neutrons; B.S. University of Kansas, electrical engineering, 1943.
Present: High Energy Radiation Section; calorimetric methods for measurement of absorbed energy.

PLACIOUS, Robert C. (NBS 1952)
M.S. University of Iowa, 1953, specific ionization of cosmic ray mesons; B.S. University of Rochester, 1950.
Present: X-ray Section; Bremsstrahlung cross sections.

PRUITT, John S. (NBS 1953)
PhD. Johns Hopkins University, 1952, energies and angular distributions of neutrons using nuclear emulsions; B.S. Antioch College, 1947, physics.
Present: High Energy Radiation Section; development of methods for absolute determination of high energy X-ray intensities.

RICHARDSON, Allan C.B. (NBS 1957)
M.S. University of Maryland, 1958, physics, isotherms of methane at pressures to 60 atmosphers; B.S. College of William and Mary, 1954, chemistry.
Institute of Molecular Physics, 1954-58, graduate Assistant.
Present: Neutron Physics Section; neutron elastic and inelastic scattering cross sections, neutron age measurements.

SCHARF, Karl (NBS 1957)
PhD. University of Vienna, Austria, 1927, photoelectric effect in submicroscopic particles.
Technische Hochschule, Dresden, Germany, 1928-33, teaching and research assistant, magneto-optics, solid state physics; Industrial laboratories, Paris and Vienna, 1933-35, electric gas discharges; Palestine and Israel Government, Public Works Department, 1935-52, electrical engineering (head of electrical section 1948-1952); Israel Institute of Technology, Haifa, Israel, 1952-56, senior lecturer, physics, electroluminescence; Cornell University, 1956-57, research associate, field emission microscopy.
Present: Radiological Equipment Section, solid state and chemical dosimetry.

SCHRACK, Roald A. (NBS 1951)
PhD. University of Maryland, 1961, neutral meson photoproduction from complex nuclei; M.S. University of California, 1950, physics; B.S. City College of New York, 1945, mathematics.
NBS Central Radio Propagation Laboratory, 1949-51; NBS Atomic Physics Section, 1951-53, application of cyclotron resonance to light mass determination; NBS Electron Physics Section, 1953-56, X-ray microscope, field emission.
Present: High Energy Radiation Section; neutral meson production from complex nuclei; Monte Carlo analysis of photomeson data.

SCHWEBEL, Abraham (NBS 1946)
PhD. University of Maryland, 1958, chemistry; M.S. New York University, 1938, organic chemistry; B.S. Brooklyn College, 1935, chemistry.
Water Service Laboratory, 1941-43, Chemist; University of Chicago Metallurgical Laboratory, 1943-44, Analytical Chemist; Carbide and Carbon Chemical Corporation, 1944-46, Research Technician.
Present: Health Physicist; evaluation of radiation hazards in laboratories using radionuclides or instruments producing ionizing radiations; radiochemistry; consultation on safe use of radionuclides and setting up of facilities for use of radionuclides. Teaching radiochemistry and health physics.

SMITH, Scott W. (NBS 1947)
PhD. University of Pittsburgh, 1931, index of refraction of liquids for X-rays.
University of Rochester, 1931-37, Assistant Professor of Physics;
Kelley-Koett Manufacturing Co., 1937-47, Physicist.
Present: Chief, Radiological Equipment Section; radiation instrumentation and X-ray equipment.

SPENCER, Lewis V. (NBS 1948)
PhD. Northwestern University, 1948, photographic action of X-rays.
NBS Nuclear Physics Section, 1948-57, Physicist (Nuclear Physics);
Ottawa University, Ottawa, Kansas, 1957-60, associate professor of mathematics and physics.
Present: Acting Chief, Radiation Theory Section; theory of penetration and diffusion of radiation in matter. Theoretical evaluation of cross sections for inter-action of radiation with matter.

SPIEGEL, Valentine, Jr. (NBS 1955)
PhD. University of Notre Dame, 1956, elastic electron nuclear scattering at 1.00, 1.75 and 2.50 Mev; B.A. Catholic University of America, 1950.
Naval Ordnance Laboratory, summers of 1950 and 1951, student aid and physicist.
Present: Neutron Physics Section; measurement of neutron ages in water and heavy water, measurement of neutron dose in water, neutron polarization.

SPOKAS, Otto E. (NBS 1946)
George Washington University, 1938-47, electronics; Pennsylvania State College, 1945-46, electronics.
NBS Ordnance Division, 1941-45, 1948-53, high-frequency antenna design and measurements for proximity fuzes, dielectric measurements, component studies; NBS Computer Laboratory, 1946-48, basic circuitry; Diamond Ordnance Fuze Laboratory, 1953-54, electronic component studies.
Present: High Energy Radiation Section; electron spin resonance detector; 180 mev synchrotron circuitry.

STOCKMANN, Leroy L. (NBS 1926)
B.C.E. Catholic University, 1935, civil engineering.
NBS Radioactivity Section, 1926 to present; from 1948-60 in charge of radon testing, radon analysis of ores and sludges.
Present: Radioactivity Section; instrumentation and counting; low-level radioactivity measurements.

TAYLOR, Lauriston S. (NBS 1927)
D.Sc. (Hon.) University of Pennsylvania, 1960; A.B. Cornell University, 1926, physics; Cornell University, 1927-30; Stevens Institute, 1920-21. Columbia University, 1929, X-ray diffraction, absorption sattelite fine structure, oscillation hysteresis; NBS Optics Division, 1927-40, X- and gamma-ray dosimetry, protection, standards, ionization chambers, scattering; NBS Ordnance Development Division, 1940-42, Chief, Proving Ground Group; NBS Ordnance Development Division, 1943, Assistant Division Chief; Ninth Air Force, 1943-46, Chief, Operational Research Division; NBS X-ray Section, 1946-48; AEC, 1948, Chief, Biophysics Branch; NBS, 1940-49, Chief, X-ray Section; NBS, 1949-51, Chief, Radiation Physics Laboratory; NBS, 1951-60, Chief, Atomic and Radiation Physics Division.
Present: Chief, Radiation Physics Division.

WEAVER, James T. (NBS 1956)
B.S. Lynchburg College, Va., 1956, physics.
Present: Radiological Equipment Section; radiation instrument studies and calibration.

WYCKOFF, Harold O. (NBS 1941)
PhD. University of Washington, 1940, Cerenkov radiation.
NBS X-ray Section, 1941-43; Ninth Air Force, 1944-45, Asst. Chief, Operational Research Section; NBS X-ray Section, 1945-50; NBS, 1951, Chief, X-ray Section.
Present: Chief, X-ray Section; X- and gamma-ray attenuation, dosage measurement, radiation shielding and protection.

WYCKOFF, James M. (NBS 1951)
M.S. University of Rochester, 1951, continuously operating cloud chamber.
NBS Radioactivity Section, 1952-53, alpha-ray measurements.
Present: High Energy Radiation Section; X-ray measurements to determine attenuation coefficients in the 0 to 100 Mev region.

IV. FACILITIES OF THE RADIATION PHYSICS DIVISION

The present facilities of the Radiation Physics Division are housed in four buildings at the National Bureau of Standards' Washington site--the High Voltage Laboratory, the Betatron Laboratory, the Gamma-ray Laboratory, and the Materials Testing Laboratory. The equipment available to the division staff includes a full complement of stock laboratory apparatus, certain specialized instrumentation adapted to the division program, and a number of rather large scale, complex pieces of equipment of unique importance to the research work of the division.

Also available to division staff members, by means of cooperative programs, are the services and facilities of a number of the other technical divisions of the Bureau. These, of course, are in addition to the more general administrative and service assistance provided by the Bureau administration.

The National Bureau of Standards is at the present time engaged in designing new laboratories to be located at Gaithersburg, Maryland. Plans for the new NBS "campus" provide for 20 buildings to house the Bureau's programs. Funds have now been appropriated to begin construction and site development and it is expected that ground will be broken in the summer of 1961.

One of the new buildings at this site will be the Radiation Physics Laboratory. The design of this laboratory has afforded an opportunity to design a facility especially adapted to the unique requirements of the research program of the Radiation Physics Division.

The planned laboratory consists essentially of four major areas: the linear accelerator area, the cyclotron wing, the connecting wing, and the north wing. The linear accelerator area will house the new high-intensity electron accelerator and consists essentially of a three-level machine and control area and a three-room experimental complex. The experimental rooms because of the radiation shielding required will be 40 feet below ground level and separated by concrete walls 12 feet thick. The accelerator is described in more detail below. Provision has been made in the two level cyclotron wing for the addition of a new variable energy cyclotron (see description below). In addition, this wing will house four neutron research labs, four radioactivity labs, and space for associated facilities. The connecting wing, a two level area, will contain X-ray and neutron experimental areas. The 3 Mev and the 1.5 Mv generators described below and other X-ray machines will be housed in this wing. This area will also include a gamma-ray calibration range and a 2-Mev Van de Graaff positive ion accelerator for neutron research. The north wing, a three story and basement structure, will include low-level radioactivity laboratories, health physics laboratories, nucleonic instrumentation laboratories, and office space. An indication of the magnitude of building is the fact that it will contain about 70,000 square feet of usable floor area divided into some 72 laboratory areas and over 50 offices.

