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The National Measurement System for Ionizing Radiations

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Center for Radiation Research
Institute for Basic Standards
National Bureau of Standards
Washington, D.C. 20234

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DEPARTMENT OF COMMERCE * NATIONAL BUREAU OF STANDARDS

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THE NATIONAL MEASUREMENT SYSTEM FOR IONIZING RADIATIONS

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EXECUTIVE SUMMARY

In this study the structure of the National Measurement System for Ionizing Radiation[1] has been investigated for eight classes of radiation users: medical, nuclear power, industrial radiation processing, defense, environmental, science, chemical analysis, and miscellaneous radiation applications. In addition two fields of increasing importance to all radiation users were investigated: regulatory control of radiation and personnel monitoring. Needed major actions on the part of the National Bureau of Standards were identified particularly for nuclear power and its related environmental and safety impacts, medical applications of radiation, assistance to regulatory control of radiation and measurement assurance for personnel monitoring. Brief summaries of system structure and identified needs are given below.

The regulatory control of radiation is a divided responsibility among several groups: the Nuclear Regulatory Commission, the Environmental Protection Agency, the Food and Drug Administration including the Bureau of Radiological Health, the Occupational Safety and Health Administration of the Department of Labor assisted by the National Institute of Occupational Safety and Health of HEW, the U.S. Energy Research and Development Administration,[2] and the Department of Transportation. Forty-seven out of 50 states (plus Puerto Rico) have radiation control laws. The authority for radiation regulation is normally given to state health departments. These departments vary widely in support, staff, and technical competence. They work together to help solve radiation regulation problems through the Conference of Radiation Control Program Directors. Two apparent needs are: (1) all regulators of radiation need to use the same measurement scale -- this can be attained by establishing traceability to NBS; and (2) the great majority of state health departments with responsibility for radiation control would be benefited by a program of technical assistance in radiation measurement. In response to these needs, the NBS Center for Radiation Research (CRR) has (1) instituted a program of measurement assurance testing to establish traceability with quality assurance laboratories of the Nuclear Regulatory Commission, the Environmental Protection Agency, and other regulatory agencies, and (2) instituted a national radiation measurement calibration system for the benefit of the states, regional calibration laboratories, and regulatory agencies.

The study of personnel monitoring has found that in the United States about 800,000 persons considered to be radiation workers wear personnel monitors. The majority of personnel radiation monitoring services are supplied by fewer than 20 commercial suppliers, although government laboratories and the military services largely provide their own service. Two needs are apparent: (1) a reliable measurement assurance testing laboratory is needed to test monitoring services -- this could be NBS or another laboratory traceable to and in close contact with NBS; and (2) monoenergetic neutron calibration fields are needed to test existing neutron personnel monitors and for use in developing improved neutron personnel monitors. NBS actions in response to (1) are under active discussion with the states and other Federal Government agencies. NBS has developed a radiation calibration facility for neutron personnel monitoring with the Energy Research and Development Administration support.

Four medical radiation user groups have been identified: radiation therapy, diagnostic x rays, dental x rays, and nuclear medicine. About 350,000 patients are treated with radiation therapy per year, representing 50-60% of cancer cases. In 1970, 129 million persons received 210 million diagnostic x-ray examinations. In 1974 there were more than 132,000 diagnostic x-ray machines and 142,000 dental x-ray machines. In 1971 there were eight million applications of radiopharmaceuticals given for diagnosis. One patient

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[1] Ionizing radiation is a convenient (but not precisely accurate) term used to describe energetic x rays, electrons, neutrons, gamma rays, beta rays, alpha particles and other particulate radiations such as protons and pi mesons.

[2] Now U.S. Department of Energy.

in four entering the hospital will be administered radioisotopes for diagnostic test(s). Needs apparent from this study include: (1) wider dissemination of NBS dosimetry calibrations through further development of a regional calibration laboratory system; (2) development of primary absorbed dose standards where they do not now exist -- for high-energy (linac and betatron) x rays and for fast neutron radiotherapy; (3) extension of a system of quality control throughout the approximately 8,000 institutions doing nuclear medicine; (4) straightening out problems with radionuclide dose calibrators in collaboration with manufacturers and by provision of appropriate check sources. In each case CRR actions are under way or being developed with others to meet these needs.

The study of nuclear power is concerned with two areas: nuclear fuel cycle operations, and design data and reactor operations. In the first area, a special study by John W. Bartlett, Assessment of the Nuclear Fuel Materials Measurement System, confirmed that the need for accurate accountability of fissionable materials stems not from buyer-seller equity but rather from the need to safeguard nuclear material. The importance of the safeguards problem depends on decisions currently being made -- priority of the breeder reactor (a producer of plutonium), use of mixed-oxide fuels (PuO_2 and UO_2), amount and methods of recycling of plutonium, whether uranium enrichment will be privately owned, and the ground rules for waste management. In any case, it seems almost certain that there will be a need for NBS participation in and technical assistance for a major measurement assurance system for nuclear fuel materials accountability, and discussions on this subject are underway between NBS and the Nuclear Regulatory Commission. At present, NBS programs are responding to needs for new Standard Reference Materials, improvement of the technical base for calorimetry, collaboration with the Energy Research and Development Administration New Brunswick Laboratory in support of the measurement assurance activities of the Safeguards Analytical Laboratory Evaluation (SALE) program, and analysis of materials diversion paths and data requirements. These activities, while valuable in themselves and useful in providing NBS orientation in the safeguards field, by no means constitute a measurement assurance system of the high accuracy and real-time accountability needed if there is to be widespread circulation of nuclear fuel materials in the nation.

In the area of design data and reactor operations, needs are for standards for neutron cross section measurement in support of LMFBR (liquid metal fast breeder reactor), HTGR (high temperature gas-cooled reactor), and thermal neutron power reactor programs; and for measurement standards for in-reactor measurements of neutron fluence and spectra and fission rates in fuel elements. For fission reactors improved cross sections are needed for shielding, fuels, neutron properties of structural materials, integrity of reactor components, and reactor control and safety. For fusion reactors, nuclear cross section data needs are less immediate since the plasma physics problems have not yet been solved; but data will be needed for shielding, heat transfer element design, tritium breeding design, integrity of structural materials, and induced radioactivity problems. Standards for in-reactor measurements of neutron fluence and spectra and fuel element fission rates are important in testing reactor performance versus calculations, testing of fuel, temperatures of fuel, reactor lifetimes, power level, control, and safety. NBS responsed to these needs in 1971 by proposing a neutron standards program aimed at greatly improving the accuracy of standard reference neutron cross sections, and neutron flux densities used to measure other cross sections, and providing standard reference neutron fields for the basis of in-reactor neutron measurements. This program has been funded by NBS and is now at full strength using the NBS linac, Van de Graaff, and reactor.

The field of industrial radiation processing continues to grow, although more slowly than indicated by some earlier predictions. The energy crisis may speed development in this area since radiation processing uses less energy than do corresponding thermal processes. NBS does offer calibration services for the megarad dosimetry range on a limited basis. Establishing measurement service requirements is somewhat hindered by the proprietary nature of this field and the high degree of industrial secrecy. Some needed calibration services are being developed, but no needs for major new programs have been identified.

The study of radiation measurement for national defense has identified needs in the area of high-intensity, pulse x- and gamma-radiation measurement. The NBS action in response has been development of new very intense calibration sources for those who measure this radiation. In the area of Defense Department needs in the measurement of radioactivity, these appear to have been met by NBS programs for development of radioactivity standards, particularly for the noble gases.

The study of environmental radiation measurement confirmed a previously-identified need for environmental radioactivity standards and for environmental radioactivity measurement assurance testing. CRR has recently developed a new series of mixed radionuclide environmental radioactivity standards which are now available to the environmental measurement community, and many measurement assurance tests are being carried out to help members of the community and quality assurance laboratories of the Nuclear Regulatory Commission and the Environmental Protection Agency test and improve their measurement performance. State laboratories receive NBS-traceable standards from NRC and EPA quality assurance laboratories, and participate in measurement assurance testing with them.

In two areas studied, science and chemical analysis, existing programs in support of these fields need to be continued. For science, a data compilation effort on charged-particle stopping powers, ranges, straggling and delta-ray production below about 10 MeV is needed.

Miscellaneous radiation applications utilize radiographic equipment, gauges, irradiators, oil-well logging apparatus, self luminous products, smoke detectors, static eliminators, and heat sources. The annual business in these devices is in excess of 70 million dollars. The most stringent requirements for accurate measurement appear to be at the manufacturing, rather than the user, level. A chief problem is the need for adequate safety measures in the use of this equipment. This problem is being attacked through vigorous NBS participation in voluntary standards committees such as American National Standards Institute (ANSI) Committee N43 which is concerned with promulgating recommendations for safe use of radiation equipment.

Some further support for NBS participation in this work is needed to ensure that these documentary standards are available when needed.

A number of common threads stand out quite strikingly in the studies of the various users of radiation: (1) There is often a need for new NBS measurement standards where they do not exist -- however, where NBS measurement standards do exist their accuracy is generally sufficient for present needs. (2) There is a great need for measurement assurance, especially where regulatory requirements are involved. Usually priorities found in this study are much higher for dissemination of standards to users and carrying out measurement assurance testing than for development of new measurement standards. (3) A need exists for help to the poorly-qualified user -- training, convenient laboratory standards, handbooks for guidance. (4) A single measurement system under NBS leadership is needed to help both regulators and users, to avoid duplication and competition among regulators, to simplify the radiation user's problems of measurement and reporting, and to protect the health and safety of the public. (5) Needs for NBS to play its traditional "independent third party" role are often found.

1. INTRODUCTION[1]

The use of ionizing radiation is very widespread today, principally through the rapidly increasing use of nuclear energy for the production of electric power needed by the world, and the growing breadth of applications of radiation in medical practice and in industry. As a consequence, accurate radiation measurements are of increasing importance. Measurements of about 1% accuracy of neutrons, x- and gamma-rays, and radioactivity are needed to obtain data for the efficient design of nuclear power reactors. Accuracy of about 5% is needed for controlling radiation dose to tumors in radiation therapy of cancer, which in turn requires radiation measurement standards of 1 or 2%. While high accuracy is needed in some of these radiation applications, the broadening use of radiation throughout society requires reliable measurement of somewhat lower accuracy for protection of workers, the general public, and the environment. Examples in this area of radiation safety include personnel monitoring for radiation workers, measurements of radioactive effluents from nuclear power plants, and environmental measurements of radioactivity in water, air, and soil.

The national concern may be summarized simply -- the public demands the safe and effective use of radiation. The public wants the benefits of radiation: cheap, abundant electricity through nuclear power; better medical diagnosis through x-rays and radionuclide scans; improved radiation therapy for the treatment of cancer; improved products through industrial radiation processing; nondestructive testing of materials and products with x rays and neutrons; and many others. Public concern for safety has resulted in assignment of major regulatory radiation safety responsibilities to Federal Government agencies such as the Nuclear Regulatory Commission, the Environmental Protection Agency, the Bureau of Radiological Health and the Bureau of Drugs of the Food and Drug Administration, and the Occupational Safety and Health Administration; and in 47 out of 50 states (plus Puerto Rico) having passed radiation safety laws.

If ionizing radiation is to be used effectively and safely, then the many kinds of radiation must be measured many times, in many places, under many different circumstances, with widely differing intensities, by people with very different amounts of training, always with an accuracy sufficient for the purpose. What is the objective of this report? We wish to find out in the United States who makes radiation measurements, how they are made, what accuracies are needed, and what accuracies are achieved, how calibrations of instruments are obtained, what the National Bureau of Standards provides for this system and what it should provide. That is, we want to find out as much as we can about the structure of the National Measurement System for Ionizing Radiations and how it functions. The final question is: what actions should be taken by NBS management as a result of the study? Without further ado, we proceed into the content of the study.

2. STRUCTURE OF THE MEASUREMENT SYSTEM

First we must say what we mean by the term ionizing radiation. By ionizing radiation in this study we mean radiations such as x rays, gamma rays, electrons, alpha rays, beta rays, neutrons, pi mesons, protons, deuterons, and heavier charged particles. These radiations are often called ionizing radiations or corpuscular radiations (since they usually produce ions, and since we usually deal with the particle, rather than the wave, properties of the radiations). Neither term is precise. We exclude from our study such usually nonionizing radiations as visible light, infrared radiation, long-wavelength ultra-violet radiation, and microwave radiation, since the responsibility for the measurement system for these radiations lies elsewhere in NBS.

The measurement system for ionizing radiation is very complex, there being many different radiations of widely varying energies, several radiation quantities of interest, and a number of user groups interested in radiation measurement. To keep the study as simple as possible while focusing on the users of radiation and the measurements they need, it was decided to organize the study around the main groups of users. The user categories adopted are given in table 1.

For each of the eight main categories of radiation use, we have separated groups involved in that category having differing functions into activity classes (see table 1). As an example, the x-ray department in a hospital is a direct user of radiation for human benefit; the manufacturer has a different role of manufacturing and servicing effective and safe equipment; Federal and State regulatory agencies are involved to see that the equipment is used properly and safely; standards and calibration laboratories provide

[1]Systematic assembly of information for this study was completed in June 1975.

Table 1. Organization of the CRR radiation measurement system study

Main Categories of Radiation Use

1. Medical
2. Nuclear electric power
3. Industrial radiation processing
4. Defense
5. Chemical analysis
6. Science
7. Environmental radioactivity
8. Miscellaneous radiation applications

Activity Classes

1. Direct users of radiation
2. Manufacturers
3. Regulators
4. Standards and calibration laboratories
5. Other interested groups

the measurement base for safe and effective use; and other interested groups, such as the National Council on Radiation Protection and Measurements (NCRP), influence the setting of permissible radiation exposure limits, and rules and guides for proper and safe use of radiation.

2.1 Conceptual System

Radiation Quantities. The quantities of interest for the radiations with which we are primarily concerned are given in table 2.

The part of the National Measurement System included in this study concerns those radiations and physical quantities listed in table 2, plus others which may become of concern in the future, for example, pi mesons and heavy ions for cancer therapy.

Table 2. Radiations, quantities, and units

Radiation	Quantities	Traditional Unit	Usual SI Units
X and gamma rays	Exposure	Roentgen	coulomb kg^{-1}
	Absorbed dose	rad	joule kg^{-1} (a)
	Energy spectrum (b)	cm^{-2} MeV^{-1}	cm^{-2} $joule^{-1}$
	Energy flux density (beam power density)	MeV cm^{-2} s^{-1}	watt cm^{-2}
Electron beams	Absorbed dose	rad	joule kg^{-1} (a)
	Energy spectrum (b)	cm^{-2} MeV^{-1}	cm^{-2} $joule^{-1}$
	Beam current and power	ampere, watt	ampere, watt
Radioactivity	Activity (nuclear transformation rate)	curie	s^{-1} (c)
	Emission rate (particle or photon)	s^{-1}	s^{-1}
	Power	watt	watt
Neutrons	Emission rate	s^{-1}	s^{-1}
	Fluence	cm^{-2}	cm^{-2}
	Flux density (fluence rate)	cm^{-2} s^{-1}	cm^{-2} s^{-1}
	Energy spectrum (b)	cm^{-2} MeV^{-1}	cm^{-2} $joule^{-1}$
	Absorbed dose	rad	joule kg^{-1} (a)
	Kerma	rad	joule kg^{-1} (a)
	Cross sections	barn	cm^2

(a) Unit gray (Gy) adopted for 1 joule/kg. One rad equals one cJ/kg.

(b) Differential distribution of fluence with respect to energy.

(c) Unit becquerel (Bq) adopted for 1 s^{-1}.

The nature of the standards for ionizing radiations can easily be understood with a few examples. The primary measurement standard for the unit of exposure below 250 keV x-ray energy is a parallel-plate free-air ionization chamber. At higher energy such as 1.3 MeV (^{60}Co) such chambers would be physically too large, so cavity ionization chambers (graphite-wall, air-cavity) are used. For absorbed dose for x rays, gamma rays, and electrons, the primary measurement standard is a calorimeter made of graphite. A primary measurement standard for neutron absorbed dose would be a calorimeter made of "tissue-equivalent" plastic, except that with present technology such calorimeters are too insensitive, therefore tissue-equivalent ionization chambers are used. High-energy electron beam current is measured with a "Faraday cage", an instrument designed so that essentially all electrons incident are trapped and the charge they represent is recorded. The standard for x-ray energy flux density is an ionization chamber, known as the P-2 chamber, which is designed so that the current measured is proportional to both the energy and the number of x-ray photons.

For radioactivity, the activity is determined with precision instruments such as a $4\pi\beta$-γ coincidence counting apparatus, or an internal gas counter (the radioactive gas is admitted to the sensitive volume of a proportional counter). Emission rate, for example gamma-ray emission rate from a source, is determined with a detector such as an NaI(Tl) scintillation crystal or a Ge(Li) solid state detector which has been carefully calibrated versus energy. The power emitted by a source is usually measured with a calorimeter. In radioactivity measurement, and for neutrons, embodiment of a standard in an instrument becomes increasingly difficult. We become increasingly dependent on very careful experimental measurements whose results are captured in some durable form: a radioactivity standard source or standard neutron source, or a constant of nature such as a neutron cross section (that is, a piece of nuclear data). For example, neutron flux density measurements may require very complex apparatus including background discrimination by neutron time-of-flight. The result must somehow be kept in permanent form: a cross section, or stable calibrated source. Neutron information may also be embodied in a standard reference field, a known flux density with a well-determined energy spectrum, which is maintained by NBS or other standards laboratories and made available to radiation users for calibrations of user's devices.

In addition to the primary measurement standards themselves, developed and maintained by NBS or other standards laboratories, some transfer method or instrument is needed to get the calibration to the user. Examples of methods for calibration transfer are: direct calibration (the user sends in his instrument for direct comparison against the standard), a transfer ionization chamber (a quality instrument which is calibrated against the standard and sent to the radiation user to compare against the user's instrument), and radioactivity standards (Standard Reference Materials) which are prepared by NBS or another laboratory and sent to the user to serve as a standard in his measurements.

2.2 Basic Technical Infrastructure

2.2.1 Documentary Specification System

2.2.1.1 Standardization Institutions

The most important international organizations writing standards and recommendations in the field of ionizing radiations are the International Organization for Standardization (ISO), the International Electrotechnical Commission (IEC), the International Commission on Radiation Units and Measurements (ICRU), the International Commission on Radiological Protection (ICRP), the International Atomic Energy Agency (IAEA), and the World Health Organization (WHO).

The International Organization for Standardization, headquartered in Geneva, Switzerland is an independent organization with member bodies from 56 nations and 13 correspondent members (as of 1971). It is governed by a General Assembly and Governing Council. Technical Committee TC 85 has the prime responsibility in ISO for standardization in the field of nuclear energy and its peaceful application. The work of TC 85 in the United States is conducted through the Secretariat, formerly held by the American National Standards Institute, now held by Germany. Within TC 85 there are five subcommittees: Terminology, Definitions, Units, and Symbols; Radiation Protection; Nuclear Reactor Technology; Radioactive Sources; and Nuclear Fuel Technology. The chief emphasis is on standards for the safe use of nuclear energy.

The International Electrotechnical Commission is an autonomous technical division of ISO. In the nuclear field its Technical Committee 45 considers "Electrical Measuring Instruments used in Connection with Ionizing Radiation." Technical Committee 62 covers "Medical X-Ray Equipment."

The ICRU and the ICRP are both sponsored by the International Society of Radiology, a world organization of radiologists and radiotherapists which meets every three or four years. In addition to working closely with each other, both organizations have official relationships with the World Health Organization and the International Atomic Energy Agency.

The International Commission on Radiation Units and Measurements, with Secretariat in Washington, D.C., was formed in 1925 under the sponsorship of the First International Congress of Radiology with a mission to recommend: (a) quantities and units of radiation and radioactivity; (b) procedures for measurement of radiation quantities; (c) physical data related to radiation measurement; and (d) in cooperation with ICRP, the International Commission on Radiological Protection, it recommends measures for radiation protection.

The International Commission on Radiological Protection was organized in 1928 to serve radiological and medical groups from all countries by providing technical guidance and recommendations in the field of radiation hazards. It is also sponsored by the International Society of Radiology. The ICRP policy in preparing its recommendations is to deal with basic principles of radiation protection, and to leave to the various national protection committees the responsibility of providing detailed technical regulations, recommendations or codes of practice best suited to the needs of their individual countries. The ICRP has the following committees: Radiation Effects, Internal Exposure, External Exposure, and Application of Recommendations. The headquarters is in Sutton, England.

The International Atomic Energy Agency, established in 1957 and located in Vienna, Austria, is an agency of the United Nations with 102 Member States as of 1972. The IAEA's interests are: (a) nuclear power and desalting; (b) application of ionizing radiation in agriculture, hydrology, medicine, and industry; (c) regulatory activities in health and safety; (d) technical assistance to developing countries; and (e) the establishment and administration of safeguards, particularly in connection with the Treaty on the Non-Poliferation of Nuclear Weapons. The agency operates three laboratories; in Vienna and Seibersdorf, Austria, and in Monaco (devoted to marine radioactivity). The IAEA publishes a large number of guidebooks, safety standards, codes of practice, and panel reports in the field of ionizing radiation.

The World Health Organization was formed in 1948, and is a directing and coordinating authority on international health work, dealing primarily with governments and with their central health authorities. In the field of radiation health, it is concerned with protection of workers and the public against undue radiation exposure from any radiation source, as well as the promotion and improvement of the medical uses of radiation and radioisotopes for the diagnosis and therapy of disease. In addition to preparing standards and technical reports, in cooperation with IAEA, the WHO is sponsoring the development of regional secondary radiation calibration laboratories to help developing countries. The headquarters of WHO is in Geneva, Switzerland.

One other organization, the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) does not promulgate standards, but is mainly concerned with obtaining radiation information that other bodies may use in establishing standards. Another organization, the International Organization of Legal Metrology (OIML), does not yet prepare standards in the field of ionizing radiation, but is planning to do so.

A summary of international nuclear standards activities is given in <u>Compilation of Nuclear Standards</u>, Part II, 8th edition, 1971, ORNL-NSIC-102.

<u>National Standards-Preparing Organizations</u>. In the field of ionizing radiation, a wide variety of applications in power, industry, medicine, and science have led to a broad need for safety regulations. These regulations are most frequently specific to the type of hazard associated with a particular application. As a result not only government agencies such as the Nuclear Regulatory Commission (NRC), the Energy Research and Development Administration (ERDA, now Department of Energy), the Environmental Protection Agency (EPA), the Food and Drug Administration (FDA) of the Department of Health, Education and Welfare, the Department of Labor (DOL), and the Department of Transportation (DOT) enter the picture, but also many industrial and trade organizations. Since the hazards of ionizing radiation are a matter of concern, a number of interdisciplinary standards setting organizations have been established. It is most usual for large portions of government regulations to be taken directly from such consensus setting organizations as the American National Standards Institute (ANSI), the American Nuclear Society (ANS), the Institute of Electrical and Electronic Engineers (IEEE), the American Society for Testing and Materials (ASTM), and the National Council on Radiation Protection and Measurements (NCRP).

A compendium of all existing nuclear standards is published by the Oak Ridge Nuclear Safety Information Center. Available for this study was the 9th edition 1972, identified as ORNL-NSIC-112. Also included in this document is a brief discussion of the organizations listed in appendix B, table B-1.

A listing of the biomedical societies with some interest in radiation is given in appendix B, table B-2. A brief summary of the mission of these organizations is given in the pamphlet "Radiological Organizations 1970" published by the American College of Radiology, 20 North Wacker Drive, Chicago, Illinois 60606.

Since the number of organizations which write standards is very large, we shall discus here only three of the most important: ANSI, NCRP, and ANS.

The American National Standards Institute (ANSI), (previously known successively as American Engineering Standards Committee, American Standards Association, United States of America Standards Institute), with headquarters in New York City, is the only national coordinating organization representing industry, consumer and government which meets the increasing demand for voluntary standards. As a federation it provides an orderly framework for initiating standards setting committee work and reviewing the consensus results which, when adoped, become voluntary standards. The base operating units of ANSI are the Standards Management Boards (SMB). The Nuclear SMB is headed by a full-time staff member and had developed 402 nuclear application standards by December 1972. The Nuclear Regulatory Commission has referenced 19 ANSI standards in their Nuclear Safety Guides and planned to reference 40 more as of December 1972.

ANSI Committee N43, organized under NBS sponsorship, is charged with developing "standards pertaining to products and equipment for non-medical scientific, industrial, and educational uses, involving ionizing radiation sources including radioactive materials, accelerators, and x-ray equipment but excluding nuclear reactors."

Reports in November 1973 showed 3,000 people working on nuclear standards under ANSI. In 1972-73, 176 standards had been approved, 116 new committees were formed, 10 quality assurance standards were completed, and 1,074 nuclear application standards were available. One hundred new standards were due in 1973-74 out of 1,000 still needed.

The National Council on Radiation Protection and Measurements (NCRP) is an independent organization chartered by Congress to prepare definitive handbooks on radiation protection. These documents are used in preparation of regulations by Federal and State governments in pursuit of safe use of radiation. Each report is prepared by a broadly representative group of specialists and reviewed by the approximately 70-member council before publication. A detailed discussion of the organization and its publications now numbering over 40 can be found in Radiation Protection Standards by Lauriston S. Taylor, CRC Press, (a division of Chemical Rubber Company), 18901 Cranwood Parkway, Cleveland, Ohio 44128. Headquarters of the NCRP are in Washington, D.C.

The American Nuclear Society (ANS), formed in 1954, had 4,600 members in 1970. Its Standards Committee has a number of subcommittees dealing with units, terminology, standards and practices related to nuclear engineering. The committees work closely with the ANSI Nuclear Standards Management Board in areas such as Nuclear Criticality Safety and Nuclear Design Criteria. The Office of ANS is in Hinsdale, Illinois. News on Standards is published regularly in a separate section of the ANS Journal Nuclear News.

2.2.1.2 Survey of Documentary Standards

There are two main classes of documentary standards: voluntary standards or recommendations, and regulatory standards. Here we will survey briefly the standards and recommendations of the organizations discussed above. Regulatory standards will be discussed under section 2.4.4, Regulatory Agencies.

As of December 1971, ISO Technical Committee TC 85 had produced 10 approved standards and 16 others were being actively worked on. They included such subjects as nuclear energy glossaries, recommendations for personnel monitors, prestressed concrete pressure vessels and containment structures, a code for nuclear reactor steel pressure vessels, and a number of documents on sealed radioactive sources. IEC Technical Committee 45 had approved 24 standards relative to nuclear instruments, and 23 were in process of development, including the standard nuclear instrument module systems known as NIM and CAMAC.

The International Commission on Radiation Units and Measurements (ICRU) had published 23 reports as of March 1975. Perhaps the most basic of these is ICRU Report 19 on Radiation Quantities and Units (with a supplement on

Dose Equivalent). Other reports discuss and make recommendations on various aspects of x-ray, gamma-ray, neutron, and radioactivity measurements, radiation protection instrumentation, radiobiological dosimetry, certification of sources, etc.

The International Commission on Radiological Protection has produced at least 23 reports on radiation protection recommendations on such subjects as dose calculations, radiobiological models, permissible dose (extremely important), and various radiobiological subjects of importance for radiation protection.

The International Atomic Energy Agency has published at least 36 standards, guidebooks, and codes of practice on a wide variety of subjects such as safe handling of radioisotopes, radioactive waste disposal, transport of radioactive materials, methods of personnel monitoring, safe operation of nuclear power plants, and radiation protection in the mining and milling of radioactive ores.

The World Health Organization has published at least 8 radiation-related reports, mostly on public health considerations in various situations where radiation is or may be involved: medical uses, radiation accidents, and contamination of food or drinking water.

As discussed earlier, the American National Standards Institute believes that over 2,000 nuclear standards are needed, especially with reference to nuclear reactor and fuel technology, with only about 1,200 currently available. The ANSI standards are particularly important because many of them are adopted verbatim by regulatory agencies such as the Nuclear Regulatory Commission.

The National Council on Radiation Protection and Measurements has published 43 reports (some of which have been superseded by others) mostly on radiation protection in various situations (e.g., educational institutions) and for various radiations (e.g., medical x rays), with some reports devoted to radiation measurement standards. Of these, the most important is Report 39 on Basic Radiation Protection Criteria, which is very influential in establishing permissible dose levels in the United States. Many of these recommendations have been adopted by regulatory agencies, or written into state radiation protection laws.

The American Nuclear Society has about 60 committees working on nuclear standards for all aspects of nuclear power plant design, siting, and safety considerations. A relatively small number of standards have been approved, about 10. These ANS standards are fed into the ANSI standards system and will provide some of the needed nuclear standards.

2.2.2 Instrumentation System

2.2.2.1 Measurement Tools and Techniques

The discussions in this and succeeding subsections of section 2 are introductory and rather brief since the study of the Measurement System for Ionizing Radiation was carried out in eight microstudies according to user areas and a ninth microstudy of personnel monitoring (which is a common need of nearly all users of radiation). These nine studies are presented in a special section, section 2/3.

Radiation detectors may be used in both simple and sophisticated ways: just to detect the presence of radiation, to count radiation particles or events, to measure the "radiation dose" in the field (dosimeters), or to measure the energy spectrum of the radiation (spectrometers). Radiation detectors may be active (respond instantly) or passive (record for later read-out). They may be pulse-type detectors (for example a Geiger-Müller counter) or average-level detectors (a current-measuring ionization chamber). In table 3 are listed some examples of detectors categorized according to whether they are gas-filled, liquid, or solid (the latter two often being desirable for high efficiency).

2.2.2.2 The Instrumentation Industry

The radiation instrumentation industry is a vital part of the total radiation-associated industry. It includes manufacture of instruments and controls for nuclear power reactors, equipment for nuclear fuel and material assay, nuclear medicine equipment including scanners and dose calibrators, monitors and calibration instruments for x-ray therapy, industrial radioisotope gauges and gauging systems, standard radioactivity sources, radiation survey and personnel monitoring instruments, environmental radiation measuring instruments, instrumentation for industrial radiation processing, scientific laboratory radiation measuring instruments, radiographic equipment, medical x-ray diagnostic equipment, x-ray film and processing equipment, and fluorescence equipment. This subject will be discussed much more fully in section 2/3 on the various major applications of radiation.