Described below are a number of the large-scale, specialized pieces of equipment presently employed in the Division program and also some of the equipment planned for installation in the Gaithersburg laboratory. Also included are brief descriptions of certain of the facilities available through cooperation with other divisions of the Bureau.

1. X-ray Section

At the present time the section has available a d.c. generator capable of supplying potentials of from near 0 to 1.4 Mv. This generator has a current capability of 15 milliamperes for continuous operation. It may be connected to either of two electron accelerating tubes. At the present time one of these tubes is provided with a thick tungsten target for the generation of X-rays. The other one has a thin window so that electron experiments can be performed in air, other gases or solid materials.

This generator and the two accelerator tubes are to be replaced at the time of the move to Gaithersburg. The new laboratory will house a 3 Mv Van de Graaff with provisions for directing the electron beam into either of two experiment rooms. Either of these rooms may be used for X-rays or electron experiments. The current capability of this unit will be of the order of 1 milliampere. It is also planned to have a 1.5 Mv accelerator in the new laboratory. This will also have current capabilities of the order of 1 milliampere.

The section has a free air ionization chamber with a plate separation of 44 cm. This ionization chamber is contained within a large pressure tank so that it may be operated at pressures up to 12 atmospheres. It is currently being used to examine the requirements for measurement of X- and gamma-rays in roentgens. It is anticipated that in the future it will be used to examine the details of ionization production from electrons and X-rays. In order to collect the ionization produced in such a high-pressure vessel, two very well stabilized d.c. power supplies are available which will provide both positive and negative potentials from 0-50 kv. in steps of 1 kv.

For some of the work in time-of-flight measurements high-speed coincidence circuitry has been developed. At the present time, the circuitry is capable of measurements down to about 10^{-11} sec.

2. Radioactivity Section

Essential facilities utilized by the Radioactivity Section in its program are described below.

$4\pi\gamma$ Ionization Chamber

The NBS $4\pi\gamma$ ionization chamber is used chiefly for the relative standardization of gamma-emitting radionuclides. It is a stable instrument, as is evidenced by the reproducibility (within 1%) of its response to radium reference standards over the past several years. Its ultimate precision is ±0.02%. It is also characterized by its linear current response to gamma radiation over an energy range of .4 Mev to 2 Mev. This is the case for samples of a given geometry placed within the re-entrant source tube of the chamber. Given a radioactive sample of "standard" geometry, and given the relative amounts of gamma rays and their energies within the range of .4 to 2 Mev, an assay of the total amount of gamma-ray activity can be determined to within ±2% within an hour or less depending on the strength of the source.

Low-Level Radioactivity Laboratory

An existing room in the Radioactivity Section has been extensively renovated and modified to furnish a low-level radiochemistry laboratory and a source preparation room, with an airlock at the entrance. Special air-filtration and air-conditioning arrangements provide a clean, dust-free atmosphere. Special clothing and shoes or plastic bootees are worn in these rooms.

The counting room is adjacent to the source preparation room and is connected by a small wall air-lock through which samples may be passed. This room is equipped with low-level alpha, beta and gamma detectors shielded by mercury, iron, lead and anticoincident counting circuits or a combination of two or more of these. Activities as low as 10^{-12} curie can be measured.

One of the gamma detectors feeds into a 100-channel pulse-height analyzer permitting the determination of radioactive nuclides present in a given sample from the gamma-ray energy levels. This is particularly useful in the determination of radiochemical impurities in chemical reagents.

Although radon testing for the public and for Federal and State Government agencies has been discontinued, several units of the equipment have been retained. These are available for occacional check measurements for Army, Navy, and Air Force health agencies for which we formerly made routine analyses and for radon measurement of emergency breath or air samples.

Radiochemical Laboratory. Four laboratories are present in the Section for the purpose of providing facilities for radiochemistry. Two of these laboratories are equipped with special hoods and foot-control sinks for the handling of radioactive materials, while the other two provide counting facilities, one in particular being for the gas counting of hydrogen-3 and carbon-14.

Cryogenic Equipment Employed in Nuclear Spectroscopy. Through the generosity of the Cryogenic Physics Section of the Heat Division, the Nuclear Spectroscopy Project being carried out by the Radiation Physics Division, has available the necessary cryogenic equipment for performing radioactivity measurements involving oriented nuclei.

The principal items in use are an adiabatic demagnetization cryostat with an associated 125 kilowatt electromagnet and a large capacity helium bath pumping system. All liquid helium is produced on the premises. With this equipment, it is possible to achieve temperatures as low as $0.001^{\circ}K$, sufficient for producing nuclear polarization. Certain specialized electronic detection and counting equipment used for these measurements consists of scintillation detectors operating at $0.01^{\circ}K$, gamma-ray polarimeters for the measurement of both plane and circular polarization, and multichannel coincidence and pulse-height measuring equipment.

Other Equipment. The Radioactivity Section has designed and constructed compensated internal gas counters for the calibration of radionuclides, such as hydrogen-3, carbon-14 and sulfur-35, that can be prepared as samples in gaseous form. The accuracy of measurement in these counters is of the order of ±1%.

A Peltier-effect microcalorimeter, capable of a precision of the order of 0.1% has also been developed.

3. Radiation Theory Section

While the Radiation Theory Section, being a theoretical group, does not have need for a considerable amount of major experimental equipment, other than desk calculators, it does make extensive use of the facilities made available by the Applied Mathematics Division. Some of these facilities are described below along with some of the plans for their future expansion.

The services provided by the Computer Laboratory include the assistance of the trained staff as well as the use of the electronic computing equipment. The technical staff aids in the formulation of problems and their solution, as well as in the programming and coding of problems for solution on the IBM-704 electronic computer

The electronic computer, which is available, has a 32,000 word-core-memory, a drum and 10 tapes on line. The present off-line equipment consists of a card-to-tape converter and off-line printer. In addition, there exists standard IBM electro-mechanical equipment.

An order has been placed with Royal McBee for a RPC-4000 computer, which should arrive in the near future, and a small desk-size computer to be used in exploratory scientific and technical work.

At the moment, the plans for the future indicate that the present 704 system will be replaced by the most advanced system available. It is anticipated that a computer of the IBM stretch type may be installed at the Bureau even prior to the move to Gaithersburg, and certainly by the time that the Bureau moves a computing facility of this magnitude is expected. There will be a considerable increase in the staff to fully utilize this large-capacity machine.

4. High Energy Radiation Section

The major facilities of the High Energy Radiation Section at present consist of two sources of high energy radiation, a 50 Mev betatron and a 180 Mev synchrotron. A high intensity linear electron accelerator (linac) is now being acquired. This new facility is scheduled for completion early in 1963. The principal features of this new accelerator will be a very greatly increased intensity and the ready accessibility of external electron beams. Table I gives a comparison of the present accelerators as well as the new linear accelerator.

The linac will be housed in a special laboratory building at the new Gaithersburg site of NBS. The electron beam from the linac is first sent into a magnet room where it is energy analyzed and deflected into one of three experimental rooms. The energy of the electron beams in these rooms will be variable from about 5 Mev to the maximum energy of the accelerator. The energy resolution available will be controllable from a few hundredths of a percent to about 10 percent. Energy stability of the analyzed electron beams will be a few hundredths of a percent.

The magnetic deflection system designed to carry the electron beam from the linac to the experimental rooms is such as to take an initially parallel beam from the linac into a parallel beam in the experimental rooms. The beams in the experimental rooms will be focused on the targets of experimental equipment by additional quadrupole focusing elements in the experimental rooms.

It is planned in the initial installation to have prepared three major experimental setups. In one room will be located a high resolution magnetic spectrometer, together with associated gear, for performing electron scattering experiments. In the second installation will be a low resolution magnet, together with associated gear, for counting heavy particles (protons, deuterons, alphas). The third initial installation will be equipment designed for generating monoenergetic photon beams. Monoenergetic photons will be generated by the annihilation in thin, low Z foils of energetic positrons generated in electron-photon cascades by the direct beam from the linac.

In addition to the three experimental rooms already mentioned, provision is also made for two small irradiation bays for radiation damage and dosimetry studies. A slot is also to be left between two of the experimental rooms to allow for neutron flight paths up to 150 feet for photoneutron studies.

Although the linac will be an extremely powerful source of neutrons for a neutron physics program, specific provision of a neutron facility is not planned in the initial installation. Consideration is being given to the needs of such an installation if this is considered desirable in the future.

Comparisons of Present Accelerators and New Linear Accelerator

	50 Mev Betatron	180 Mev Synchrotron	Linear Accelerator
Radiations Available	X-rays (Electrons with difficulty at low currents)	X-rays	Electrons, X-rays
Type	Circular	Circular	Linear
Size	4-1/2x2 1/2x3 1/2 ft.	18x8x10 ft. magnet	1-1/2 ft. diameter x 100 ft. long tube
Orbit Radius	11 inches	33 inches	-
Weight	10 tons	150 tons	5 tons
Accelerating mechanism	Rate of change of magnetic flux	rf cavity in alternating magnetic field	traveling electric wave
Average beam current	$2x10^{-8}$ ampere	$2x10^{-8}$ ampere	$5x10^{-4}$ ampere
Beam power available	20 milliwatts	100 milliwatts	40 kilowatts
Maximum beam energies	50 Mev	180 Mev	130 Mev at low current 60 Mev at high current
Duty cycle	about 0.002	about 0.04	0.002

5. Radiological Equipment Section

Summary of Special Facilities Available for Carrying out the Programs.

1. X-ray standards.

   A. Free-air parallel-plate ionization chambers:

      1. For X-rays produced at 20 to 100 kvcp.

      2. For X-rays produced at 60 to 250 kvcp.

   B. Constant potential X-ray machines for use with free-air standard chambers:

      1. Range 0 to 50 kvcp.

      2. Range 20 to 100 kvcp.

      3. Range 50 to 250 kvcp.

2. Collimated-beam gamma-ray standard instrument calibration ranges:

   A. Cesium 137: 2000 curies, 120 curies.

   B. Cobalt 60: 1000 curies, 200 curies, 50 curies and 5 curies.

3. High-intensity gamma-ray water-shielded cobalt-60 sources:

   A. 2000 curies.

   B. 50,000 curies.

4. Radium calibration range.

5. X-ray machines for dosimetry research:

   A. Two 50 to 250 kvcp.

   B. One 30 to 150 kvcp.

6. Nucleonic Instrumentation Section

The equipment employed by the Nucleonic Instrumentation Section includes the very considerable electronic apparatus necessary for the operation of a full-scale electronic laboratory. In addition to this and of particular significance to the division program, however, are the several multi-channel pulse-height analyzers and the high speed pulse test equipment maintained by the section.

7. Neutron Physics Section

Neutrons are provided for experimentation by a 2 Mev Van de Graaff positive ion accelerator (see table attached) and by radioactive neutron sources. Neutron sources available include Ra-Be(γ,n), Ra-Be(α,n), and Pu-Be(α,n). When required, short life neutron sources are obtained such as Sb^{124}-Be(γ,n) and Po^{210}-Be(α,n).

Neutrons are produced by the Van de Graaff accelerator at energies of 1 Mev and less by the T(p,n) and the Li(p,n) reactions, from 2 Mev to 5.3 Mev by the H^2(d,n) reaction and from 12 to 18 Mev by the T(d,n) reaction. These neutrons are monoenergetic, which is valuable for calibration of neutron spectrometers and dosimeters at specific neutron energies, for measurements of neutron cross sections, and for precise neutron penetration experiments. The neutrons from the H^2(p,n) and Li(p,n) reactions are polarized, making possible studies of fast neutron polarization. The Van de Graaff accelerator is also used to provide monoenergetic high energy gamma rays of 17.6 and 20 Mev by (p,γ) reactions. The proton and deuteron beams are available for direct use in charged particle experiments. Beam pulsing equipment has been ordered to make possible neutron time-of-flight experiments with low background and improved time resolution. The new equipment also makes possible use of the H^2(d,n) reaction in time-of-flight experiments.

The proposed variable energy cyclotron planned for installation in the Gaithersburg laboratory will permit neutron cross section measurements over a wide range of fast neutron energies without the energy gaps that exist with the Van de Graaff. The natural pulsing of the cyclotron will permit time-of-flight experiments with orders-of-magnitude higher instantaneous pulse currents. Since the incident neutrons are monoenergetic, time-of-flight may be used to measure the energy distribution of the scattered neutrons and also for background reduction. The large external beam of the cyclotron coupled with a flexible low resolution or high resolution magnetic analyzing system may be used for many kinds of charged particle and neutron nuclear physics experiments. For example, the large external beam can be used for neutron and charged particle polarization experiments where maximum intensity is required. For charged particle scattering and reaction experiments, the small beam with high energy resolution will be used. The variable energy cyclotron is the most flexible positive ion accelerator available in terms of the many kinds of particles which can be possible.

ACCELERATORS FOR NEUTRON PHYSICS

	Present 2 Mev Van de Graaff	Proposed 40 Mev Variable Energy Cyclotron
Proton energies	0.250-2 Mev	1-40 Mev
Deuteron energies	0.150-2 Mev	1-20 Mev
Alpha particles	-----	1-40 Mev
Other particles	possible, but would require modifications	C^{12}, N^{14}, many others, energy typically 50 Mev
Current	50 microamperes (0.1% energy resolution)	1 milliampere (internal) 50 microamperes (external) (0.1% energy resolution) 1 microampere (0.01% energy resolution)
Neutron energies (approximately monoenergetic)	.05-1, 2-5.3, 12-18 Mev	1-37 Mev (continuously variable)
Maximum neutron source strength	10^{11} neutrons/sec	1.4×10^{14} neutrons/sec
Beam pulsing	D.C. 3-10 nanosecond (internal pulsing in order) 1 nanosecond (astigmatic magnet on order)	4 nanosecond (naturally pulsed)
Auxiliary equipment	---	Charged particle spectrometer for reaction products 40 Mev, 0.1% energy resolution. Radiochemistry lab, for target handling
Chief uses	Neutron cross sections, polarization, penetration	Neutron cross sections, polarization, charged particle nuclear physics
Ion source	Radiofrequency	Hooded arc
Pole-tip diameter		64 inches
Extraction radius		26 inches
Beam analyzing magnets	90°, 40 cm radius, 7500 gauss	2-90°, 86 cm, 12000 gauss

8. Health Physics Group

The Health Physics Laboratory has a variety of portable instruments such as geiger counters, scintillometers, gamma and neutron detectors, ionization chamber instruments and air samplers. The laboratory is equipped with proportional windowless flow counters both for ordinary work and low-level work. A Tracerlab low level (0.7 cpm - beta background) counter has been purchased to use in low-level Sr^{90} counting. For the low-level detection of gamma emitters, there is a single channel analyzer utilizing a 3-inch NaI (Tl) counter.

V. INTRODUCTION TO THE PROGRAM

Most of the work of the Division can be grouped loosely into the categories of "aimed" or applied research. By "aimed" is meant research that is basic in character, but oriented so as to offer a reasonable possibility of being applicable to some specific problem or class of problems, the exact nature of which may not be known at the time. Aimed research also has the purpose of filling the broad requirements for scientific information that arise from practical problems; it implies that the research, however basic, is undertaken as a part of a concerted effort that has a place in the national requirements. This is in contrast to applied research, which has as its primary objective the solution of some defined problem--possibly even resulting in the production of specific equipment or in a routine testing program.

To develop a program and staff of high capability, it is necessary to take advantage of opportunities as they arise. Thus, for example, when we develop the staff and facilities for some aimed research, we frequently find ourselves in a unique position to carry out some research of a pure or basic nature. By taking advantage of such opportunities, the general background and experience of the staff are strengthened and the members of the staff are placed in an improved position for undertaking tasks of new kinds and complexity. Furthermore, through the encouragement of such possibilities, it has been demonstrated that we can attract better scientific personnel than would otherwise be possible. This general policy has been followed by the Division for the past several years, and its effectiveness has been proved.

VI. DETAILED PROGRAMS OF THE SECTIONS

1. X-ray Section (4.01)
H. O. Wyckoff, Chief

The program of the X-ray Section at the present time is devoted primarily to experimental investigations in the dosimetry of X- and gamma-rays and in the production of X-rays. For the most part its interests are confined to the energy range below 3 Mev.

Dosimetry. At the present time, the section is interested in research with both free-air ionization chambers and cavity ionization chambers. The section is responsible for the determination of correction factors for the free-air ionization chambers and for the design and testing of the national standards for measurement in roentgens. At the present time such standards are available for the 20 kilovolt to the million volt range. With these instruments, it is estimated that the error does not exceed about 1.2% below 500 kilovolts but is perhaps as much as 2% in the million volt region provided measurements are made at a distance of a half a meter or greater from the radiation source. Presently investigations are underway to permit measurements at less than a half a meter and at lower potentials than 20 kilovolts.

In addition, the section is responsible for the comparison of our national standards with those of other national laboratories. For this purpose, the section has established close liaison with the International Commission on Radiological Units and Measurements, with the Bureau International des Poids et Mesures, and with the responsible persons in other national laboratories. To expedite such intercomparisons, the section has developed transfer instruments. It is expected that from such intercomparisons it will be possible to further reduce the uncertainty of measurements.

Two of the most important factors needed for the evaluation of cavity ionization chamber measurements are the stopping power and the energy required to produce an ion pair in the gas (W). Research is currently underway in the section to determine more accurate values for both of these factors. One method for obtaining the stopping power ratio is to compare the ionization results obtained with a free-air chamber and with a cavity chamber. Such measurements have recently been completed with cobalt-60 and cesium-137 gamma-ray sources. The uncertainty of the ratio of these two measurements is estimated to be about 3%. However, measurements are now underway with a gold-198 gamma-ray source. It is expected that the maximum uncertainty in the ratio of the two measurements will not exceed about 2%. One can also determine the product of the stopping power and W by comparison of measurements made with a calorimeter and a cavity chamber. With the acquisition of the Bureau's new 50 kilocurie cobalt source such measurements will be easily possible. Some thought has been given to such measurements.

Many values of W for electrons and alpha particles have been reported in the literature. Here W is the average energy required to produce an ion pair as the ionizing particle is reduced from its maximum energy to zero. Generally, the numerical values so obtained are in fairly good agreement. However, a different value is obtained for fast and for slow collection of the ionization produced by alpha particles. At the present time the section is investigating the value of W obtained by both of these methods with a single source in order to clear up this discrepancy.