Table 3. Examples of radiation detectors

Class	Detector	Signal Used	Example of Application
Gas-filled	Geiger-Müller counter	electrical pulse	radiation survey
	Ionization chamber	electrical pulse	counting nuclear fission events
	Ionization chamber	electrical current	x-ray dosimetry
	Proportional counter	electrical pulse	measuring radioactivity of gases
	Gas scintillator	light flash	neutron detection
Liquid	Liquid scintillation counter	light flash	tritium counting
	Ferrous sulfate solution	optical density	electron dosimetry (for therapy)
	Dye dosimeter	color change or optical density	dosimetry for industrial radiation processing
Solid	Sodium iodide scintillation crystal	light flash	x-ray spectrometer
	Ge(Li) solid state detector	electrical pulse	gamma-ray spectrometer
	Photographic film	optical density	personnel monitoring
	Gold foil	induced radioactivity	thermal neutron detector
	Thermoluminescent dosimeter	light emission upon heating	personnel monitoring
	Calorimeter	temperature increase	x-ray absorbed dose standard
	Dye film	color change or optical density	industrial radiation processing

2.2.3 Reference Data

The standard reference data for ionizing radiations consist of atomic and nuclear data which may be used directly or processed into a form useful for applications, usually by large computer calculations. Examples of atomic data are x-ray attenuation coefficients and scattering cross sections, electron interaction cross sections, range, stopping power, straggling, delta-ray production, average energy per ion pair data for charged particles, and spectra of highly-ionized atoms. Nuclear data include neutron interaction cross sections, photo-nuclear reaction data, radionuclide decay scheme data, electron scattering at high energies, charged-particle reaction data, and general nuclear data such as level schemes, atomic masses, and Q-values. Examples of processed data include depth-dose curves (the distribution of absorbed dose with depth) for radiations used in radiation therapy, radiation shield penetration data, electron and charged particle slowing-down spectra, point-sources dose distributions for beta-ray sources, absorbed fractions (dose factors for radionuclides inside the body), neutron and gamma-ray energy deposition factors, and microdosimetry parameters and distributions (energy deposition information on the scale of the biological cell).

The data are measured in scientific laboratories all over the world. Much of the applied data comes from national nuclear energy and standards laboratories.

Much of the atomic data is compiled at data centers under the auspices of the National Standard Reference Data System (NSRDS): the X-Ray and Ionizing Radiation Data Center, the Atomic Energy Levels Data Center, and the Joint Institute for Laboratory Astrophysics Information Analysis Center, all located at NBS. Average energy per ion pair data are being evaluated by a committee of the International Commission on Radiation Units and Measurements, Range, stopping power, straggling and delta-ray production data are only sporadically compiled.

In the area of nuclear data, neutron cross section data, compiled and evaluated by a number of data centers, are available from the National Nuclear Data Center at Brookhaven National Laboratory, which exchanges data with three other major data centers in the world (IAEA, Vienna; CCDN, Saclay, France; and Obninsk, USSR). This data file is known as ENDF/B (for Evaluated Nuclear Data File Version B), and is periodically updated. Much data, including photon cross section data, is fed to ENDF/B from the Radiation Shielding Information Center (RSIC) at Oak Ridge National Laboratory. The Photonuclear Data Center at NBS (under NSRDS sponsorship) prepares bibliographies and evaluates photonuclear data which will also appear in the ENDF/B file. General nuclear data are compiled by the Nuclear Data Project at Oak Ridge National Laboratory and are available as Nuclear Data Sheets and Nuclear Data Tables. The Table of Isotopes Project at the Lawrence Berkeley Laboratory prepares the Table of Isotopes, a major source of radionuclide and decay scheme data.

Processed data for ionizing radiations are not systematically compiled, although a considerable amount is available, especially from theoretical research groups at Oak Ridge National Laboratory and the National Bureau of Standards. Some processed data are also available in reports of the Medical Internal Radiation Dose (MIRD) Committee of the Society for Nuclear Medicine. The X-Ray and Ionizing Radiation Data Center at NBS is planning to include processed data in the future.

The users of these data are everywhere throughout the ionizing radiation applications community. Particularly important users with voracious appetites for data are: nuclear power reactor designers, radiation shielding designers, medical radiation physicists, nuclear medicine physicians, and the Defense Nuclear Agency of the Department of Defense.

2.2.4 Reference Materials

The most important reference materials for ionizing radiations are radioactivity standards (Standard Reference Materials). They may be gaseous (a radioactive gas in a sealed glass bottle), liquid (a solution in a sealed glass ampoule), or solid ("point"-source gamma-ray emitters, alpha particle standards). They may be at millicurie levels for radiopharmaceutical applications or at relatively low levels for environmental radioactivity measurements. One recently developed standard is a mixture of gamma-ray emitters of different gamma-ray energies in solution (for calibration of the efficiency versus energy of a sodium-iodide scintillator or Ge(Li) solid-state detector in one measurement). Radioactivity standards in environmental matrices are becoming important for calibration of environmental radioactivity measuring equipment. For example, a radioactivity standard of homogeneous river sediment has recently been developed. These standards play the role of transfer standards -- they transfer the standardizing laboratory calibration to the user. While many of these standards are produced by NBS, some are also produced by several commercial companies, and by large government-related laboratories in England and France. Radioactivity standards are used for calibrating or checking of the user's radioactivity measuring equipment. They also make possible a very convenient method of measurement assurance testing -- they can be sent to the user as an unknown, and after the user's measurement is reported, a certificate can be sent giving the NBS value. The comparison of these two values gives a measure of traceability.

Other important standard reference materials include standard fission foil sets (known amounts of fissionable material and known isotopic composition), isotopic composition standards for fissionable materials such as uranium and plutonium, and boric acid and boron glass standards of known isotopic composition for thermal neutron measurements. A standard fission foil set is being developed at NBS, but much more work is needed in this area. Isotopic composition standards are issued under the SRM program, but this is not sufficient for nuclear fuel needs (see section 2/3.B.1 on the Nuclear Fuel Cycle).

2.2.5 Science and People

The study of ionizing radiation is a broad, interdisciplinary field including both physical and biological sciences. The participants are nuclear and atomic physicists; applied mathematicians; radiochemists and radiation chemists; nuclear, electrical and mechanical engineers; health physicists;

radiation biologists and geneticists; and physicians with specialties in radiotherapy, diagnostic radiology, and nuclear medicine. A few other specialties are occasionally involved; for example, sanitary engineering, safety engineering, meteorology. Some of the major societies concerned with ionizing radiation are the American Physical Society, the American Association of Physicists in Medicine, the American Chemical Society, the Radiation Research Society, the American Nuclear Society, the Health Physics Society, and some medical societies, notably the American College of Radiology, the Radiological Society of North America, the American Radium Society, the American Society of Therapeutic Radiologists, the American Dental Association, the College of American Pathologists, the Society for Nuclear Medicine, and the College of Nuclear Medicine Physicians. Other groups include the American Society for Nondestructive Testing and the American Welding Society. Most professional publication is through the journals of these societies, and a few commercial journals such as Nuclear Physics and the International Journal of Applied Radiation and Isotopes; proceedings of numerous symposia, conferences, congresses, and institutional journals. Further discussion of ionizing radiation and science may be found in section 2/3.F.

2.3 Realized Measurement Capabilities

Accuracy requirements for radiation measurement vary widely with the radiation application as do accuracies achieved. These will be discussed in the studies arranged by radiation application of section 2/3. For orientation, accuracy requirements vary from a fraction of 1% for certain nuclear fuel measurements, to 1% accuracy in the neutron cross sections of some of the fissionable isotopes, to 5% needed for tumor absorbed dose in radiation therapy, to 10% accuracy required by FDA for radiopharmaceuticals used in nuclear medicine, to 20% or poorer accuracy in radiation protection applications where the dose is low. As a general statement, the required accuracies of the measuring instruments can usually be achieved where NBS standards have been fully developed. However, measurement assurance testing has demonstrated that they are frequently not achieved by the user unless he has participated in measurement assurance testing to straighten out problems and has high-quality standards available to him for instrument calibration. In addition are areas where NBS standards do not exist or are just being developed -- for example, in the neutron-induced fission cross sections cited above where presently achieved accuracies are 3% rather than 1%.

2.4 Dissemination and Enforcement Network

2.4.1 Central Standards Authorities

(1) Standards and Calibration Laboratories. The measurement system with which we are concerned is an international measurement system coordinated by a small laboratory with a Consultative Committee structure, the Bureau International des Poids et Mesures (BIPM, the International Bureau of Weights and Measures), located in Sèvres, near Paris. This laboratory, with a total staff of about 60, has a staff of about 10 who work in the field of ionizing radiation measurements (five physicists and five technicians). For the ionizing radiation measurement system, the committees are called sections of the CCEMRI (Consultative Committee for Measurement Standards for Ionizing Radiations). The three sections are: X and Gamma Rays and Electrons; Radionuclide Measurements; and Neutron Measurements. NBS is represented on each of the sections. The chief function of BIPM in the radiation area is to be the common focal point for the national standards laboratories by arranging intercomparisons between standards laboratories, or making calibrations or comparative measurements itself, to see that the national laboratories are on a consistent international measurement scale. In medical radiation dosimetry, exposure comparisons were carried out with NBS for 250 kV x rays some years ago, and recently comparisons for x rays of 50 kV and below and for Co-60 gamma-ray sources have been completed. In past years, a number of radionuclide intercomparisons were carried out, although recently the emphasis has been on analysis of measurement procedures. The intercomparisons are very important because, in addition to keeping the world on a single measurement system, they serve as an independent check on each national standards laboratory which must provide calibrations to users in its own country.

(2) National Bureau of Standards (NBS). NBS has legislative authority for developing methods and standards of measurement, including the "investigation of radiation, radioactive substances, and x-rays, their uses, and means of protection of persons from their harmful effects ... as the need may arise in the operation of government agencies, scientific institutions and industrial enterprises" (reference: Act of 22 July 1959, 64 Stat. 371, PL 619-81st Congress). The objectives of the NBS program in radiation measurement are: to provide the central basis for measurement of ionizing radiation in the United States; to ensure compatibility of U.S. standards and units with those of

other countries; and to develop standards, measurement techniques, and calibration capability appropriate to the needs.

(3) Other National Standards Laboratories. There are a number of national standards laboratories, such as the National Physical Laboratory (U.K.), the National Research Council (Canada), Physikalisch-Technische Bundesanstalt (West Germany), the Electro-Technical Laboratory (Japan), and designated laboratories under the Bureau National de Metrologie (France), which frequently are larger and better equipped than the international laboratory, BIPM. The Central Bureau for Nuclear Measurements (BCMN), Geel, Belgium, serves as a nuclear standards laboratory for the Commission of the European Communities. These laboratories affect the U.S. national measurement system in two ways: (a) through the BIPM where possible or sensible, and bilaterally where appropriate, international intercomparisons with other national standards laboratories provide an independent check of the validity of NBS standards, and insure a uniform international measurement system; and (b) foreign-manufactured radiation sources, machines, and instruments in the U.S. marketplace usually will have calibrations traceable to the national standards laboratory in the country of orgin. Confidence in the foreign standards laboratory and measurement system is necessary -- otherwise such products must be recalibrated in the United States.

2.4.2 State and Local Offices of Weights and Measures

These are not directly involved in the Ionizing Radiation Measurement System. The corresponding activity is carried out by state and local radiation control offices, which are regulatory agencies, and thus are covered under section 2.4.4.

2.4.3 Standards and Testing Laboratories and Services

A number of these exist, for example, regional calibration laboratories for the medical radiation community, measurement assurance laboratories for personnel monitoring (e.g., the National Sanitation Foundation), and the New Brunswick Laboratory of AEC (now DOE). These will be discussed in section 2/3 under the appropriate community of radiation users.

2.4.4 Regulatory Agencies

Some of the regulations that have been issued by federal and state regulatory agencies are summarized in table 4.

(1) U.S. Nuclear Regulatory Commission (NRC). The Nuclear Regulatory Commission, an independent regulatory agency established by the Energy Reorganization Act of 1974, came into being on January 19, 1975. The NRC is the successor to the regulatory part of the AEC which was established by the Atomic Energy Act of 1946, amended 1954, and amended again in 1959. The authority of the NRC includes regulation of the use of reactor-produced radioactive materials. Title 10, Code of Federal Regulations, Part 20 establishes standards for protection against radiation hazards arising out of activities under licenses issued by the NRC (which includes all reactors and nuclear power plants and users of reactor-produced isotopes above certain very small levels). This regulation requires inspection and monitoring to determine compliance. In 1959 the Congress amended the Atomic Energy Act of 1954 by adding section 274 allowing transfer to states of the AEC's regulatory authority over non-Federal use of source, byproduct, and special nuclear material in quantities not sufficient to form a critical mass. The transfer is effected by an agreement between the NRC and the governor of the state after it is established that the state program is adequate and compatible with that of the NRC. To date 25 states have entered into such an agreement with the Commission.

The NRC encourages standards setting operations under the Nuclear Standards Management Board of ANSI; under appropriate committees of the American Nuclear Society; NCRP; IEEE and other organizations.

(2) Environmental Protection Agency (EPA). Authority for regulation of radiation in the environment comes under the National Environmental Policy Act of 1969 (PL 91-90). Authority for setting standards and radiation regulation by EPA is contained in Reorganization Plan #3 (1970), the Water Quality Act of 1972, the Clean Air Act of 1970, and the Ocean Dumping Act of 1972. EPA has the responsibility for generally applicable environmental standards outside NRC-licensed facilities ("outside the fence"). Under Reorganization Plan #3, EPA took over the general guidance function for federal activities in radiation formerly the function of the Federal Radiation Council. The above-quoted authorities, together with the Public Health Service Act (42 U.S.C. 241), give EPA responsibility in technology assessment -- "best practicable and best available technology" --, radiation monitoring, and training and assistance to the states.

Table 4. Some regulations and regulatory guides for ionizing radiations

1. Bureau of Radiological Health, FDA

   Television Receivers

   Cold-Cathode Gas Discharge Tubes

   Diagnostic X-Ray Systems and Their Major Components

   Radiographic Equipment

   Fluoroscopic Equipment

   Cabinet X-Ray Systems

   Recommendations to states re X-Ray Baggage Inspection Systems (August 8, 1973)

   Model Legislation for Users of Ionizing Radiation in the Healing Arts (to states) (October 1970)

2. Occupational Safety and Health Administration, Department of Labor

   1910 Subpart G96, 100 Ionizing Radiation (February 15, 1972)

   Draft 3176 revision to (29CFR 1910.96) (July 5, 1973)

3. Environmental Protection Agency

   Federal Radiation Council rulings adopted for standards.

   EPA is a regulatory agency which has little exercised its regulatory powers in the radiation field. The recommendations of the Federal Radiation Council, which became part of EPA at the outset, have been applied directly to the agencies of the Federal government by Presidential order. They are:

Report #1	Radiation Protection Guidance for Federal Agencies, May 13, 1960, sets protection principles and guides.
Report #2	Radiation Protection Guidance for Federal Agencies, September 20, 1961, sets radiation protection guides for radium 226, iodine 131, strontium 90 and 89.
Report #5	Radiation Protection Guidance for Federal Agencies, July 31, 1964. Recommendations for normal production, processing, distribution and use of food products for human consumption.
Report #7	Radiation Protection Guidance for Federal Agencies, May 21, 1965, deals with food contaminated by strontium 89, 90, or cesium 137.
Report #8	Revised Radiation Protection Guidance for Federal Agencies, July 27, 1967, on radiation protection in underground uranium mines and January 11, 1969 (revision of 7) and December 15, 1970 (revision of 7 and 8).

4. Nuclear Regulatory Commission

   Rules and regulations of the Nuclear Regulatory Commission appear as Title 10 - Chapter 1, Code of Federal Regulations, and are updated frequently. Some of the parts relevant to radiation questions are:

10CFR1	Statement of Organization and General Information
10CFR2	Rules of Practice
10CFR20	Standards for Protection Against Radiation
10CFR30	Rules of General Applicability to Licensing of Byproduct Material
10CFR31	General Licenses for Byproduct Material
10CFR32	Specific Licenses to Manufacture, Distribute, or Import Certain Items Containing Byproduct Material
10CFR33	Specific Licenses of Broad Scope for Byproduct Material
10CFR34	Licenses for Radiography and Radiation Safety Requirements for Radiographic Operations
10CFR35	Human Uses of Byproduct Material
10CFR40	Licensing of Source Material
10CFR51	Licensing and Regulatory Policy and Procedures for Environmental Protection
10CFR70	Special Nuclear Material
10CFR71	Packaging of Radioactive Material for Transport and Transportation of Radioactive Material Under Certain Conditions
10CFR100	Reactor Site Criteria

Table 4 (Continued)

10CFR150 Exemptions and Continued Regulatory Authority in Agreement States Under Section 274

Regulatory Guide Series, updated lists published by Nuclear Safety Information Center, ORNL, in "Nuclear Safety" or obtainable from USNRC, Washington, D.C. 20545.

Categories are:

(1) Power Reactors
(2) Research and Test Reactors
(3) Fuels and Materials Facilities
(4) Environmental and Siting
(5) Materials and Plant Protection
(6) Products
(7) Transportation
(8) Occupational Health
(9) Antitrust Review
(10) General

Sample titles are:

4.1 Programs for Monitoring Radioactivity in the Environs of Nuclear Power Plants

4.2 Preparation of Environmental Reports for Nuclear Power Stations

8.6 Standard Test Procedures for Geiger-Müller Counters

8.7 Occupational Radiation Exposure Records Systems

8.8 Information Relevant to Maintaining Occupational Radiation Exposures as Low as Practicable (Power Reactors)

8.9 Acceptable Concepts, Models, Equations, and Assumptions for a Bioassay Program

A total of 33 Safety Guides had been released by April 1973.

Proposed changes in NRC rules are published in the Federal Register and in Nuclear Safety.

5. Department of Transportation

Regulations for containers, labels, and procedures to be used in shipment of radioactive materials are established as part of procedures for all hazardous materials shipment (except special nuclear materials). See 49CFR170 to 173.389. Further details may be obtained from:

U. S. Department of Transportation
Office of Hazardous Materials
Operations Division TSA24
400 Sixth Street, N.W.
Washington, D.C. 20590

(3) Food and Drug Administration (FDA). Three organizations within the FDA are concerned with radiation: (a) the Bureau of Radiological Health (BRH) has responsibility to reduce unnecessary human exposure to man-made radiation in the use of electronic products, and in the application of radiation in the healing arts under primarily the Radiation Control for Health and Safety Act (PL 90-602). Two of the most important divisions of BRH concerned with radiation measurement are the Division of Radioactive Materials and Nuclear Medicine and the Division of Electronic Products, the latter being concerned with x-ray equipment for hospitals, as well as radiation from consumer products such as television sets. (b) A second group within FDA is the Physical Chemistry Research Branch of the Office of Pharmaceutical Research and Testing of the Bureau of Drugs which is concerned with quality control of radiopharmaceuticals -- i.e., do pharmaceuticals meet the standards of the U.S. Pharmacopoeia? In terms of radioactivity, a radiopharmaceutical must be within ± 10% of the stated value. To establish non-compliance in court, traceability to NBS is considered necessary by this group and is now being pursued. (c) The Radiological Analytical Laboratory (Winchester, Mass.) of the Executive Director for Regional Operations, formerly in EPA, did quality control work for EPA. Its present function seems to be quality control for the Association of Official Analytical Chemists, some state laboratories, for EPA laboratories (Las Vegas and Montgomery), the Physical Chemistry Research Branch (FDA), and the Nuclear Medical Laboratory of BRH (Cincinnati).

(4) Occupational Safety and Health Administration (OSHA). Located in the Department of Labor, OSHA has the prime responsibilities in carrying out the Occupational Safety and Health Act of 1970 (PL 91-596): determination of priorities, setting standards, enforcement, operating a national record-keeping and reporting system, providing employer-employee education, in approving

state plans and awarding grants to states. Radiation standards and compliance wherever the health of workers is concerned is primarily the concern of OSHA (but the responsibility of the employer and employee). The National Institute for Occupational Safety and Health (NIOSH) is not a regulatory agency, but has joint responsibility with OSHA under the Occupational Safety and Health Act of 1970. NIOSH is under the Center for Disease Control, Department of Health, Education, and Welfare. The HEW responsibilities under the Act include health and safety research, industry-wide studies, hazard evaluations and toxicity determinations, annual compilations of a list of toxic substances, and training of personnel to carry out the purposes of the Act.

(5) DOT Office of Hazardous Materials (OHM). Located in the Department of Transportation, the Office of Hazardous Materials, which was established by the Department of Transportation Act of 1966 (PL 89-670), has responsibility for regulation of hazardous material transportation including radioactive materials, covered in section 6E, para. 4, with enforcement of 18 CFR 831 to 835 taken from the Interstate Commerce Commission.

(6) State and Local Radiation Control Offices. As of January 1, 1974, 47 out of 50 states (plus Puerto Rico) had passed enabling acts for ionizing radiation protection (BRH, 1975).[1] Those missing were Iowa, Rhode Island, and West Virginia. The number of state enabling acts for ionizing radiation increased from 10 in 1960 to 68 at the end of 1971. In these areas, 35 pieces of state legislation were passed in 1971, with an additional 14 pending. In nearly every state, the State Health Department is designated as the agency responsible for radiation protection with the authority to adopt regulations. The states discuss common problems in radiation control at the annual "National Conference on Radiation Control." As mentioned earlier, in 1959 the Congress amended the Atomic Energy Act of 1954 by adding section 274 allowing transfer to states of the AEC's (now NRC's) regulatory authority over non-Federal use of source, byproduct, and special nuclear material in quantities not sufficient to form a critical mass. About 25 states are now "NRC-agreement states." The NRC does not control the use of radium, x rays, or accelerator-produced radionuclides, so these are, in general, automatically the responsibility of the states. Possession of non-NRC controlled material and use of radiation-producing machines in some states requires licensing of the user, in others registration of the user, and in others no specific requirements are established.

[1]A list of references may be found at the end of the report. Notation of reference listing is (author, year).

2.5 Direct Measurements Transactions Matrix

2.5.1 Analysis of Suppliers and Users

The direct measurements transactions matrix is provided as table 5.

2.5.2 Highlights re Major Users

For this information, the reader is referred to Section 2/3 below.

2.6 Study Method for Ionizing Radiation Measurement System

Ionizing radiations involve many radiation quantities for a number of different radiations with many distinct uses. It was decided that it would be most efficient to organize the study around different groups of users and their needs, rather than by type of radiation or by the particular radiation quantity. In Section 2/3 we shall consider nine subsystems of the Ionizing Radiation Measurement System one at a time: Medical, Nuclear Power, Industrial Radiation Processing, Defense, Chemical Analysis, Science, Environmental Radiation, Miscellaneous Radiation Applications, and Personnel Monitoring. Elements which can logically be treated in common have already been discussed, or will be discussed in the sections after Section 2/3.

2/3 MEASUREMENT SYSTEM STRUCTURE, IMPACT, STATUS, AND TRENDS BY MAJOR CATEGORIES OF RADIATION USERS

2/3.A MEDICAL

Users, manufacturers, and standards and calibration laboratories of the medical radiation measurement system are given in table 6. An "interaction" diagram of the structure of the system is given in figure 1 for gamma and x rays, and in figure 2 for radioactivity standards and radiopharmaceuticals for nuclear medicine. Following this classification, we discuss the components of the medical radiation measurement system not previously covered.

Table 5. Direct measurements transactions matrix

DIRECT MEASUREMENTS TRANSACTIONS MATRIX FOR — USERS / SUPPLIERS	KNOWLEDGE COMMUNITY (Science, Education, Prof. Soc. & Publ.) 1	INTERNATIONAL METROLOGICAL ORGANIZATIONS 2	DOCUMENTARY STANDARDS ORGANIZATIONS 3	INSTRUMENTATION INDUSTRY (SIC Major Gp 38) 4	NBS 5	OTHER U.S. NATIONAL STANDARDS AUTHORITIES 6	STATE & LOCAL OFFICES OF WEIGHTS & MEASURES (OWM's) 7	STANDARDS & TESTING LABORATORIES AND SERVICES 8	REGULATORY AGENCIES (excl. OWM's) 9	DEPARTMENT OF DEFENSE (excl. Stds. Labs) 10	CIVILIAN FEDERAL GOVT AGENCIES (exc. Stds Labs & Reg. Ag) 11	STATE & LOCAL GOV'T AGENCIES (exc. OWM's & Reg. Ag.) 12	INDUSTRIAL TRADE ASSOCIATIONS 13	AGRICULTURE, FORESTRY FISHING; MINING (SIC Div. A & B) 14	CONSTRUCTION (SIC Div. C) 15	FOOD/TEXTILE/LBR/PAPER/LEATHER/ETC. (SIC 20-26, 31) 16	CHEM/PETROL/RUBBER/STONE/CLAY/GLASS... (SIC 28-30, 32) 17	PRIMARY & FAB. METAL PRODUCTS (SIC 33-34, 391) 18	MACHINERY EXCEPT ELECTRICAL (SIC Major Gp 35) 19	ELECTRIC AND ELECTRONIC EQPMT (SIC Major Gp 36) 20	TRANSPORTATION EQUIPMENT (SIC Major Gp 37) 21	TRANSPORTATION & PUBLIC UTILITIES (SIC Div. E) 22	TRADE/INS/FIN/REAL EST/PERS SVCS/PRINT (SIC F-H, bal 1, 27) 23	HEALTH SERVICES (SIC Major Gp 80) 24	GENERAL PUBLIC 25
1 KNOWLEDGE COMMUNITY (Science, Education, Prof. Soc. & Publ.)	C3 A4	3	3	3	C2 A3			3	3	3	4	1		2		2	2	4		2	2	4	3	4	2
2 INTERNATIONAL METROLOGICAL ORGANIZATIONS	2	4	3	2	4																				
3 DOCUMENTARY STANDARDIZATION ORGANIZATIONS	2	4	4	3	4			3	4	2	4	3		2		2	4	4		3	2	4	3	4	2
4 INSTRUMENTATION INDUSTRY (SIC Major Gp 38)	3	2	2	3	4			3	3	4	4	1		3		2	4	4		3	3	4	3	4	1
5 NBS	C2 D1 A3	C3 D2 A4 B2	C3 D3 A4 B3	C3 D1 A4 B3	4		C4 D3 A4 B4 2	C3 D3 A3 B2	C3 D3 A4 B3	C3 D2 A3 B0	C4 D3 A4 B2	C4 D3 A3 B4 2	C2 D2 A3 B2 ?			C2 D2 A2 B1	C2 D2 A4 B2	C4 D3 A2 B4		C2 D2 A4 B3		C4 D3 A4 B4	C4 D4 A3 B3	C4 D3 A4 B2	C1 A1
6 OTHER U.S. NATIONAL STANDARDS AUTHORITIES																									
7 STATE & LOCAL OFFICES OF WEIGHTS & MEASURES (OWM's)																									
8 STANDARDS & TESTING LABORATORIES AND SERVICES	2		1	C3 D3 A2 B2 R	1			2	C3 D2 A3 B2	2	3			1		1	3	C3 D3 A3 B2		1	2	C3 D3 A3 B2	C4 D4 A2 B2	C4 D3 A3 B2	
9 REGULATORY AGENCIES (excl. OWM's)	1		4	3 R	C4 D3 A4 B4 R			3 R	4	3 R	4 R	3 R		3 R		2 R	4 R	4 R		3 R	2 R	4 R	C4 D2 A4 B3 R	3 R	2 R
10 DEPARTMENT OF DEFENSE (excl. Stds Labs)	1		2	3 R	3 R			2 R	2	4	3					1	3 R	4 R		2 R	3 R	2 R	2 R	2 R	1
11 CIVILIAN FEDERAL GOV'T AGENCIES (excl Stds. Labs & Reg. Ag.)	3		4	3	4			2 R	4	2	4	1		2 R		1 R	1 R	4 R		1 R	1 R	4 R	2 R	4 R	2
12 STATE & LOCAL GOVERNMENT AGENCIES (exc. OWM's & Reg. Ag.)			1							1 R	1 R	1										2 R		2 R	1 R
13 INDUSTRIAL TRADE ASSOCIATIONS																									
14 AGRICULTURE, FORESTRY FISHING; MINING (SIC Div. A & B)	1		2	2 R	1 R				3	1	3			4			2	1				1		1 R	1
15 CONSTRUCTION (SIC Div. C)																									
16 FOOD/TOB/TEXTILE/APPAREL/LBR/FURN/PAPER/LEATHER (SIC 20-26, 31)			1	1 R	1 R				1	1	2					2									
17 CHEM/PETROL/RUBBER PLASTICS/STONE/CLAY/GLASS (SIC 28-30, 32)	2		3	3 R	3 R			2 R	4	3	4			3			4	3		1	1	2	3	1 R	1
18 PRIMARY & FAB. METAL PRODUCTS (SIC 33-34, 391)	3		4	4 R	3 R			2 R	4	4	4			1 R			1 R	4		2 R	2	4	3	1 R	1
19 MACHINERY, EXCEPT ELECTRICAL (SIC Major Gp 35)																									
20 ELECTRIC AND ELECTRONIC EQPMT (SIC Major Gp 36)	2		2	2 R	2 R				2	2	2						1	2		3	1	2	1	2	1
21 TRANSPORTATION EQUIPMENT (SIC Major Gp 37)	1		2	2 R	2 R				2	3	1							2 R		1 R	3		1		
22 TRANSPORTATION & PUBLIC UTILITIES (SIC Div. E)	3		4	3 R	3 R			2 R	4	1	4	1		1 R			1 R	3 R		2 R	1 R	4	3	1	2
23 TRADE/INS/FIN/REAL EST/PERS SVCS/PRINT-PUB (SIC F-H, bal. 1, 27)	2		3		3 R			2 R	4	3	3			3		2	4	4		2	2	4	3	3	2
24 HEALTH SERVICES (SIC Major Gp 80)	3		3	4 R	C4 D2 A4 B3 R			3 R	3	1	2	1		2		1	2	2		2	1	2	2 R	4	3
25 GENERAL PUBLIC			2 R	1 R	1 R				3 R	2 R	2 R	2 R					2 R	2 R		1 R	1 R	2 R	1 R	2 R	1

KEY TO MATRIX ENTRIES

C - IMPORTANCE OF TRANSACTIONS
- 1 = Purely convenience
- 2 = Strongly desirable
- 3 = No real alternatives
- 4 = Essential

D - (IN)ADEQUACY OF SERVICES
- 0 = No improvements needed
- 1 = Could be improved
- 2 = Marginal
- 3 = Serious deficiencies
- 4 = Out of control

USERS

C	D
A	
B	R

B - RATE OF CHANGE
- N = Declining
- 0 = Stable
- 2 = Growing
- 4 = Growing explosively

A - MAGNITUDE OF TRANSACTIONS
- 0 = Trivial
- 1 = Minor
- 2 = Moderate
- 3 = Important
- 4 = Major

R = Flow of requirements info dominates

? = Unknown, X = Not studied, Blank = 0

Table 6. Classification of medical radiation users by activity and specific interest

1. Direct Users of Radiation

   a. Radiotherapists
   b. Diagnostic radiologists
   c. Dentists
   d. Nuclear medicine physicians

2. Manufacturers

   a. Instrument makers
   b. Radiation source equipment manufacturers
   c. Radiopharmaceutical manufacturers

3. Regulatory Agencies

   a. Nuclear Regulatory Commission
   b. Environmental Protection Agency
   c. Food and Drug Administration (Bureau of Radiological Health, Bureau of Drugs)
   d. Occupational Safety and Health Administration (OSHA), Department of Labor
   e. State and local radiation control offices

4. Standards and Calibration Laboratories

   a. National Bureau of Standards
   b. Bureau International des Poids et Mesures (BIPM), Sèvres, France
   c. Foreign national standards laboratories
   d. Regional calibration laboratories (sponsored by American Association of Physicists in Medicine)
   e. Other calibration laboratories or consultants

5. Other Interested Groups

   a. Professional societies
   b. Standards setting organizations
   c. Educational institutions
   d. Government agencies

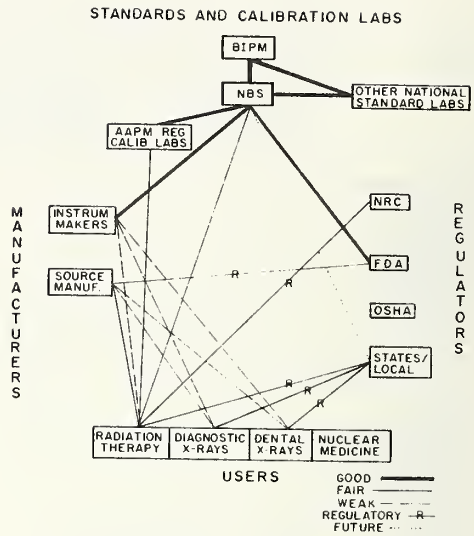

Figure 1. Medical radiation measurement system for x and gamma rays.