These data indicate that W for some gases increases as the particle energy decreases. These results indicate that a more interesting factor for investigation would be the differential quantity; that is, the charge produced by a small energy loss in the region of energy E. For convenience this will be called $w = \Delta E / \Delta n$. An initial investigation with alpha particles in air near 5 Mev indicates that the value of w for these particles is very nearly the same as that obtained for electrons. This experiment was possible because the stopping power is well known in this energy region. However, it would be of interest to determine w at lower energies. For this purpose it is necessary to determine small increments of E. A time-of-flight method using high-speed coincidence techniques is now being developed for such measurements.

With the development of these techniques it is expected that fruitful areas of future research will be opened. For example, it will be possible to investigate the response of solid state radiation detectors at different energies.

<u>X-ray Production</u>. Present calculations of X-ray production are based on the Born-approximation and for the medium electron energy range (say 50 kev to few Mev) are known to be in error. For this reason the section has pioneered in the experimental determination of the absolute cross section of continuous X-ray spectra and its polarization. These X-rays are produced in thin targets so that the producing electron direction is known. As a logical extension of this effort the section now has under investigation the spectral distribution as the target thickness is increased. Here the electrons soon lose their initial monodirectional property by scattering. Such investigations not only provide data for the evaluation of the continuous X-ray losses but also give ideas about the electron scattering.

A second logical extension of this initial effort, which is now under consideration, is the distribution of electron directions resulting from the continuous X-ray production process. If the electrons ejected from the various shells do not provide too high a background, the above distribution can be investigated by coincidence methods.

2. Radioactivity Section (4.02)
W. B. Mann, Chief

The Radioactivity Section has several main objectives ranging from basic nuclear research to routine testing. Its activities include: (1) the development of techniques and facilities for measuring radioactivity, (2) the preparation and distribution of standard samples of both the naturally occurring and artifically produced radioactive elements, (3) the analysis of room-air, breath, and ore samples for radon and radium content, (4) the development of techniques of low-level counting and the preparation of low level standards of radioactivity, and (5) investigations in the field of nuclear spectroscopy. To carry out these programs, the section is comprised of an Alpha-Ray Standards Laboratory, a Beta- and Gamma-Ray Standards Laboratory, a Nuclear Spectroscopy Laboratory, a Low-Level Counting Laboratory, and a Radiochemical Laboratory.

Radioactivity Standards. The Section presently prepares and distributes polonium-210, americium-241 and uranium-oxide (U_3O_8) alpha-ray standards and beta- or gamma-ray standards of the following naturally occurring or artifically produced radioactive nuclides: hydrogen-3, carbon-14, sodium-22, scandium-46, zinc-65, krypton-85, strontium-85, niobium-95, mercury-203 and radium-226, and also rock and ore standards containing thorium, radium, and uranium.

There are also available point-source gamma-ray standards in the energy range 0.279 to 1.28 Mev, namely of sodium-22, manganese-54, zinc-65, strontium-85, niobium-95 and mercury-203. The Radioactivity Section also maintains the national radioactivity standards, for testing and calibration purposes but not for distribution, of the following nuclides: sodium-24, phosphorus-32, sulfur-35, potassium-42, iron-59, cobalt-60, strontium-yttrium-90, iodine-131, cesium-barium-137, tantalum-182, gold-198 and thallium-204. Radioactivity standards of the nuclides in this last group are no longer distributed by the National Bureau of Standards as such standards are now commercially available.

This radioactivity-standards program is the responsibility of the Alpha-Ray Measurements Laboratory and the Beta- and Gamma-Ray Standards Laboratory.

Alpha-Ray Standards. A program to provide alpha-particle standards has been established on a long-range basis. Presently, alpha-particle-emitting standards are furnished in a number of different intensities, the source material being uranium oxide (U_3O_8), polonium-210, or americium-241.

The recipients of the alpha-emitting standards are engaged in many diverse activities, such as medical research or application, physical and industrial research, oil prospecting, radiation protection, and thermonuclear-weapons development. The demand for these standards is a continually increasing one as new applications are found.

Beta- and Gamma-Ray Standards. This standardization program, is concerned with the preparation of the beta- and gamma-ray standards and is discussed in the section entitled "Radioactivity Standards,"

The techniques used for the production of national radioactivity standards are the usual ones of $4\pi\beta$ counting, coincidence counting and internal gas counting. The emphasis in recent years, and currently, in $4\pi\beta$ counting and 4π X-ray counting, has been on methods of source preparation with a view to minimizing and determining source self-absorption.

The Radioactivity Section, together with other national laboratories, is cooperating in trying to establish international uniformity in the measurement of national radioactivity standards. With this end in view it has already participated in the measurement of phosphorus-32 which was distributed internationally on behalf of the International Bureau of Weights and Measures.

Low-Level Radioactivity Measurements. Work is in progress on methods of measuring the amounts of radionuclides present at very low concentrations (10^{-10} to 10^{-12} curies/ml) and on preparing standards of radioactivity at these concentrations. Radionuclides under present investigation are natural uranium, radium-226, thorium-230, strontium-yttrium-90; other nuclides to be investigated at the earliest opportunity include sulfur-35, cobalt-60, ruthenium-106, and cesium-barium-137. The general program includes the determination of low levels of radiocontamination by any nuclide of materials and reagent chemicals, and, possibly, the preparation of materials and reagent chemicals free from any detectable radioactivity.

Two methods of radon analysis are being investigated both of which will eliminate the necessity of removing all oxygen from breath and air samples before measurement. Radon analysis, to a limited degree, will also become a part of the low-level measurements program.

Radiochemistry Studies. Counting in formamide solution for secondary calibrations of certain radionuclides has been re-evaluated. Nuclides that can be satisfactorily counted by this procedure include carbon-14, sodium-22, sodium-24, sulfur-35, phosphorous-32, strontium-yttrium-90, iodine-131, thallium-204. The sodium carbonate-C^{14} standard has been recalibrated, and a benzoic acid-C^{14} in toluene has been prepared and calibrated. Preparations are well underway for the calibration of hydrogen-3 and sulfur-35 standards by absolute gas counting, and these measurements should be made shortly.

Plans have been started for a study of adsorption of radionuclides on glass. Of particular interest are the adsorption of low concentrations of radionuclides from solution, and the adsorption of carbon dioxide on glass. In the latter case, it is planned to use carbon-14 as a tracer, and also to try to determine the effect of relative concentration of carbon-14 on the adsorption.

Nuclear Disintegration Studies. Using the techniques of beta- and gamma-ray spectroscopy combined with cryogenic techniques for achieving nuclear polarization, experimental investigations are under way to determine detailed mechanisms of radioactive disintegration processes. The results of these studies have had a profound effect on the understanding of the weak interaction process and elementary particle physics in general and are currently contributing to the understanding of certain aspects of nuclear structure.

The rapid developments in the field of nuclear spectroscopy in the past few years have greatly extended the scope of this project. While nuclear spectroscopy used to imply the measurement of the energies and intensities of radiations emitted by certain nuclides so that a complete disintegration scheme could be made, the connotation of the term now implies that measurements are also made of the correlations among the direction of emission and the polarizations of the radiations and the polarizations of the parent and daughter nuclei.

The emphasis of the program has been to study those nuclides that are of considerable theoretical or experimental interest. Examples of these are cobalt-60, cobalt-58, and cobalt-56 used in the study of parity nonconservation effects for both electron and positron emitters and manganese-52 for the study of time reversal invariance and the role of isotopic spin admixtures in the relative contribution of spin-flipping and non-spin-flipping beta transitions. Currently measurements are being made with beta emitters where a change of parity is involved. The matrix elements in these transitions depend rather sensitively on the radial details of the nuclear wavefunctions. This relativistic type of matrix element occurs only in the beta-decay process.

This type of measurement of the beta decay from polarized nuclei was first performed in this laboratory, and this laboratory is the only one in the United States and one of few in the world that has a program of this type of nuclear spectroscopy.

3. Radiation Theory Section (4.03)
L. V. Spencer, Acting Chief

This Section operates under several broad objectives: (1) to constitute the focal point for the theoretical work of the division, (2) to investigate the problems of radiation penetration and diffusion in matter, and (3) to produce, collect, and evaluate fundamental data on radiation constants and properties.

General Theoretical Work. A considerable amount of consultation on the theoretical aspects of work of other Sections is in progress at all times. Where a sustained theoretical effort has been necessary in other Sections, theoretical personnel have been added to their staffs. Nevertheless, some work on targets of opportunity has been in progress in the Nuclear Physics Section at all times. For example, considerable effort has been devoted to problems of nuclear theory.

Radiation Penetration and Diffusion. A few years ago, there existed an important gap in our knowledge of the action of high-energy radiations on matter. On the one hand, the elementary processes are to a great extent well understood and are under attack by the most advanced centers of research in physics. On the other hand, for most conditions encountered in practice, the action of radiation on matter involves a large number of atomic processes. The resulting complication of radiation phenomena caused the work on radiation protection to rely on large-scale tests of an engineering character whose results could not be extrapolated to different conditions. This situation affected not only the development of ordinary radiological protection but even more the novel and extensive design of nuclear reactors and of devices for radiological defense. The importance of a solid knowledge in this field for naval and aircraft propulsion and for atomic warfare and defense needs hardly be stressed and is demonstrated by the large sums spent by various agencies for shielding and for related purposes.

This problem has been under continuous study since 1948 with the support of the Office of Naval Research and the Atomic Energy Commission, and later also of the Defense Atomic Support Agency and the Office of Civil and Defense Mobilization. Almost complete solutions of the theoretical problems of gamma-ray and electron penetration and degradation in infinite media have been obtained (under conditions where the shower mechanism is unimportant). Some model experiments have provided satisfactory experimental verification of the theory.

The theoretical progress has been achieved by preliminary analytical solutions of schematized problems, utilized in later steps as mathematical models to be fitted to the actual situation by numerical calculations. Additional results are also provided by Monte Carlo calculations, which provide in effect the solution of schematized experimental problems.

Related experimentation, especially on electron penetration and diffusion, is carried out by other Sections. Studies of back-scattering and transmission of electrons and positrons performed in the last few years in the Radioactivity Section (4.02) fall in this line.

Data on Radiation Interactions. Data on elementary processes of interaction of radiations with matter constitute the starting point for the solution of specific complex problems. Such data are adequately available from theory only for processes that involve one or two atomic particles. Processes involving many-electron atoms are inadequately known in detail even though their theoretical principles are well established. Experimental data cover only a small fraction of the required range of information. Here again, as in the theory of radiation diffusion, the problem is to develop effective computational methods to deal with a complicated situation, and an attempt is being made to apply to this problem the techniques that have been developed for radiation diffusion.

Because the data on gamma-ray absorption are spotty and contain serious gaps in certain energy regions, a compilation, evaluation, and analysis of known data has been prepared and has met with great success in its circulation. A series of publications is planned that will provide critical data and a discussion of present knowledge on various effects of radiations on matter. In addition to the work on gamma-ray absorption, completed tasks include detailed and complete calculations of the Compton scattering law, studies of the distribution of oscillator strengths and of atomic form factor, and electron ranges and stopping powers.

The work carried out thus far in this line of critical analysis has clearly shown a requirement for a basic theoretical attack upon the problem, going much beyond the original formulation of the project. Increasing attention is being devoted to this phase of the work, the more so because university laboratories that used to lead in this field have recently been pushing in other directions.

4. High Energy Radiation Section (4.04)
H. W. Koch, Chief

The program of the High Energy Radiation Section deals with the study of X-ray and electron interactions with matter in the energy range from 2 to 180 Mev. An understanding of this program and its relation to the Bureau's mission of providing basic data, standards, and technique developments requires an appreciation of our present inadequate knowledge of the details of the interaction of X-rays and electrons. This section was established in order to satisfy the need for some of the basic data and physical measurement techniques required in various areas of science and technology. An increasing application of high-energy radiations is being made to radiology, radiography, nuclear physics research, and the recent radiation processing of materials by the use of intense, high-energy electron beams. The research of the section has resulted in data on fundamental electromagnetic interactions (i.e., bremsstrahlung and pair production) and on fundamental photonuclear interactions (i.e., elastic nuclear scattering, total nuclear absorption, photoneutron, photoproton, and photomeson cross sections); also, this research has resulted in the development of instruments and standards for the measurement of X-ray intensity and absorbed dose and has formed the basis for contributions by staff members to various national advisory committees.

The research of this section is conducted by a total of 20 people working with two electron accelerators, a 50-Mev betatron and a 180-Mev synchrotron. In addition, a third accelerator - a 100-Mev linear electron accelerator (linac) with 40 kilowatts in the electron beam - has been funded by Congress. This new accelerator will produce the same energies and radiations as the existing betatron and synchrotron. However, the electron beam powers from the linac will be 100,000 times the powers presently available. This accelerator will, therefore, make possible many new types of investigation not possible with the present accelerators.

A. Present Program

Detailed knowledge of the interaction of high-energy X-rays with matter requires an examination of the characteristics of the X-ray source, the X-rays, and their macroscopic and microscopic interactions with atoms and nuclei. This complete examination is required especially for a nuclear physics program and can be useful in a thorough understanding of all other applications of high-energy radiations. The High Energy Radiation Section has emphasized a program of basic research and has, therefore, carried out an active program with the betatron and synchrotron in the following fields: 1) Photonuclear Physics; 2) Radiation Physics; and 3) Measurement Techniques and Standards. These programs have led to significant data for inclusion in the recommendations made by the National Committee on Radiation Protection and Measurements.

1. Photonuclear Physics. The high-energy X-rays from the betatron and synchrotron are being used to study the X-ray interaction with the atomic nucleus. The predominant processes that result from this interaction are neutron and proton emissions around 20 Mev and meson emissions around 150 Mev.

a. Photoneutron Cross Sections. A detailed examination of the shape of the photoneutron cross section has been made for a wide range of target materials. This cross section has a simple resonance shape for a spherical nucleus such as gold or lead. However, for a deformed nucleus, such as tantalum, the cross section is composed of two resonances peaked at 12.5 and 15 Mev. Both the theory and experiment of this process were developed at NBS and have resulted, as a by-product, in a relatively accurate method of measuring nuclear quadrupole moments or nuclear deformations.

b. Photoproton Cross Sections. The photoproton cross section of carbon in which the residual boron nucleus is left in the ground state has been measured. This cross section is shown to decrease from its value at the giant resonance peak-energy of 22 Mev to about one hundredth of this value at 60 Mev. Angular distributions measured at five energies exhibit an asymmetry around 90° which increases rapidly with increasing energy. In addition to these and other cross-section data that are of interest to nuclear theorists, the measurements provide a sensitive means of calibrating the energy scales of electron accelerators at energies in the 25 to 50 Mev region.

c. Photomeson Cross Sections. Angular distributions of neutral mesons photoproduced by 170-Mev bremsstrahlung from the synchrotron have been measured for carbon, aluminum, copper, cadmium, and lead. The experimental distributions have been compared to Monte Carlo predictions and thereby have provided a 3% measurement of the r.m.s. radii of nucleon center distributions. These results are 0.3 fermi lower than the electron scattering results obtained at Stanford University, which measure the r.m.s. radii of charge distributions. The difference is understandable on the basis of the proton size. The photomeson data also provide an accurate method for calibrating the synchrotron energy scale at 137 Mev.

d. Nuclear Elastic Scattering Cross Sections. Differential cross sections for the elastic scattering of X-rays by the nucleus have been measured at X-ray energies ranging from 4 to 40 Mev for a wide range of atomic numbers. The cross sections versus energy tend to exhibit two maxima, one below the particle threshold that corresponds to scattering by individual nuclear levels, and one that is related to the giant resonance for X-ray absorption. The dispersion relations have been used to relate X-ray absorption with the scattering in the giant resonance region and have provided a valuable check on the absolute absorption cross sections inferred from photoneutron cross section measurements. For the deformed nuclei, such as tantalum, holmium, and erbium, the scattering cross sections when compared with the predictions made by the dispersion relation from the measured absorption cross section strongly support the hypothesis that the polarizability of these nuclei has a tensor character.

The scattering from the single 15.1-Mev level in C^{12} has permitted an evaluation of level parameters for that level. The knowledge of the width of this level has been very important to recent developments in the theory of weak interactions. It has also provided the most accurate method available for calibrating the absolute energy scale of a high-energy accelerator at 15.1 Mev.

e. Total Nuclear Cross Sections. Total nuclear cross sections between X-ray energies of 15 and 80 Mev have been measured using long absorbers of carbon, water, and aluminum. A scintillation spectrometer developed at NBS has been able to resolve the total nuclear cross sections in the X-ray spectra transmitted by the absorbers and to locate the energies and magnitudes of the gross structure in these cross sections.

2. Radiation Physics.

a. Pair Production Cross Sections. The long absorber technique employing the good resolution spectrometer has also been used to evaluate the total attenuation cross sections for 60-Mev X-rays on carbon, water, and aluminum. The analysis of the data suggests that the experimental results are larger than the theoretical predictions by about 2% and attributes the difference to the pair process. Recent calculations show that the radiative corrections to the pair production process approximately confirm the experimental conclusions.

b. Bremsstrahlung Cross Sections. Experimental determinations of the cross sections for the production of X-rays by the bremsstrahlung process have been made. The resonance fluorescence of the narrow 15.1 Mev level in carbon was used to measure the shape of the high-energy tip of the X-ray spectrum with very good energy resolution. A scintillation spectrometer was used to measure the absolute differential cross sections at other parts of the spectrum for beryllium, aluminum, and gold. Based on experiments such as these, a critical review of experiments and theories of the bremsstrahlung process has been published in collaboration with the X-ray Section (4.01).