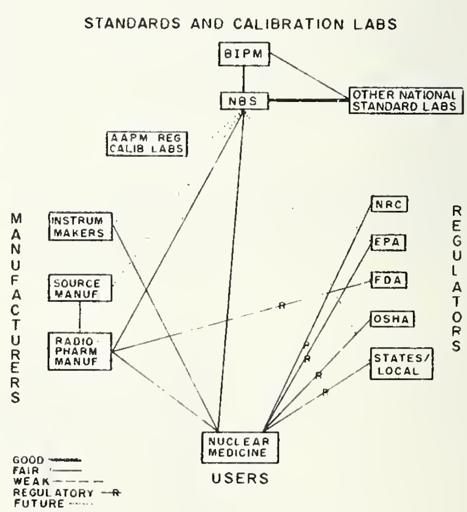

Figure 2. Measurement system for radioactivity standards and radiopharmaceuticals used in nuclear medicine.

2/3.A.1 Direct Users of Radiation:

(1) Radiotherapy. 350,000 patients are treated with radiation therapy per year, which includes 50-60 percent of cancer cases (Yarborough, 1970). As of 1970 there were 400 full-time radiotherapists in the United States. However, radiation therapy is also done on a part-time basis by a much larger number of radiologists and other physicians which we estimate at 5000 (based on the number of x-ray machines used for radiation therapy). In December 1969 there were 574 Co-60 and 30 Cs-137 gamma-ray therapy machines in the United States (IAEA, 1970). Of 138,000 medical x-ray sets in the United States, 5800 were used for radiation therapy (BRH, 1974). As of 1973 there were an estimated 280 high energy electron accelerators in the United States used for radiation therapy, according to information from manufacturers. Included in this category are linear accelerators, Van de Graaffs, and betatrons. The linear accelerators are extremely popular at present due to excellent depth dose characteristics, beam definition, and the flexibility of using electrons for therapy -- and are currently selling at a rate of about 50 per year in the United States, about 100 per year world-wide.

There has been great progress in radiation therapy in recent years, spearheaded by the use of the linear accelerators (linacs), betatrons, and Co-60 teletherapy units. Radiotherapists now try for cure in an estimated 20-60% of the cases depending upon the hospital (Cox, 1976).

Another development, use of the so-called high-LET (linear energy transfer) radiations, such as neutrons, pi mesons, and heavy ions, in radiation therapy is beginning to require development of dosimetry standards. Radiobiological evidence indicates that the high-LET radiations may be able to cure some tumors which are resistant to low-LET radiations such as x rays, gamma rays, and electrons. At least three cyclotrons in the United States are now treating patients with fast neutrons (University of Washington, M. D. Anderson Hospital using the Texas A&M cyclotron, and a consortium of hospitals led by the Medical College of Virginia, using the Naval Research Laboratory cyclotron, see Appendix C). The proton linac of the Los Alamos Meson Physics Facility is testing the use of pi mesons in radiation therapy. Heavy charged particles such as neon and argon are being used at the Bevalac facility of the Lawrence Berkeley Laboratory.

(2) Diagnostic x rays (for diagnostic radiology). In 1970 a National Academy of Sciences panel estimated that 129 million persons received 210 million diagnostic radiological examinations. The growth rate in radiological examinations has been 2 percent per year since 1964 (NAS, 1972). There were 138,000 medical x-ray sets in fiscal year 1974. In 1971, 91 percent of the sets were used for diagnostic purposes (BRH, 1972). Exciting new developments are occurring in diagnostic radiology equipment using new imaging methods and computer control and analysis. One such new apparatus is the EMI scanner developed in England for improved scanning for brain tumors. It is being bought widely in the United States despite a purchase price of about $400 k. Other scanners have been developed in the United States. This field is called computerized axial tomography (CAT). CAT scanners now number in the hundreds.

(3) Dental x rays. About 225 million diagnostic dental x rays are taken per year (BRH, 1970). There were 143,000 dental x-ray machines during fiscal year 1974 (BRH, 1974).

(4) Nuclear medicine. There are about 10 million applications of radiopharmaceuticals per year, of which 98 percent are diagnostic and 2 percent therapeutic (AEC, 1974). Radiopharmaceutical sales are increasing at a rate of approximately 25 percent per year, a sevenfold increase being expected during the 1970's (NAS, 1972). The number of physicians in the field has doubled in five years (Wagner, 1973). It was estimated that in 1974 5,000 U. S. hospitals used radioisotopes and 2,500 physicians used them in private clinics (AEC, 1974). One patient in four admitted to hospitals in the United States has had a radioisotope play some important role in the diagnostic process. In 1972, 2.9 million patients received technetium-99m as part of the diagnostic process.

2/3.A.2 Manufacturers.

(1) Instrument makers and source manufacturers. Medical nuclear equipment had sales of 50 million dollars in 1971 (AEC, 1971) which increased to 140 million dollars in 1974 (AEC, 1974). There are 11 principal suppliers of radioisotope teletherapy units (see appendix C). There are four principal suppliers of medical linear accelerators. Eighteen other manufacturers produce medical x-ray equipment (see appendix C). In addition, there is a large business in x-ray film and processing equipment, and fluorescence equipment.

(2) Radiopharmaceutical manufacturers. Radiopharmaceutical sales are about 70 million dollars annually while other retail radioisotope sales are about 17 million dollars annually, 2 million dollars of which is for cyclotron-produced radioisotopes, and much of the rest being C-14 and H-3 labeled compounds (AEC, 1974). There are about 35 manufacturers of radiochemical and radiopharmaceutical compounds (see appendix C).

2/3.A.3 Standards and Calibration Laboratories.

Calibrations for the user may be obtained directly from NBS, through regional calibration laboratories (see Figure 1), or through other calibration laboratories or radiological physicists who serve as consultants.

(1) Regional calibration laboratories. In recognition of the impossibility of NBS providing direct calibration services to more than a small fraction of the thousands of hospitals using x rays and Co-60 for therapy, the American Association of Physicists in Medicine (AAPM), in cooperation with NBS, has established a program for setting up and certifying regional calibration laboratories. Thus far, three regional calibration laboratories have been certified (M. D. Anderson Hospital, Houston; Memorial Hospital, N. Y., and Victoreen Instrument Co., Cleveland). The three calibration laboratories are capable of calibrating about 200 instruments per year. All three institutions are traceable to NBS, and are believed to be technically competent and adequately equipped for the job. In addition, a Radiological Physics Center (RPC) has been set up at M. D. Anderson Hospital, operated by the AAPM, and funded by the Committee for Radiation Therapy Studies (CRTS), which is in turn funded by NIH. Their job is to see that the dosimetry of the approximately 200 hospitals in the United States participating in clinical trials of radiation therapy is uniform and correct. In addition to calibrating the x-ray sets and Co-60 therapy equipment, they also check the treatment plan. The tumor dose is considered satisfactory if the institution value and the RPC value are within ± 5%. They visit 30-35 institutions per year and, therefore, require about six years to complete the cycle of visiting all institutions. The discrepancies found in their studies range from -25% to +21%. A statistical study of the Radiological Physics Center calibrations through October 1971 has been reported by Golden, et al (1972). Some of their results are shown in figures 3 and 4. Of 71 institutions visited, 80% had machine calibrations within ± 5%, but only 65% had tumor dose within 5% (due to treatment plan and other uncertainties), 18 of the problems leading to differences exceeding 5% have been resolved but 7 have not been resolved. One should note that the set of 200 hospitals represents about half of the best hospitals in the United States doing radiation therapy. The National Cancer Institute has now set up six Centers for Radiologic Physics to help hospitals in the NCI Cancer Control Program. In the much larger number of other hospitals doing radiation therapy, the situation may be worse.

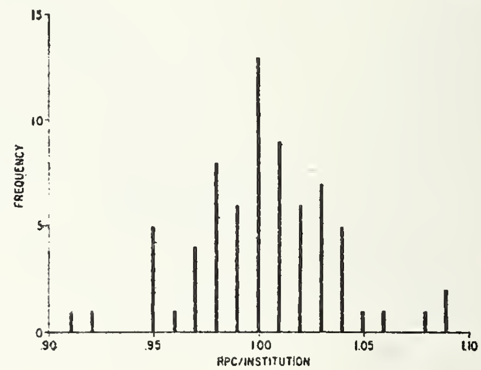

Figure 3. Comparison of radiation therapy machine calibrations by the RPC with those in use at institutions. Frequency refers to number of institutions; an average comparison is given if an institution had more than one radiation machine. From Golden et al, 1972.

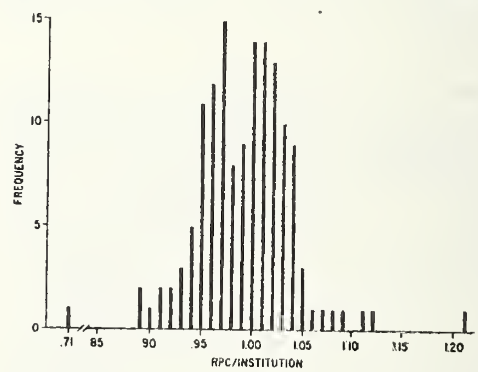

Figure 4. Comparison of tumor dose delivered (RPC) with that prescribed (institution). Radiation machines and types of treatment are counted separately in determining frequency. From Golden et al, 1972.

In the field of nuclear medicine, standardization may be done in several ways. The problem is to give the correct dose (radioactivity) to the patient. Several methods of dose determination are: (1) give an aliquot of the material supplied by the radiopharmaceutical manufacturer; (2) check the material against a standard of the same radionuclide or of another radionuclide with a similar decay scheme ("mock standard"); (3) measure the activity to be given to the patient with a "dose calibrator" which is usually an ionization chamber instrument with a calibration for each of the common radionuclides used in radiopharmaceuticals. Method (1) does not work for nuclides such as Technetium-99m which are drawn off a Molybdenum-99-Technetium-99m generator. Commercial laboratories which sell radioactivity standards (as does NBS) and the manufacturers of dose calibrators play a role as calibration laboratories in that the user is dependent on their calibration. A list of producers of radioactivity standards, and of dose calibrator manufacturers is given in appendix C.

2/3.A.4. Structure and Problems of the Medical Radiation Measurement System

We shall now discuss the structure of the measurement system for medical radiation, identifying areas where measurements are demonstrably unsatisfactory and where more study is needed, and suggesting NBS actions needed.

(1) Radiation therapy. There are about 1200 high energy accelerators, Co-60 and Cs-137 machines plus more than 5800 x-ray sets being used. The total number of instruments calibrated per year by NBS for medical institutions is not greater than 50, and regional calibration laboratories and the Radiological Physics Center, among them, calibrate instruments for perhaps 150 institutions per year. The instrument companies provide fewer than 500 calibrations per year for radiation therapy. It seems unlikely that there are more than 200 high quality and 500 medium quality calibrations per year of instruments to be used with more than 7000 machines. In radiation therapy, it is generally agreed that an accuracy in dose to the tumor of 5% is desirable. (See, for example, Herring and Compton, 1971.) Since among the best hospitals about one-third are outside the 5% limit (see figure 4), it is likely that most of the radiation therapy done today in the United States is outside this limit.

If we consider figure 1, which applies to x-rays and gamma-rays of Co-60 and Cs-137 energies, we see that the international system and the calibrations to the level of the AAPM regional calibration laboratories and the instrument makers (such as Victoreen) are generally satisfactory. However, between all the calibration laboratories and the users there are simply not enough calibrations being performed to assure that every patient is being treated with satisfactory (5% accuracy) dosimetry.

A study at NBS by Dr. Robert Loevinger of the errors in absorbed dose to a tumor under relatively desirable conditions with an optimum chain of calibrations (through regional calibration laboratories to NBS) showed that present uncertainties in NBS standards do not make a major contribution to the final error in the tumor dose.

In the case of x and gamma rays below 1.25 MeV (Co-60 energy), satisfactory NBS standards exist. It therefore appears that, since much radiation therapy equipment is uncalibrated or not in proper calibration, the NBS program should be aimed at building the calibration network through creation of more regional calibration laboratories, rather than at improving existing standards. However, at least one of the three existing regional calibration laboratories has economic problems. It is the author's belief that the solution lies in the area of establishing codes of good practice (or possibly regulations) which require that radiation therapy calibration instruments shall be calibrated at regular intervals (for example, every two years) by qualified laboratories or radiological physicists, and that therapy beams shall be calibrated at more frequent intervals. This possibility is being investigated. Some recommendations for calibrations at regular intervals have been made by the International Commission on Radiation Units and Measurements (ICRU, 1973). It is important that the calibration centers be run by medical physics personnel to be of maximum help to the medical physics users.

The existing research program for dissemination of standards being carried out at NBS under National Cancer Institute sponsorship will be helpful in establishing a better calibration system. A schematic diagram of the x- and gamma-ray calibration system is given in Figure 5.

In the case of electron therapy, NBS has developed a calorimeter as a primary standard. A ferrous sulfate dosimeter calibration service now exists, which is used by about 25 hospitals and clinics, which is a significant fraction of the institutions now doing electron therapy.

NBS has developed an improved calibration service using thermoluminescent dosimeters (TLD) for calibration of Co-60 teletherapy units.

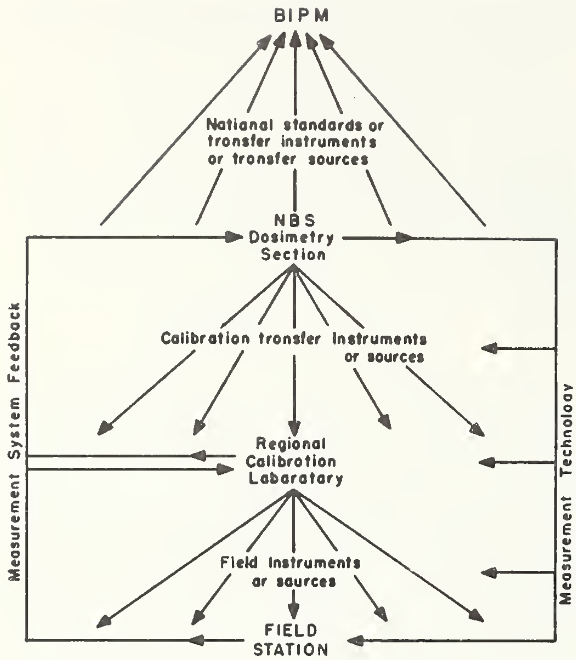

Figure 5. Medical dosimetry calibration system.