3. Measurement Techniques and Standards.

a. Calorimeter for Measuring X-ray Beam Energy. The total integrated X-ray energy incident on a patient or experimental arrangement is a physical quantity which can be measured accurately. This section has used both a calorimeter and a scintillation spectrometer to measure this quantity. These measurements can be used to calibrate a continuous duty monitor so that its response serves as an indication of the total X-ray energy. The section can now assist in the routine calibration of transmission monitors of this type. A standard instrument has been developed and experimentally calibrated so that when it is placed in a bremsstrahlung beam with a peak X-ray energy between 6 and 170 Mev, and a diameter of less than 20 centimeters, the ionization charge collected during the X-ray exposure can be used to evaluate the total energy to within ±2%. Several of these standard instruments have been calibrated and are available on loan to transfer the NBS absolute calibration to other laboratories.

b. Absorbed Dose Calorimeter. The development of an absorbed dose calorimeter has also been undertaken along with an investigation of the feasibility of using this calorimeter to calibrate a small volume ionization chamber. Absorbed dose rates of 50 ergs/gram-sec can be measured with the calorimeter to within 2% accuracy. This effort is part of the division's basic dosimetry studies. There is no plan to use the results to incorporate a calibration service for absorbed dose instruments.

c. Absolute Calibrations of Accelerator Energy Scales. Nuclear constants, such as photoneutron, photoproton, and photomeson thresholds, are important for providing calibrations to the energy scales of electron accelerators. However, these thresholds cannot supply a detailed examination of the stability and pulse-to-pulse variations in energy of the betatron and synchrotron. Therefore, an instrument was developed which can do this and is capable of measuring time-varying and space-varying magnetic fields such as are encountered in circular particle accelerators (i.e., betatrons, synchrotrons, and cosmotrons). The instrument uses electron paramagnetic resonance of the free radical in the DPPH molecule. Magnetic fields over a range from 2900 to 4200 gauss and rates of rise of about 3500 kilogauss sec^{-1} can be measured to a 0.1% accuracy.

d. X-ray Scintillation Spectrometer. Continuing efforts to improve the energy resolution of high-energy scintillation X-ray spectrometers have been made. The latest results have produced a sodium-iodide spectrometer with a resolution of 2.5% at 17.6 Mev, which is comparable to that of a pair spectrometer, but with a detection efficiency several orders of magnitude better than the pair spectrometer. The improved resolution was obtained by placing a second crystal spectrometer so as to detect a single annihilation photon escaping from the front surface of the main spectrometer crystal which was a 9 inch diameter by 6.4 inch long sodium iodide crystal. The second crystal was set in coincidence with the main crystal.

B. Future Programs

1. Photonuclear and Radiation Physics. Many of the experiments completed at NBS with the betatron and synchrotron involve processes that occur very infrequently. The increase in intensity by a factor of 100,000 that appears possible with the new accelerator would make possible and productive a whole new area of research. Precision experiments on elastic and inelastic scattering of electrons and positrons will be possible and should supply unique information on fundamental electromagnetic and nuclear processes. Other experiments that previously required months of effort and exposure time, if achievable at all, might now be accomplished in hours. For example, it will probably be possible to measure the polarization effects in the nuclear photoeffect that will provide extremely valuable information regarding nuclear wave functions. Polarization investigations are almost non-existent with conventional electron accelerators. In addition, the proposed accelerator will produce strong beams of positrons and neutrons, and relatively strong beams of monoenergetic X-rays that can be used for research. None of these radiations are produced in sufficient quantities with the betatron and synchrotron to be used for direct experimental studies.

2. Absorbed Dose Standards and Measurement Techniques.

a. Dosimetry. Existing dosimetric standards are based on absorbed doses of hundreds of rads and dose-rates of tens of thousands of rads per hour. Nuclear physics research, personnel protection studies, investigations of solid state phenomena, and industrial developments have created pressing needs for additional standards. In addition, the military services are rapidly developing needs for standards in the range from 100,000 to 10 million rads and future demands for standards at 10 billion rads can be predicted with certainty. The proposed accelerator will provide 100 billion rads per hour. This dose rate, added to those available from the existing cobalt, radium, X-ray and electron beam sources at NBS, will make it possible to conduct investigations of dosimetry problems in most of the important ranges of energies and dose rates presently in use or expected in the foreseeable future. Considerable effort must be expended over a long period of time, however, in order to achieve the accuracy necessary to establish national standards.

b. Physical Measurement Techniques. A prerequisite to the work on dosimetry or any research with the accelerator will be the development of controls for the intense electron beams. Instruments must be developed to monitor the electron-beam current, the energy, and the spatial distribution of the beam. Magnetic systems of different types must be devised to analyze and focus the beam. The development of better methods for controlling and measuring electron beams will continue to be important during the lifetime of the accelerator. While these techniques will be needed for the proper use of the machine by NBS, they are also applicable to the use of such machines by other research institutions and by industrial organizations. NBS should serve a leading role in the development of such new measurements and control techniques.

c. Shielding. Detailed theoretical and experimental research on the absorption of high-intensity, high-energy X-ray and neutron beams by concrete, lead, and other materials should be carried out to provide data for use in the design of shielding for future industrial and government installations. The requirements described in the section on facilities for the NBS installation call for 12-foot thick concrete barriers and a 100-foot exhaust stack to remove safely the ozone and radioactivities produced in the air of the laboratory rooms. These dimensions point up the immediate need for accurate design data to promote the efficient and economical design of other installations. Past studies of lower intensity sources at NBS have been of great service to hospitals and laboratories in reducing costs while at the same time assuring safe radiation levels for personnel in radiological installations.

5. Radiological Equipment Section (4.05)
S. W. Smith, Chief

The program of the Radiological Equipment Section is, for the most part, centered about experimental problems involving standards for low- and medium-energy X-rays and gamma rays, of both dosimetric and performance character. It may be conveniently divided into the following categories: (1) primary and secondary standards, (2) certification of radium and calibration of encapsulated gamma-ray sources, (3) radiological instruments calibrations and investigations, (4) investigations in radiation dosimetry with photographic emulsions, chemical systems, solid state devices, etc. and (5) high-intensity gamma rays for irradiation purposes.

Primary and Secondary X-ray Standards. The laboratory has, since 1928, maintained primary guarded-field free-air standard ionization chambers against which all moderate energy X-ray exposure dose measurements in this country are compared. The standard which covers the range of 60 to 250 kv, has been compared with a number of European standards indicating close agreement. A free-air chamber for lower energy X-rays in the range 20 to 100 kv has been constructed and its characteristics studied. The design factors for a standard for Grenz rays generated at 5 to 30 kv are being investigated. Standards for measurements at low energies for the very high dose rates (up to 10^6 r/min) from beryllium-window X-ray tubes are of particular importance.

Secondary standards, usually in the form of cavity or enclosed chambers, have been under continuous study by the laboratory for many years. A wide variety of these have been investigated and developed, and further studies are underway. Chambers of this type have been developed (4.01) for use as transfer standards for intercomparing the free-air standard chambers of various countries. Measurements so far carried out have indicated their usefulness for this purpose. Cavity chambers have been used for the calibration of the laboratory's standard gamma-ray collimated-beam instrument ranges. They have been used also for the calibration of radiac instrument calibration ranges employing Co^{60} or Cs^{137}, developed for the Navy and Signal Corps. Considerably more than a hundred of these calibration ranges have been calibrated by the laboratory for these agencies.

Certification of Radium and Calibration of Gamma-Ray Sources. The Gamma Ray Laboratory was specifically designed to carry out the measurement of encapsulated radium, Co^{60}, Cs^{137}, and other gamma-ray sources. Improvement in the measurement techniques and calibration procedures has resulted in substantial increases in efficiency without sacrificing accuracy requirements, and at the same time has achieved a reduction in radiation exposure to personnel. The radium measurements are in terms of radium content certified to 0.7 percent, and most of these sources are used for medical treatment purposes. Small cobalt-60 preparations are measured in terms of roentgens per hour at a given distance and are generally used as laboratory standards.

Radiological Instrument Calibrations and Investigations. Radiation instruments, usually of the condenser ionization-chamber r-meter type, are submitted by instrument manufacturers, medical institutions, research laboratories, the public and other Government agencies, for calibration as laboratory secondary standards, on X-rays of various energies and gamma rays. The number of requests for such calibrations has made it necessary to place some limitations on the frequency of recalibration and the number of calibration points for a given laboratory, in order to make this service both effective and available to the maximum number of laboratories requiring it.

All types of radiation detection and measuring instruments and devices are calibrated for energy dependence, dose-rate dependence, and other factors affecting the instruments' response to radiation. These instruments include ionization chambers, Geiger-Mueller counters, scintillation counters, chemical-solution dosimeters, radiation-sensitive glasses, etc. A major portion of this program is conducted for the Department of Defense, Atomic Energy Commission, and Civil Defense, who are engaged in large-scale development and procurement programs. For a number of years, agencies lacking testing facilities have submitted prototype instruments for evaluation of sensitivity, energy dependence, and other characteristics. On the whole, the Bureau's Radiation Physics Laboratory probably has the most completely staffed and equipped laboratory for this type of work in the country. The results of the studies carried out for the above agencies are put into report form and distributed to the interested agencies.

Radiation Sensitometry of Photographic Emulsions and Dosimetry With Chemical, Solid State and Other Devices. The laboratory has been conducting a broad program for investigating the radiation sensitivity of photographic emulsions for more than ten years. Investigations of the sensitometric factors for most commercial films, with regard to energy dependence, useful range, and rate dependence, have been carried out, and are being continued and extended. This has covered a wide range of energy, exposure dose, and exposure dose rates for X- and gamma rays, and for neutrons and electrons. Particular emphasis has been placed on attempts to extend the useful range of film dosimeters in both directions, such that gamma-ray doses in the range from 10^{-2} to 10^{8} r may now be measured with good precision, using commercially supplied films

Measurements made with film-scintillator combinations showed that exposure doses as low as 10^{-4} r can be measured, but that rate dependence at the lower rates limits the accuracy. Interpretations of total exposures in the range from 10^4 to 10^8 r were made possible by measuring changes in the transmission of near-infrared by the films, as a result of increased print-out darkening by exposures in the megaroentgen range.