The situation is entirely different where NBS standards do not yet exist, for example, absorbed dose for high energy x-rays and fast neutrons. An experimental program on the NBS linac is planned for development of the calorimeter as the primary standard for high energy x-rays (1-50 MeV). At present, the laboratories working with the high energy x-rays from linacs and betatrons use a Co-60 calibrated ionization chamber with a correction factor calculated from physical data rather than based on a standard. The development of the high energy x-ray primary standard should considerably improve the accuracy of the dosimetry at these high energies, but would not be expected to change the values now in use by more than about 4 percent.

In the case of fast neutrons, each institution develops its own dosimetry (except in the United States the three cyclotron institutions are using identical instruments). Since the number of institutions is still small, they do make intercomparisons with each other -- the problems may not yet be serious. However, a 10% difference was found between the Hammersmith Hospital (England) rad and the M. D. Anderson Hospital (Texas) rad. Agreement in dosimetry is important so that clinical experience can be transferred from one hospital to another. A need exists for NBS to develop primary dosimetry standards for fast neutron radiation therapy, since the number of institutions planning to do neutron therapy is increasing rapidly.

(2) Diagnostic and dental x-rays. Here the chief measurement need is to assure a safe and as-low-as-practicable dose to the patient. The fraction of the 280,000 x-ray sets used for these purposes which are calibrated with instruments calibrated at NBS must be very small. A general problem not solely measurement, is indicated by a survey of diagnostic and therapeutic x-ray machines in Suffolk County, New York, in 1972 (see table 7).

Table 7. Survey of Diagnostic and Therapeutic X-ray Machines, Suffolk County, New York, 1972.

X-ray Machines Inspected	1411
X-ray Machines in Violation (some Multiple)	479
X-ray Machines Corrected	368
Violations	
Inadequate Collimation	260
Inadequate Filtration	183
Operator Cannot Stand 6 Feet Away	76
Inadequate Shielding for Operator	45
Inadequate Shutters (Fluoroscope)	32
Inadequate Timer (Fluoroscope)	35
Others	73

From Becker, 1973.

Most x-ray sets are periodically surveyed (from once each year to once every four years) by state or local health or radiation control departments. Such departments tend to use rather simple equipment which will detect gross errors, and check for scattered x-rays (protection of medical and technical personnel). Frequently they do not measure the radiation level in the useful beam (patient dose) but rely on the radiologist's or dentist's judgment to keep the patient dose acceptable, or on laws requiring the use of fast x-ray film. This may lead to higher dose than necessary being given to the patient.

(3) Nuclear medicine. Although NBS provides radioactivity standards for use in the approximately 8,000 hospitals and clinics administering radiopharmaceuticals, the number sold indicates that only a small number of the institutions are using NBS standards. Many standards are provided by the radiopharmaceutical supplier -- often the same company furnishes both radiopharmaceuticals and radioactivity standards. This practice provides no double

check on calibration accuracy. To study and to help improve the accuracy of measurements in hospitals and clinics, the NBS has embarked on a quality assurance program in cooperation with the College of American Pathologists, and has found that many institutions lie outside the accuracy limits (10% of the stated radioactivity) required by the U. S. Pharmacopeia for radiopharmaceuticals. The measurement assurance program of NBS for radiopharmaceuticals involves not more than 300, presumably of the best, of the approximately 8,000 hospitals and private clinics using radionuclides in nuclear medicine. The measurement accuracy required is less than for radiation therapy because of the low doses involved. However, in the measurement assurance tests conducted so far factors-of-two are common and factors-of-ten do occur. It therefore appears that some system of quality control needs to be extended to the rest of the about 8,000 institutions doing nuclear medicine.

An obvious improvement in the accuracy of radioactivity measurements could be obtained if every hospital and clinic used a reliable dose calibrator instrument in proper calibration. These could be used to check every dose, and some such instrument is absolutely necessary to check doses where an unknown amount of radioactivity is drawn from a radionuclide "generator" in the hospital -- in this case, the amount of activity cannot be predetermined by the radiopharmaceutical supplier. The problem is that the calibrations of present-day dose calibrators are not reliable, as was shown in the NBS-VA study by Garfinkel and Hine (1973), and has been shown in later studies of commercial dose calibrators carried out in the NBS Radioactivity Section (errors of a factor-of-two are not uncommon). NBS action called for here seems to be (1) for NBS to work with the dose-calibrator manufacturers to correct the calibration problems with the instruments, (2) to provide dose calibrator check source sets for the hospital user to routinely check his instrument, and (3) for NBS or an NBS-traceable laboratory to distribute medically-important radionuclides for dose calibrator instrument check-out.

Some of the "future" links in figure 2 which are being developed are: (1) NBS is working with the instrument manufacturers to improve accuracy of dose calibrator instruments; (2) NBS is working with the radiopharmaceutical manufacturers to provide traceability of the manufacturers to NBS (a Research Associateship has been established, sponsored by the Atomic Industrial Forum at NBS); (3) NBS is developing traceability to the laboratory of the FDA which has cognizance over radiophamaceuticals, and to the EPA standards laboratory at NERC-Las Vegas; (4) NBS has established a program to help the States to obtain satisfactory measurement competence to carry out their regulatory responsibilities in medical (and other) uses of radiation. An Office of Radiation Measurement has been established to provide liaison between NBS and the States and other groups with radiation measurement problems.

Note the common thread of the above discussion of the medical measurement system: where a measurement system tied in to NBS exists, many users are in satisfactory shape although some need improvement -- but where either no system exists or no measurement assurance checks are made, the measurement accuracy upon testing is found to be worse and frequently outside of acceptable limits.

2/3.B. NUCLEAR POWER

In the first quarter of 1977, 66 commercial power reactors with a total installed capacity of 47,200 megawatts were licensed to send power into grids across the nation; this represented about 10% of the nation's entire electricity generation capability (see also figure 6). Projections indicated that by 1985, uranium will be the fuel for nearly 30% of all electric power generation, and that by the end of the century it will supply more than half of our expanded needs for electricity (AEC, 1974). In addition, 58 units were under construction, and a total of 111 units were in the design process. The magnitude of American investment in nuclear power can be illustrated by the fact that over $102 billion are presently committed to the nuclear power program (AEC, 1974). The rate of investment in nuclear power has slowed due to decreased demand for electricity, lessened availability of capital to the utilities (AEC, 1974), and due to problems with licensing and intervention.

The economic advantage of nuclear power can be seen from the fact that the fuel cost is approximately half that for a coal-fired power plant, and total operating costs per kWh of electricity are roughly 80% of that of the coal-fired plant, based on a LWR (lightwater reactor) and a coal plant, each of 1,000 MW (electrical) capacity (AEC, 1974).

The Measurement System for Ionizing Radiation plays an important role in the nuclear power industry in several ways: (1) Many of the measurements thoughout the nuclear fuel cycle are ionizing radiation measurements. (2) Radiation measurements and nuclear technology play a very large role in providing design data for reactors, in the development and testing of new reactor designs,

NUCLEAR POWER REACTORS IN THE UNITED STATES

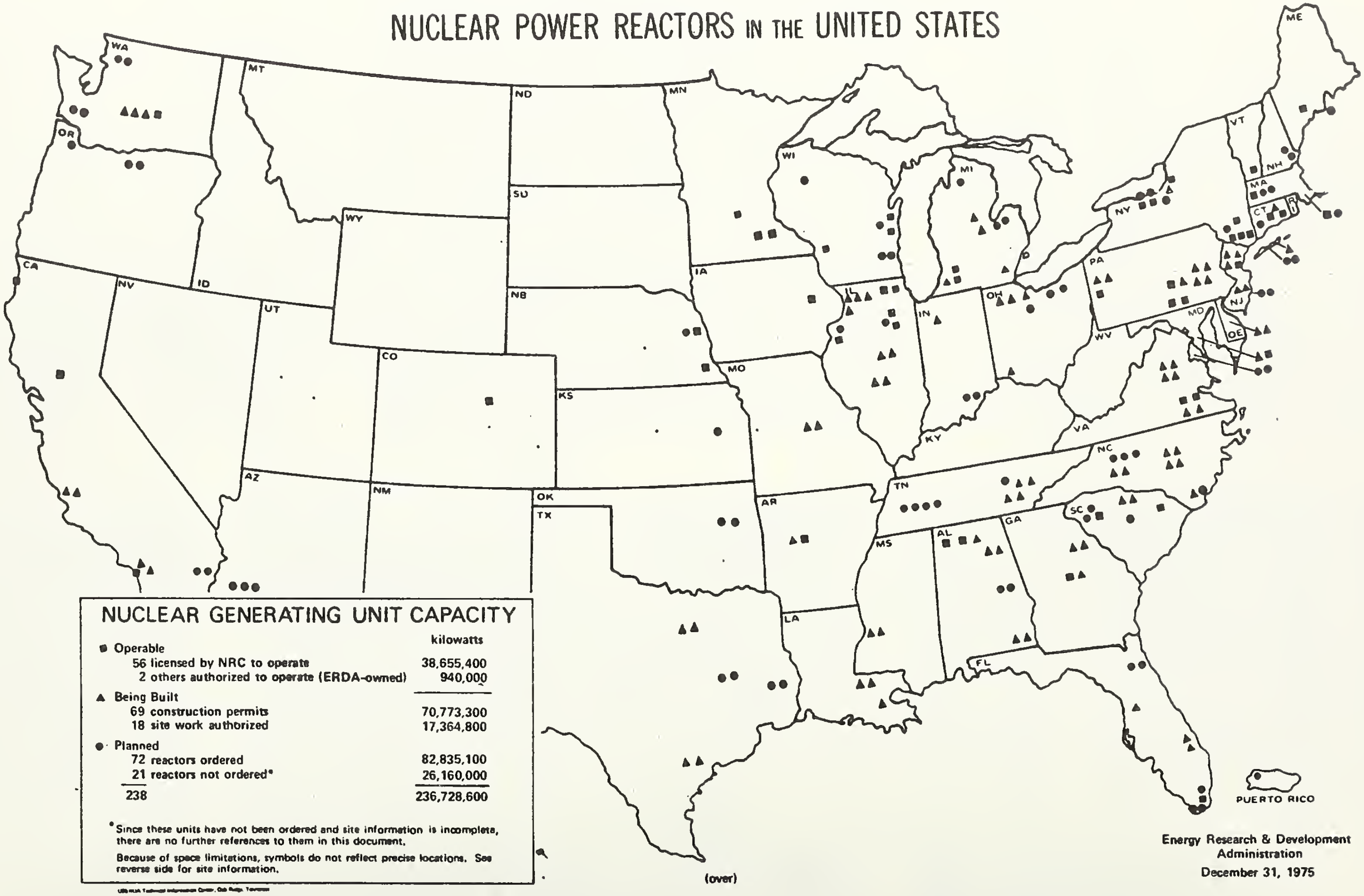

Figure 6. Nuclear power reactors in the United States (ERDA, 1975).

and in the instrumentation, control, and safety systems of operating power reactors. (3) Monitoring of radioactive effluents in the plant and in the environment are necessary for public safety. This last subject will primarily be discussed under section 2/3.G Environmental Radioactivity Measurement. We now proceed to a discussion of the first two topics.

2/3.B.1 Nuclear Fuel Cycle Operations

Information contained here was obtained as a part of a study (Bartlett, 1974, given as appendix D to this study) to assess needs for NBS services in support of the nuclear power industry. This one-year study was completed in July 1974.

The study was aimed at measurements made on nuclear fuel materials, i.e., uranium- and plutonium-bearing materials. The industry also makes many other measurements involving ionizing radiation. These include dosimetry for personnel protection (discussed in section 2/3.I), monitoring of effluents for environmental protection (section 2/3.G), and monitoring of power reactor operations (section 2/3.B.2).

2/3.B.1.1 Scope and Status of the Nuclear Power Industry

(1) Contributions to national energy needs. As noted by John Love (1973), former Director of the Office for Energy Policy, nuclear power currently supplies energy for national needs in an amount comparable to that being produced by burning of wood. It is projected, however, to become a key source of future electrical power: by the turn of the century, nuclear power plants are projected to constitute more than half of the total U.S. electrical generating capacity. To realize this forecast, installed nuclear capacity will have to increase to 1,200,000 MWe by the end of the year 2000 (AEC, 1972). The projections require an increase in electricity delivery to the power grid at about 1000 MW per week throughout the decade of the 90's and beyond. With present economics and technology, each 1000 megawatts corresponds, approximately, to one power station. To achieve this growth, total capital investments of approximately \$580 billion (current dollars) will be needed for the reactor plants and supporting operations.[1]

(2) Nuclear industry operations. Nuclear power plants require numerous satellite operations:

(a) a sequence of mining and milling operations to extract and purify uranium fuel;

(b) conversion operations to get the uranium into forms suitable for processing;

(c) enrichment, which increases the isotopic abundance of U-235 to levels needed for reactors;

(d) fuel element fabrication;

(e) spent fuel reprocessing, to recover unused uranium and plutonium generated during reactor operation, and

(f) waste management, to assure that radioactive wastes are not a hazard to man and his environment.

These operations constitute the nuclear fuel cycle. It is a cycle because fuel materials recovered in the reprocessing step are recycled for use in next-generation fuel elements. The sequence of operations is shown in figure 7.

Nearly all commercial reactors currently operating in the United States use uranium as their fuel and ordinary water as the reactor coolant. Beginning in the 1980's, however, two other types of reactors are expected to become commercially significant: the Liquid Metal Fast Breeder Reactor (LMFBR), which uses liquid sodium as the coolant and is the most efficient user and producer of nuclear fuels, and the High Temperature Gas-Cooled Reactor (HTGR), which promises superior thermal efficiencies and uses U-233 and thorium in its fuel. Each of these reactor types requires different technology in the support operations cited above. Thus, diversification as well as rapid growth is expected for the industry.

(3) Role of measurements. Reliable measurements are the lifeblood of the nuclear industry. Accuracy and precision beyond conventional industrial measurements are demanded because:

(a) loss of fuel material could pose a threat to national security and/or public health, and

(b) an extraordinary level of quality assurance is necessary to assure safe, reliable operation in all facets of the industry because of the complexity and potential hazards of nuclear operations.

Two basic sectors of interest in nuclear industry measurements must be identified:

(a) regulatory bodies (NRC, agreement states, and EPA) charged with responsibility to safeguard national security and public health (see section 2.4.4); and

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[1]Obtained by extrapolating data to 1985 given in AEC (1971). A capital cost of \$500 million per reactor plant was assumed, which is probably low since plants are currently running close to \$600 million.