Processing and calibration procedures have been studied to arrive at optimum procedures, particularly for use with energy-independent film dosimeters. The validity of the reciprocity law for instantaneous bursts of X-rays at intensities up to 1100 r/sec has been substantiated for the ascending branches of the characteristic curves, when vigorous processing is used. Reciprocity law failure and associated variations in curve shape, as well as changes in the maximum density levels, were demonstrated for the reversal branches of the curves, when nonvigorous processing is used. The possibilities of serious misinterpretation of doses as a result of these variations have been noted. Tests of the reciprocity law at intensities up to 10^6 r/sec are in process.

Extensive studies of the photographic response to successive exposures of different types have been carried out, including double exposures to X- and γ-radiation of different photon energy and intensity, to gamma radiation and visible light, and to visible light and infrared radiation. It was shown that it is possible to predict the gross photographic behavior as a result of exposures to two types of radiation in succession. Further studies including other radiation types and evaluation methods are planned.

Studies of effects of variations of temperature and relative humidity, both during exposure and during storage of the film before processing, have been performed. These results are important for evaluating personnel dosimetry procedures in which films are allowed to remain in their holders over periods of up to three months, before being processed and read. Special intercomparisons and evaluations of various personnel monitoring facilities have been made, resulting in suggestions for standardizing and improving the methods employed by various Government and private laboratories.

Calculations were carried out to determine the relative response of photographic emulsions to X- and gamma-ray photons, to electrons, and to neutrons on the basis of energy and number of quanta truly absorbed in the emulsion, and these data were compared with experimental results.

Increasing interest is being shown in the use of solid-state devices for measuring ionizing radiations. Solid-state devices are of rugged construction, can be produced in small sizes, are simple to operate and have a long shelf life. They also show very good reproducibility in the measured radiation effects and have a quick response.

Measurements were carried out to investigate the possibility of using silicon solar cells for dosimetry of ionizing radiations. Silicon solar cells, which are photovoltaic cells of the p-n junction type, showed a favorable response of such cells to X-rays with regard to proportionality to exposure dose, response time and dependence on photon energy. Measurements are being carried out to establish the influence of radiation damage on the photoresponse of such cells at high exposure dose rates of high-energy radiations. Investigations will be further extended to other solid state devices, in order to develop a solid state dosimeter suitable for X- and gamma rays.

Radiation-induced chemical reactions are used in increasing measure for quantitative measurement of ionizing radiations. Different systems have been developed which show a high stability and allow a high degree of accuracy in measuring the product of the radiation chemical reaction. Chemical dosimeters allow the direct measurement of absorbed energy. They consist usually of aqueous solutions which have an absorption characteristic similar to that of body tissue and body fluids. Chemical dosimeters can be used for different types of radia- over a wide range of doses and dose rates.

The most widely used system of chemical dosimetry is the ferrous sulfate dosimeter (Fricke dosimeter). Investigations were carried out of the energy dependence of G-values (ferric ion yield per 100 ev absorbed energy) for medium energy X-rays. The values obtained showed a good agreement with values obtained with high-energy X- and gamma rays. Further measurements are being carried out under different experimental conditions to confirm the obtained values. An investigation has been completed of the spectrophotometric method of determining the radiation-produced ferric ion yield. It has been shown that the sensitivity of this method can be increased by measuring the absorbance of the irradiated ferrous sulfate solution at a wavelength of 224 $m\mu$, instead of 304 $m\mu$, as is the usual standard method. Smaller temperature dependence and less acidity dependence of the absorbance at 224 $m\mu$ is a further advantage of this method. Investigations will be extended to other chemical dosimetry systems.

High Intensity Gamma Rays for Irradiation. Investigation of the radiation effects on materials and of the sterilization of foods and pharmaceuticals with radiation has greatly increased the dose rates required, and thus, the need for extended or new dosimetry procedures. A 2000-curie Co^{60} source, consisting of 12 capsules arranged in a circular array and shielded by water in a 12-ft pool, has been used for the past five years for important investigations carried out, such as the study of the effects of irradiation of polymers. As the duration of exposure required with the 2000-curie Co^{60} source is, in many instances, excessively long, a 50,000-curie source is being procured. This will greatly extend the range of radiation effects which can be investigated and, at the same time, permit extension of dosimetric procedures to systems for measuring much higher dose rates.

6. Nucleonic Instrumentation Section (4.06)

L. Costrell, Chief

The Nucleonic Instrumentation Section is concerned with several projects in the instrumentation field and also serves as a complementary unit to other sections in the Division. The Section has a responsibility for the electronic instrumentation needs of the Division. This is a growing responsibility in view of the increase in both quantity and complexity of electronic instrumentation in experimental nuclear physics. The Section develops, designs, and constructs special instrumentation as required for the nuclear physics program of the Division. For this purpose the Section develops and maintains a competence in nuclear detection techniques, in general electronic design, in high speed circuit techniques, etc. The emphasis is subject to continual change as the field advances. For example, though most instrumentation of concern to the section is for microsecond resolution, millimicrosecond and sub-millimicrosecond techniques are receiving increasing attention. These techniques have broad application in several sections in the division. Development and design and the maintaining of a competence in the nuclear instrumentation field is a continuing program that necessitates keeping abreast of the latest developments.

In addition to somewhat conventional instrumentation design, the section undertakes complex developments that fill a need in the nuclear instrumentation field. The charge-storage pulse-height analyzer development of this section fits into this category. The section also utilizes detection instrumentation, to a limited extent in performing specific experiments for which a need exists and which the section, by virtue of its capabilities and its equipment is in a position to handle.

Over the past several years the section has been heavily engaged in special projects for the armed forces and the U. S. Atomic Energy Commission. This has included several weapons test projects involving the expenditure by the section of over four million dollars. Remote-control radiation monitoring systems developed by the section have been used in several tests by the AEC.

A routine function of the section is the repair and maintenance of electronic and radiation detection instrumentation for the division.

7. Neutron Physics Section (4.07)
R. S. Caswell, Chief

Neutron Standards. Ra-Be(γ,n) sources and a moderating assembly producing a measured thermal neutron flux serve as standards for neutron emission rate and thermal neutron flux respectively. The national neutron standard source has been calibrated by two methods: (1) by the activation of calibrated foils in a water bath; and (2) by activation of a manganese sulfate solution in water. A new calibration is underway using a Sb^{124}-Be photoneutron source in heavy water. This method eliminates uncertainties due to the ratio of the manganese activation cross section and the hydrogen thermal neutron disappearance cross section. The national standard source is then compared to the absolutely calibrated Sb^{124}-Be source by a precise, but relative, method.

The standard thermal neutron flux has been recalibrated by a method based on the thermal neutron activation cross section of gold, using 4π β-γ coincidence counting. The new calibration, together with a previous calibration based on the thermal neutron reaction cross section of boron, provides a flux known to about 1.5% (standard error). Intercomparison of this flux with the absolutely calibrated fluxes of other laboratories in the United States and in the world has been underway for several years and is continuing.

Neutron sources calibrated by NBS are used as standards for fast neutron flux measurement, cross section measurements, fast neutron dosimetry, and to produce known thermal neutron fluxes in moderators. Gold foils activated in the standard thermal neutron flux are used chiefly by groups working with nuclear reactors to check or to establish their own thermal neutron flux measurements.

Neutron dosimetry measurements are made with proportional counter detectors which distinguish between neutrons and gamma rays. The neutron dosimeter (γ-insensitive) is calibrated in known fluxes of monoenergetic neutrons from the Van de Graaff accelerator. The gamma ray dosimeter (neutron-insensitive) is calibrated in X-ray and gamma-ray fields of known exposure dose. The pair of instruments is then used in mixed gamma ray and neutron radiation fields to determine the doses.

A precision long counter is being developed in cooperation with Hanford Laboratories as a standard instrument for the measurement of fast neutron flux.

Neutron Penetration. Measurements have been made of the thermal neutron distribution, the indium resonance age and the fast neutron distribution about monoenergetic neutron sources in water and heavy water. The current experiment on fast neutron dose from 4.0 Mev neutrons in water is to be followed by spectral measurements of neutrons from monoenergetic sources following penetration through various shielding materials.

<u>Neutron Cross Sections</u>. Experimental measurements of neutron elastic and inelastic cross sections and angular distributions by time-of-flight are being carried out on the 2-Mev Van de Graaff accelerator. Measurements for calcium and carbon at 14.0 Mev are partially complete. The beginning of the neutron flight is indicated by detection of the alpha particle from the $H^3(d,n)He^4$ reaction which produces the neutron. The scattered neutron is detected in a large plastic scintillator after a flight from the scattering sample of 1.2 meters. Internal pulsing for the accelerator and an astigmatic Mobley magnet system, both on order, will reduce backgrounds and sharpen time resolution (below the 2.5 nanosecond currently obtained) and permit measurements at energies of 5 Mev and below.

Polarization experiments for spin-zero nuclei will be carried out using the pulsed beam from the Van de Graaff accelerator for spin zero nuclei. It is hoped in the future to use aligned nuclei in cooperation with members of the Cryogenic Physics section.

Theoretical calculations using the nuclear optical model are being made of neutron cross sections and polarization. These calculations give results directly comparable to the elastic scattering measurements and to the polarization experiments. In addition results of these calculations are useful for neutron penetration. Calculations such as the moments method code being developed in the Radiation Theory Section are of considerable importance.

8. Health Physics Group

The Health Physics Laboratory has as its main objective the maintenance throughout the National Bureau of Standards of good practices in the handling of ionizing radiations and radioisotopes. It is charged with monitoring of personnel, machines giving rise to ionizing radiations such as X-ray machines, X-ray spectrometers, cyclotrons, betatrons, and Van de Graaff generators, as well as laboratories in which radioisotopes are used. In connection with the use of isotopes, it is sometimes necessary to make bio-assays for such nuclides as tritium and uranium. Some development work is in progress for the determination of Sr^{90}.

The laboratory offers its services to anyone in the Bureau desiring to install equipment or laboratories and in need of advice on shielding, type of equipment required, handling of wastes and other related problems.

VIII ACTIVITIES ASSOCIATED WITH OUTSIDE ORGANIZATIONS

In addition to its experimental and theoretical programs, the Radiation Physics Division has definite and immediate responsibilities in certain specific areas, the two most important of which are radiation protection and radiological units. Activities in these fields are carried out mainly through participation in the committee activity of national or international organizations. One form of this participation is the provision of information and data developed in the research program for use in the published reports of the various organizations.

National Committee on Radiation Protection and Measurements

One of the Division's major programs has been in the field of radiation protection, through the medium of the National Committee on Radiation Protection and Measurements. This activity cuts across all of the Sections of the Division. The National Committee on Radiation Protection and Measurements was organized and sponsored by the National Bureau of Standards in 1929, and is now recognized as the focal point for radiation protection activities in the United States. The principal participating organizations are the national radiological and medical organizations, United States Public Health Service. Atomic Energy Commission, and the three military services. At present, it has published 28 handbooks and several others are in preparation. These cover such fields as permissible internal and external radiation dose, medical X-ray protection, radium protection, betatron protection, neutron protection, radiological instrumentation, safe handling of radioactive isotopes, radioactive-waste disposal, and radioactive decontamination.

International Commission on Radiological Units and Measurements

The International Commission on Radiological Units and Measurements (ICRU), since its inception in 1925, has had the responsibility for developing (1) the basic principles of units, standards, and measurements needed in radiation dosimetry; and (2) the specification of radiation treatment. In connection with its radiation standards program, the Radiation Physics Division has been an active participant in all related ICRU committee activities for the past 25 years. Several members of the Division staff are active in the programs of the ICRU and the chairmanship and secretaryship of the Commission have been held by Division staff members for several years.

International Bureau of Weights and Measures

The International Bureau of Weights and Measures was established in 1875. This organization provides a central point for the intercomparison of national standards. Initially, it dealt with standards of length and mass but as new fields opened up its scope was broadened. Recently it was decided to include the measurement of ionizing radiations.

Members of the Radiation Physics Division were active in the discussions leading to the decision and in the preparation of recommendations for the organization's activities in this field. Division personnel are also members of the group which reviews future activities of the International Bureau in the radiation measurement field.

International Commission on Radiological Protection

The International Commission on Radiological Protection is concerned with the international formulation and implementation of the basic principles of radiation protection. The membership of the ICRP and its several committees has for many years included members of the staff of the Radiation Physics Division. Participation in the activities of the Commission has been continuous since its formation in 1928, and one of the staff members was its secretary for 14 years. Through its activities involving the National Committee on Radiation Protection and Measurements, this Division provides an ideal tie between the two organizations.

Federal Radiation Council

The Federal Radiation Council was formed in 1959 to provide a Federal policy on human radiation exposure. A major function of the Council is to advise the President with respect to radiation matters, directly or indirectly affecting health, including guidance for all Federal agencies in the formulation of radiation standards and in the establishment and execution of programs of cooperation with States. The Council has established a Working Group and a Division staff member acts as the Commerce Department representative on this group. Staff members have also been members of the temporary staffs utilized by the Council in the preparation of its reports.

American College of Radiology Commission on Radiologic Units, Standards and Protection

This body was formed in 1946 to coordinate the activities of the several national radiological organizations in the United States; it is an outgrowth of the consolidation of the corresponding committees of these societies. Division staff members have been quite active in the Commission programs and the chairmanships of these committees had for many years before 1946 been held by Radiation Physics Division staff members, as is the secretaryship of the new group.

American Standards Association - Nuclear Standards Board

The National Bureau of Standards has actively supported the programs of the American Standards Association in furthering the development of standards of practice such as codes, specifications, and safety standards. Radiation Physics Division staff members have been quite active in these efforts. The Safety Code for the Industrial use of X-rays (ASA, 54.1) was prepared in 1946 by the ASA Safety Standards Board under the sponsorship of NBS. A new code on this subject is now in preparation and Division staff members are participating in this work.

Because of the rapid development of application of nuclear energy, the ASA in 1957 established the Nuclear Standards Board to develop standards in this field. Division staff members are active on the Nuclear Standards Board itself and on a number of the Sectional Committees established by the Board to deal with specific problems.

In addition to the above activities, Radiation Physics Division staff members work actively with numerous other committees whose main interests are in line with the general Division program.

U. S. DEPARTMENT OF COMMERCE
Luther H. Hodges, *Secretary*

NATIONAL BUREAU OF STANDARDS
A. V. Astin, *Director*

THE NATIONAL BUREAU OF STANDARDS

The scope of activities of the National Bureau of Standards at its major laboratories in Washington, D.C., and Boulder, Colorado, is suggested in the following listing of the divisions and sections engaged in technical work. In general, each section carries out specialized research, development, and engineering in the field indicated by its title. A brief description of the activities, and of the resultant publications, appears on the inside of the front cover.

WASHINGTON, D.C.

Electricity. Resistance and Reactance. Electrochemistry. Electrical Instruments. Magnetic Measurements. Dielectrics.

Metrology. Photometry and Colorimetry. Refractometry. Photographic Research. Length. Engineering Metrology. Mass and Scale. Volumetry and Densimetry.

Heat. Temperature Physics. Heat Measurements. Cryogenic Physics. Equation of State. Statistical Physics.

Radiation Physics. X-ray. Radioactivity. Radiation Theory. High Energy Radiation. Radiological Equipment. Nucleonic Instrumentation. Neutron Physics.

Analytical and Inorganic Chemistry. Pure Substances. Spectrochemistry. Solution Chemistry. Analytical Chemistry. Inorganic Chemistry.

Mechanics. Sound. Pressure and Vacuum. Fluid Mechanics. Engineering Mechanics. Rheology. Combustion Controls.

Organic and Fibrous Materials. Rubber. Textiles. Paper. Leather. Testing and Specifications. Polymer Structure. Plastics. Dental Research.

Metallurgy. Thermal Metallurgy. Chemical Metallurgy. Mechanical Metallurgy. Corrosion. Metal Physics*

Mineral Products. Engineering Ceramics. Glass. Refractories. Enameled Metals. Crystal Growth. Physical Properties. Constitution and Microstructure.

Building Research. Structural Engineering. Fire Research. Mechanical Systems. Organic Building Materials. Codes and Safety Standards. Heat Transfer. Inorganic Building Materials.

Applied Mathematics. Numerical Analysis. Computation. Statistical Engineering. Mathematical Physics.

Data Processing Systems. Components and Techniques. Digital Circuitry. Digital Systems. Analog Systems. Applications Engineering.

Atomic Physics. Spectroscopy. Radiometry. Solid State Physics. Electron Physics. Atomic Physics.

Instrumentation. Engineering Electronics. Electron Devices. Electronic Instrumentation. Mechanical Instruments. Basic Instrumentation.

Physical Chemistry. Thermochemistry. Surface Chemistry. Organic Chemistry. Molecular Spectroscopy. Molecular Kinetics. Mass Spectrometry. Molecular Structure and Radiation Chemistry.

* Office of Weights and Measures.

BOULDER, COLO.

Cryogenic Engineering. Cryogenic Equipment. Cryogenic Processes. Properties of Materials. Gas Liquefaction.

Ionosphere Research and Propagation. Low Frequency and Very Low Frequency Research. Ionosphere Research. Prediction Services. Sun-Earth Relationships. Field Engineering. Radio Warning Services.

Radio Propagation Engineering. Data Reduction Instrumentation. Radio Noise. Tropospheric Measurements. Tropospheric Analysis. Propagation-Terrain Effects. Radio-Meteorology. Lower Atmosphere Physics.

Radio Standards. High Frequency Electrical Standards. Radio Broadcast Service. Radio and Microwave Materials. Atomic Frequency and Time Interval Standards. Electronic Calibration Center. Millimeter-Wave Research. Microwave Circuit Standards.

Radio Systems. High Frequency and Very High Frequency Research. Modulation Research. Antenna Research. Navigation Systems. Space Telecommunications.

Upper Atmosphere and Space Physics. Upper Atmosphere and Plasma Physics. Ionosphere and Exosphere Scatter. Airglow and Aurora. Ionospheric Radio Astronomy.

NBS