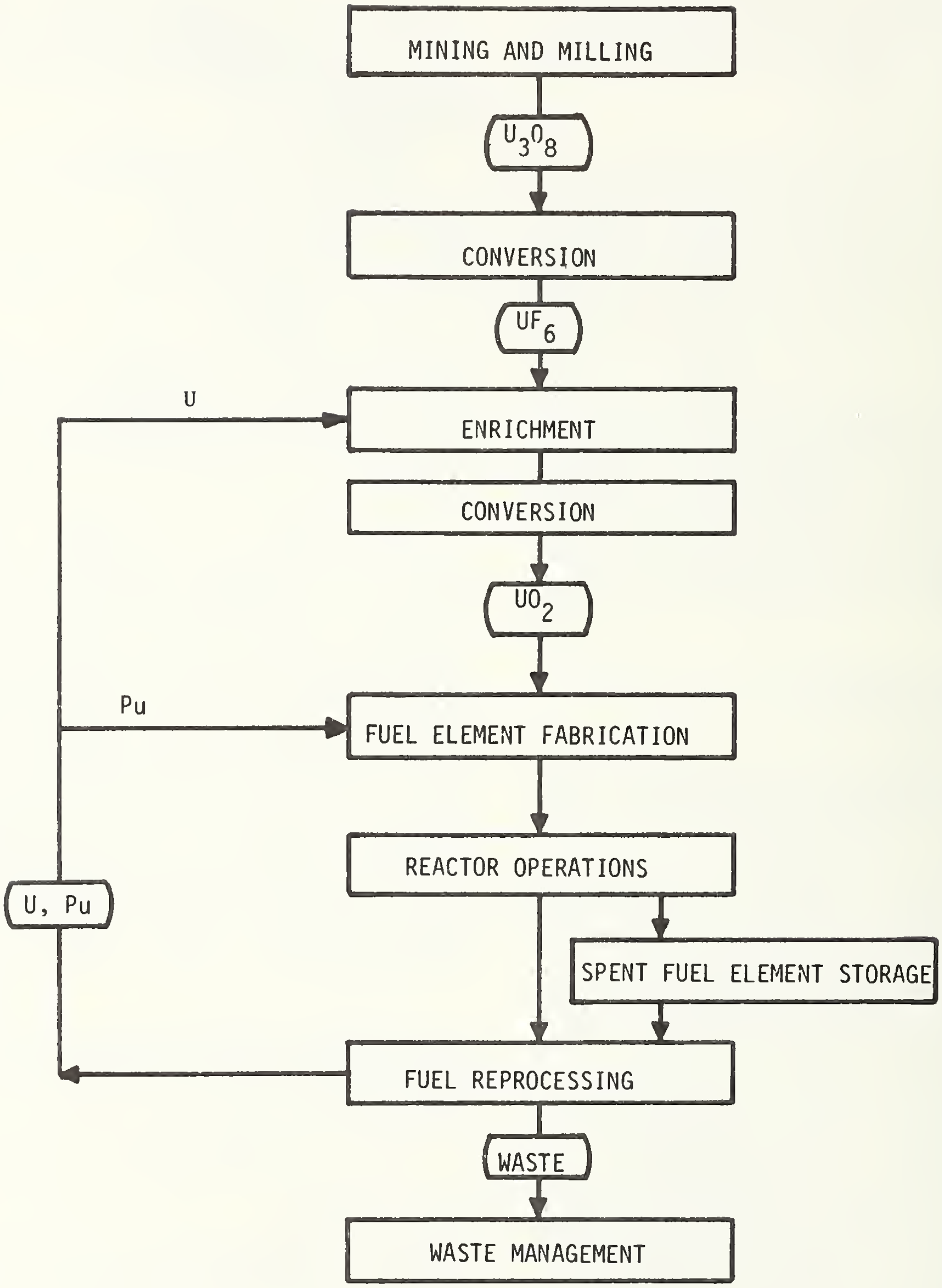

Figure 7. Outline of nuclear power industry operations.

(b) the industry companies, charged with responsibility for reliable, profitable production.

These sectors and their interests are hardly unique. However, the potential severity of the adverse consequences of failure to control nuclear materials makes measurements a focus of interest for the industry. The level of accuracy required by the Nuclear Regulatory Commission for nuclear materials control (1% error or less; see Federal Register, 1973) also forces the industry to use the very best measurement technology available. This technology is highly sophisticated and costly.

(4) Industry structure. At present, over 60 commercial nuclear power plants are in operation. Another 160 are in construction or on order. The various satellite operations are, or will be, performed by about 15 companies at less than 30 sites. Although rapid growth of installed generating capacity is expected, extensive proliferation of sites (and companies) to perform the satellite operations is not expected. Few electric companies initially had the expertise and resources required for nuclear power; expansions in capacity will most probably occur at existing sites in order to facilitate materials control.

The national laboratories and other Department of Energy prime contractors must be considered a part of the industry since they are a major source of technology (especially for measurements) and key participants in measurement assurance activities. Another key part of the industry, from a measurements point of view, is the Department of Energy laboratory at New Brunswick, New Jersey, which has been transferred to Argonne National Laboratory. The numerous measurements-related functions of this laboratory are outlined below.

Other key participants in the industry are the instrument vendors (numerous), the private laboratories (24 in number) that provide referee measurement services to the industry, the eight major (about 24 total) architect-engineer firms that build the nuclear facilities, and the four major reactor designers/manufacturers. Most of the designers/manufacturers are, to varying degrees, vertically integrated, i.e., they also perform some of the satellite operations.

2/3.B.1.2 Measurement Objectives

Nuclear industry measurements have two basic purposes: quality assurance and compliance with regulations. For the industrial operation, data obtained for compliance purpose -- although bounded by stringent accuracy and precision requirement -- are a peripheral part of their measurement objectives. They are, however, quite costly.

The reactor operator is most interested in fuel element quality assurance. Indeed, his interest in nuclear performance (e.g., fissile content of the fuel) is at least equalled if not exceeded, by this interest in assurance that the fuel will not fail in service for mechanical or other reasons. His primary objective for measurements at the fuel fabrication stage is, therefore, fuel element integrity. Shipper/receiver equity for special nuclear material (SNM) is, for present and anticipated fuel cycle economics, a secondary concern.

When spent fuel is removed from a reactor, burnup calculations are performed to estimate the fissile content. These calculations have an accuracy on the order of 5%; little chance for significant improvement in accuracy is foreseen. These calculations provide an estimate of the input to the reprocessor; the reprocessor's measurement of the input (made in the accountability tank) is much more accurate and crucial to his objectives. Significant differences ("significant" yet to be defined) between burnup calculations and accountability tank data would be resolved by referee laboratory assays.

The reprocessor and fuel fabricator also have quality assurance as their major objective for measurements. Their motive is profit. Failure to achieve quality will reduce profit as a result of downtime, need to repeat operations on out-of-specification product, etc.

The reprocessor and fuel fabricators bear the heaviest burden of costs for compliance. Regulations (Federal Register, 1973) impose strict materials accountability requirements on them. Compliance with these requirements may, but will not necessarily assure product quality. The regulations require highly accurate material balance determinations at specified intervals. Things can go wrong in the time periods between material balances. Thus, measurements for compliance supplement routine measurements for production.

2/3.B.1.3 Measurement Methods

The nuclear industry routinely uses the following measurement methods:

(1) Process equipment calibration and control. Volume calibrations, on-line sensors to measure temperature, specific gravity, electrical conductivity, etc. are used. Volumetric calibration of the reprocessor's

accountability tank is especially important. Accuracy of 0.5% is feasible but not often obtained; 3-4% error is "normal."

(2) Materials assay. Quantitative analysis (many procedures available), mass spectrometry, gamma-ray and alpha spectroscopy, neutron interrogation, photometry, and x-ray fluorescence are important materials assay methods.

Many variations of these basic assay techniques are available. Accuracies attained depend on the method, the use, and the user. Quantitative assays can achieve accuracies to 0.1%; gamma-ray spectroscopy errors range from a few percent to about 50%.

A current characteristic of the industry is that few sites will be doing similar operations, and no two sites will use the same assay techniques to make similar measurements. Many possible variants to these techniques are in use.

The assay techniques fall into two categories: destructive and nondestructive (NDA). From industry's point of view NDA is essential for some measurements (fabricated fuel pellets and elements) and highly desirable for others (scrap and waste). Rapid measurements are also needed to avoid production delays. There is, therefore, strong pressure for use of as much NDA as possible. All measurements are expected in the future, however, to be traceable to NBS (measurement capability demonstrably in agreement with that of NBS), and the link will be the destructive assay chemical techniques. A program for periodic use of such techniques will, therefore, always be necessary in addition to NDA methods.

2/3.B.1.4 Status of Measurement Technology

Largely as a result of the Department of Energy R&D programs, measurement technology commensurate with most quality assurance (QA) and compliance requirements is in existence. A major weakness is in the area of the measurements on scrap and waste. Development of methods for these measurements is continuing, and problems (e.g., major material balance uncertainties) due to scrap and waste measurement inaccuracies (today, typical performance is 15%-40% error) can be minimized by management procedures requiring measurements whenever material leaves a given process area.

Department of Energy R&D activities in support of measurement technology are currently focused on developments needed for Liquid-Metal Fast Breeder Reactor (LMFBR) operations. Programs are conventionally implemented in the laboratories of the Department of Energy prime contractors. Transfer of technology to industry from Department of Energy laboratories is achieved via vendor initiatives and consultative services provided by the contractors.

Development of technology is, on the whole, orderly, timely, and appropriate for industrial needs. The Department of Energy carefully controls its programs and uses NBS services on an ad hoc basis. NBS has in the past and will in the future contribute extensively to this development work. Mechanisms for identification and use of NBS resources in this role function well.

Companies with sufficient resources and initiative will develop their own measurement technology. In-house expertise, Department of Energy and NRC consultation, are used to extrapolate existing technology and apply it to specific needs. For example, one company invested a million dollars of its own funds into development of a fuel rod scanner. It also developed a highly-sophisticated computer model of process operations. Such initiatives are rare, however, because of the high cost.

The major measurement-related problem in the nuclear industry today is proper use of available technology. The technology is highly sophisticated, method alternatives are numerous, measurements required are numerous, accuracy requirements are extraordinary, and the stakes are high. Many companies are finding it difficult to address and resolve their problems.

Some of the key problem elements can be identified:

(1) Industry's capability to translate the technology assumed in regulatory guides into routine practice typically is limited. The high-powered technical expertise is in the national laboratories.

(2) Instrument vendors are a weak link in the chain. Although they quickly move new technology from the contractors' laboratories into the market place, the delivered equipment frequently has bugs. The typical user must rely on the vendor for assistance in assuring that the instruments deliver reliable data, but vendor expertise is also limited.

(3) Industry will probably incur major capital and operating costs to achieve compliance with new regulations. Some may face major revisions of current operation procedures; they may also need organizations and

staff competence not now on board. Losses in production and losses on existing contracts may be foreseen; reluctance to make changes may result.

(4) The NRC is increasingly demanding NBS traceability. Much of the industry does not know what this means or how to achieve it.

(5) The major mechanisms for conversion of technology to practice are the written consensus standards (e.g., ANSI, see section 2.2.1). These standards take a long time to develop. Those currently available (few in comparison with what is needed) do not provide a strong basis for procedures or action. Professional expertise that can function where standards are inadequate or unavailable is necessary.

In summary, industry faces major problems and costs in achieving compliance-demanded utilization of measurement technology. Key factors are the lack of expertise and the lack of mechanisms to assist in bridging the gap between the technology and its use.

It is important to note that the major problem industry faces is, in general, to develop a comprehensive, cost-effective system of measurements that is responsive to the already-stringent production quality assurance requirements and the demands made by the new regulations. Measurement capability may have to be rescheduled or revised to incorporate requirements for periodic inventories. And much more attention to NBS traceability may be necessary. Each operation in the fuel cycle has unique problems, and each operator has unique problems dependent on his current status. Current performance is very uneven.

2/3.B.1.5 Measurement System Infrastructure

Because QA and materials security requirements are so stringent, the nuclear power industry has a comparatively well-developed measurement infrastructure with, in general, high visibility for NBS.

With NRC funding and guidance, the industry routinely runs extensive measurement assurance programs. One of these, the General Analytical Evaluation (GAE) program, is restricted to NRC contractors; spillover and interaction with industry occur, however, through NRC consultative services. The Safeguards Analytical Laboratory Evaluation (SALE) program is highly comprehensive. Thirteen Department of Energy or Department of Energy contractor laboratories, 24 domestic licensee laboratories, and nine laboratories outside the U.S. participate in SALE. Performance in analyses of U and Pu in various forms is routinely monitored via this program.

The NRC discontinued financial support of licensee participation in SALE in FY 1975. Consequences of this action are not yet clear; a new SALE-like service for the licensees may have to be developed. The preferred alternative is to continue operation on a cost-recovery basis.

The GAE and SALE programs operate via close ties with the Department of Energy New Brunswick Laboratory (NBL) which in turn is closely linked to NBS. The New Brunswick Laboratory also does extensive characterization of uranium standards, which is supplemented by preparation of plutonium standards at Los Alamos. NBL has primary responsibility for preparation of "working" standards for the industry. Such standards are closely related to NBS standards but they are not NBS-certified. They form the backbone of the routine measurements, although the industry also makes extensive use of NBS standard reference materials.

Contacts with the Department of Energy and industry revealed extensive uncertainty and confusion concerning phraseology used to describe materials standards. A "standards lexicon" on materials standards appears to be needed.

A subject currently receiving widespread attention in the industry is material standards for NDA. At present, each operator "does his own thing" with respect to waste packaging and other operations where NDA is used. Industry-wide NBA standards have, therefore, not been developed, and an infrastructure does not exist. General Electric Co. is pressing for industry-wide NDA standardization. Development of appropriate ANSI consensus standards (estimated to take three years) seems to be a necessary first step. Subsequently the development of materials standards and an infrastructure for their use will be necessary. NBS may expect a key role. As GE personnel expressed it, industry wants "a place to take their NDA working standards to have them certified."

A possible structure for NBS interactions in nuclear industry fuel cycle measurements is given in Figure 8 (Bartlett, 1974). Present indications are that ties between NBS and the instrument vendors and independent laboratories may tend on the average to be weak. The leaders in both categories do, however, participate in the SALE program.

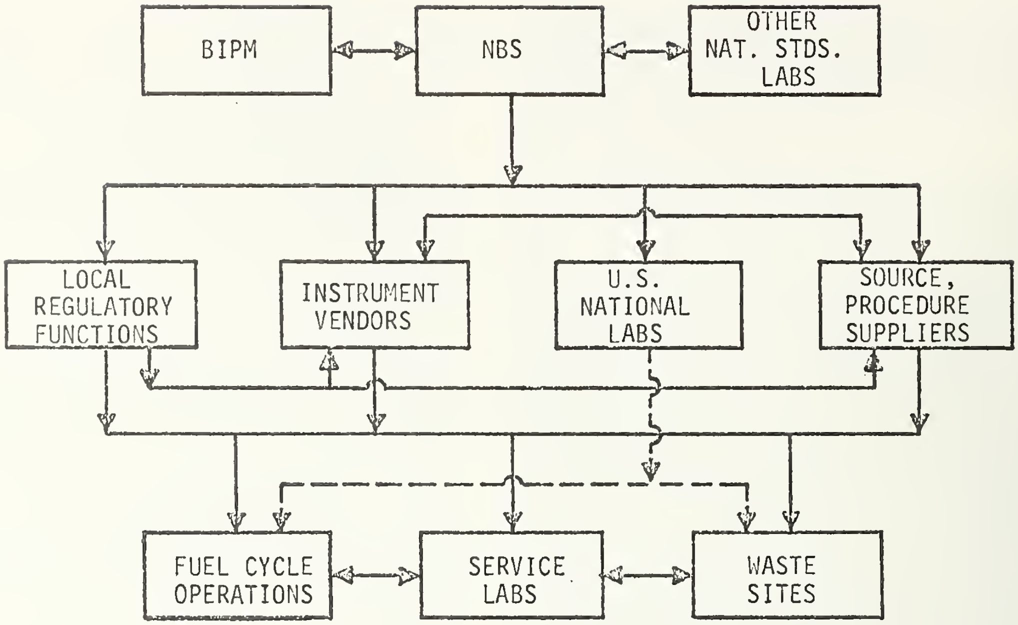

Figure 8. Possible NBS interactions for nuclear industry measurements and standards.

NBS current activities make significant contributions in this area: (1) NBS furnishes standard reference materials and a new program in collaboration with the Department of Energy (and NRC) is in progress to define needs and priorities for new standard reference materials; in collaboration with Mound Laboratory, efforts are being made to improve the technical base for calorimetry; NBS assists the measurement assurance activities of the SALE program through collaboration with the New Brunswick Laboratory; and NBS personnel are assisting the Department of Energy Division of Nuclear Materials Security in an analysis of materials diversification and data requirements.

One area where the NBS program is surprisingly small is the area of ties to ANSI on nuclear energy-related standards. Although NBS had, in 1972 (ORNL, 1972), 22 personnel working in 14 areas of ANSI standards related to nuclear energy, none of the personnel was working directly on the two committees developing standards of most concern to the nuclear materials measurement problem: N-15, Methods of Nuclear Material Control, and N-46, Nuclear Reactor Fuel Cycle. Inquiry within NBS revealed that only one staff member was currently serving in this area. This activity may be expected to increase with NBS leadership of the ANSI Technical Advisory Group for ISO TC 85.

2/3.B.1.6 <u>Summary of Conclusions of the Assessment of the Nuclear Fuel Materials Measurement System</u>

The conclusions of the report by Bartlett (1974), attached as Appendix D, may be summarized as follows:

(1) Highest accuracy requirements in nuclear fuel materials measurement are for nuclear materials safeguards, not for equity in trade;

(2) the major need is for a nationally-based measurement assurance system for fuel material measurements for demonstrably viable measurement capability;

(3) other needs include regulations, guides, consensus standards; state-of-the-art performance in the field with sophisticated measurement technology approaching NBS capability; and development of real-time Special Nuclear Materials control replacing periodic inventory; and

(4) both Institute for Basic Standards and Institute for Materials Research participation are required for a viable program.

2/3.B.2 Nuclear Reactor Design Data and Operations

The previous discussion was concerned with measurements at various points in the nuclear fuel cycle. The objective was to determine with sufficient accuracy the quantities of the nuclides present in the fuel or waste, with primary attention paid to the fissionable nuclides such as U-235 and Pu-239. Another class of measurements, primarily neutron measurements, are made to obtain the neutron cross sections for designing the reactors (both fission and fusion, in general), and to evaluate quantitatively how well the reactor is performing and for testing various components. These needs for neutron measurements for reactor design and performance test led to the present NBS program in Neutron Standards.

How are neutron standards important for the neutron cross sections needed for reactor design? Neutron cross sections (except total cross sections which can be measured simply by transmission) are measured either by a ratio measurement to a known "standard" or "benchmark" neutron cross section, or by measuring a reaction rate in an absolutely-known neutron flux density. The ratio measurement to a standard cross section is by far the most common method, since it avoids many problems which occur in an absolute measurement. The major part of the NBS Neutron Standards program is directed toward accurate determination of the standard cross sections and absolutely determined neutron flux densities needed for neutron cross section data measurement for reactor design. Some of the important neutron standards cross sections are $^{1}H(n,n)$, hydrogen elastic scattering; $^{12}C(n,n)$, carbon elastic scattering; $^{6}Li(n,\alpha)$; $^{10}B(n,\alpha)$ and $^{10}B(n,\alpha_1\gamma)$; and $^{235}U(n,f)$, uranium fission. Cross section needs in the United States are evaluated and measurement of needed cross sections is encouraged by the Department of Energy-sponsored Nuclear Data Committee (DOE-NDC), on which NBS has representation. The DOE-NDC publishes Request Lists for cross section measurements which enable measurers in the cross section measurement community (national laboratories, universities, and some industrial companies) to know specific nuclear cross sections, energy ranges and accuracies desired. Internationally the International Nuclear Data Committee (INDC), under IAEA sponsorship and the Nuclear Energy Agency Nuclear Data Committee (NEANDC) are active in this field. Evaluation of cross sections in the United States is done under the aegis of the Cross-Section Evaluation Working Group (CSEWG) which supervises the preparation of the ENDF/B compilation, available from the National Nuclear Data Center (NNDC) at Brookhaven.

2/3.B.2.1 Design Data for Fission Reactors

It is clearly more economical to design a reactor if accurate and reliable nuclear data are available. Good data help in several ways: (1) they permit design with a minimum of costly integral experiments before construction; (2) they permit true optimization of design with computer codes for calculating reactor performance; (3) if nuclear data are known accurately, minimum allowance from the standpoint of reactor safety, temperatures of components, etc., needs to be made for uncertainty in the data. For example, if uncertainties in nuclear cross sections cause fuel reaction rates to be uncertain, then the reactor must be run at a lower power to maintain proper safety margins. This uncertainty could represent a loss of millions of dollars for a typical nuclear power plant. (Uncertainties were about 20% before the successful joint effort of the Department of Energy Interlaboratory LMFBR Reaction Rate program and the NBS Neutron Standards program to improve reaction rate measurements for the breeder reactor program. They are now better than 5%.)

Another example of the importance of nuclear data is in the prediction of breeding ratios for the LMFBR and other breeder reactor designs. Values of predicted breeding ratios have recently been lowered due to refinements in nuclear cross sections, and the present uncertainty in the breeding ratio is chiefly due to nuclear cross section uncertainties. Such cross section information has great implications for the design parameters and economic success of the breeder reactor programs.

As another example of the importance of accurate nuclear reactor design data, for a typical modern light water reactor, an uncertainty of 1% in neutron multiplication at the end of life of the fuel requires a compensating enrichment-adjustment of 0.15 weight percent ^{235}U. This extra enrichment costs more than $2 million per fuel loading. Further, each 1% of uncertainty in power peaking that limits plant operation to 1% less than its rated power, can be expected to cost the utility approximately $1 million annually in replacement power costs (Uotinen, Robertson, and Tulenko, 1975). Thus there are very real economic incentives for improving predictive capability in the light water reactor industry. Sometimes this can be done by normalizations to operating data, but often it can only be improved by a more accurate knowledge of basic nuclear data (neutron cross sections).

Neutron cross sections are needed for understanding and predicting the performance of reactor shielding, fuels, neutron properties, behavior of structural materials, integrity of reactor components, and for reactor control and safety. In the following we briefly consider the effect of neutron cross sections (nuclear data) in each of the above areas.

Shielding. For reactor shielding it is not only the penetration of neutrons in bulk matter, but also neutron streaming through ducts, gamma-ray production and penetration, penetration of radiation from the primary coolant, and activation of components which will produce a secondary radiation. As an example, there are dips in the neutron total cross section for iron. As a result one reactor with an iron shield operated with unsafe radiation levels outside the shield because neutrons streamed through this "window" in the iron shield. Cross sections for neutron energies of up to 15 MeV are important for shielding.

Fuels, It is important for reactor fuel design to know the neutron cross sections of the principal fission reactions, U-235, U-238, and Pu-239 to 1%, as has been determined by reactor design "sensitivity" studies, (see, for example, Greebler and Hutchins, 1966), and reaffirmed by various nuclear data committees such as the United States Nuclear Data Committee (USNDC), the Nuclear Energy Agency Data Committee (NEANDC), and the International Nuclear Data committee (INDC) of the International Atomic Energy Agency. Present accuracy is of the order of 4-8%, clearly not satisfactory. Part of the problem is due to large uncertainties in the standard reference cross sections which the NBS neutron standards program addresses. In connection with the Liquid Metal Fast Breeder Reactor (LMFBR) program, the AEC established the Interlaboratory LMFBR Reaction Rate (ILRR) program to develop the capability to accurately measure neutron-induced reaction rates for fuels and materials development. The goal is an accuracy of $\pm$ 5% at the 95% confidence level. Nuclear data are a major part of the problem.

Cross section data are needed not only for the LMFBR program, but also for the High Temperature Gas-Cooled Reactor (HTGR) program which uses U-233 and Th-232 as fuel; and for light water reactors as discussed above.

Structural materials, neutronics. The neutron economy, and therefore the dollar economy, of a power reactor depends very much on how much neutron loss there is to materials such as zirconium and stainless steel which form the structure of the reactor. Reactor performance is somewhat less sensitive to these than to the fuel cross sections. Accuracy requirements are typically a few percent.

Integrity of reactor components. The lifetime of a reactor and the power level at which it can be operated depend strongly on the neutron flux and spectrum to which the components are subjected. For example, the LMFBR has an unusual environment for components of which the main features are the presence of liquid sodium, materials at high temperatures, and a high flux of fast neutrons. This has led to a serious problem of "helium swelling" -- that is neutron-induced void formation in the stainless steel leading to decreased ductility, dimensional instability, and swelling of material. This "has become a critical problem in the development of liquid metal fast breeder reactors," (Dudey, Harkness, and Farrar, 1970). This swelling phenomenon is believed to depend upon the presence of helium produced by an (n,α) reaction in the stainless steel -- but the reactions occuring and their cross sections are not established. Further cross section data are needed here.

Control and safety. Accurate cross sections are needed for control materials (such as boron) to predict the dynamic behavior of a reactor. Where cross sections are uncertain, correspondingly larger factors of safety must be introduced, always at a cost in the power level or the economic efficiency of the reactor.

2/3.B.2.2 Design Data for Fusion Reactors (magnetically-confined plasmas and laser fusion)

Although plasma behavior problems are at present the most important problems in fusion reactor development, when designing of a prototype fusion power plant begins, much nuclear design data will be needed (early 1980's). Most of the data needed will be neutron cross sections (at higher energies and for different nuclides than in the fission reactor case), but some photonuclear data will be needed as well. Nuclear design data will be needed for shielding, heat transfer elements, tritium breeding, integrity of structural materials, and studies of induced activities.

Shielding. A fusion reactor utilizing the D-T reaction, $^{3}H(d,n)^{4}He$, is an intense source of 14 MeV neutrons. Lower energy neutrons of all energies will be present from neutron slowing down and various reactions. In addition, high energy gamma rays will be produced in the lithium coolant and breeding material which will present a new shielding problem. Cross sections are not known for many of these reactions.

Heat transfer elements. Fusion reactor design is in early development stages, and rather exotic schemes are envisioned for heat transfer. Typically the neutrons would be absorbed in a meter-thick blanket region surrounding the plasma, consisting of niobium tubes containing graphite and lithium breeding material-coolant. The lithium coolant would exchange heat with liquid potassium causing it to boil and either operate a potassium vapor turbine or exchange heat again with a steam system which could run a conventional turbine. The neutron properties of all heat transfer elements which are exposed to the neutron flux will need to be known for system design.

Tritium breeding. Regeneration of tritium occurs in the lithium blanket when fast neutrons from the plasma undergo nuclear reactions such as $^{7}Li(n,n'\alpha\gamma)^{3}H$, and $^{6}Li(n,\alpha)^{3}H$ which yield tritium as one of the end products. The cross sections of these reactions are not accurately known in the energy regions of interest. The second reaction is one of the chosen standard reference cross sections which has been characterized by discrepancies in the hundreds of keV range, and is less well known at higher energies.

Integrity of structural materials. Radiation damage to structural materials tends to increase with fast neutron energy. Materials such as niobium, vanadium, stainless steel, potassium, and lithium will be used in fission reactors. Radiation damage problems are very likely to be limiting factors on the power level for fusion reactors, as they are for breeder reactors. However, the problems here may be more difficult because of the higher neutron energies which allow many more nuclear reactions to take place. And the intensities are so great that each atom of the inner wall of the reactor will have been struck more than ten times by neutrons during the lifetime of the reactor.

Induced activities. The high intensity and the higher neutron energies will tend to produce more and different induced radioactivities which will represent a severe personnel protection problem whenever components have to be changed, valves turned, etc. Niobium is subject to large induced activities. Nuclear data, both cross sections and decay schemes, will be needed to predict likely problems, and to control them when they exist.

2/3.B.2.3 In-Reactor Neutron Measurements

It is necessary to make neutron flux and spectra measurements and fission rate measurements in the very hostile environment in the reactor. Such measurements are useful to (1) verify that actual reactor performance is according to design parameters; (2) test new reactor design concepts; (3) quantitatively measure fuel element performance in fuels-test reactors such as the FFTF fuel test reactor; (4) do performance testing and optimization by the utilities; (5) determine the radiation fields to which reactor components are subjected to understand the radiation damage problems and estimate reactor lifetimes and operating power levels; (6) determine fuel element operating temperatures from knowledge of reaction rates.

The most crucial in-reactor measurements are those of new reactor development programs (see the ILRR program of the LMFBR development program below). However, instruments and controls represent a significant part of the cost of a nuclear power plant, \$8 million out of \$493 million (neglecting cost escalation) for a typical light water reactor power plant (AEC, 1974). Furthermore most of the activities of the operating crews, radiation protection personnel, chemistry staff are performing measurements. Other costs are environmental monitoring and personnel monitoring (although these may be contracted out -- see section 2/3.G).

An example of a program with goals for improvement of in-reactor neutron measurements is the Interlaboratory LMFBR Reaction Rate (ILRR) program being managed by Hanford Engineering Development Laboratory, operated by Westinghouse Hanford Company for the Department of Energy. The initial goal is to be able to measure the principal fission reaction rates in U-235, U-238, and Pu-239 to within $\pm$ 5% at the 95% confidence level (compares to $\pm$ 20% at the beginning of the program). Accurate measurement of other fission and non-fission reactions is required to a lesser accuracy between $\pm$ 5% and $\pm$ 10% at the same confidence level. A secondary program objective is improvement in knowledge of the nuclear parameters involved in fuels and materials dosimetry; measurement of neutron flux, spectra, fluence; and burnup. The laboratories involved in this program are listed in Table 8.

Table 8. Laboratories participating in the interlaboratory LMFBR reaction rate program (ILRR).

Aerojet Nuclear Company
Argonne National Laboratory
Atlantic Richfield Hanford Company
Atomics International
Brookhaven National Laboratory
Hanford Engineering Development Laboratory
Lawrence Livermore Laboratory
Los Alamos Scientific Laboratory
National Bureau of Standards
Oak Ridge National Laboratory
University of California at Santa Barbara

The NBS neutron standards program is aimed at meeting the needs of improved in-reactor neutron measurements through: (1) a fission cross section validation program using broad spectrum sources, and improved total neutron cross section measurements on fissionable elements to improve the knowledge of fission cross sections; (2) provision of well-characterized neutron fields such as the Intermediate Energy Standard Neutron Field (ISNF) for calibration of detectors and insuring uniform measurements in laboratories throughout the nation; and (3) development of consistent measurements of fission rates in reactor fuel elements through participation in the ILRR program.

A proposed program would provide certified activation detectors and benchmark calibrations in NBS standard neutron fields for the neutron spectrum characterizations necessary for predicting radiation damage in structural materials.

2/3.B.2.4 Note on the relationship of the NBS Neutron Standards Program to the Department of Energy Programs

In considering the neutron standard cross section program at the NBS, it is clearly necessary to recognize its relationship to the measurements efforts of the Department of Energy. The AEC (later ERDA, now Department of Energy) has made very strong statements in support of the NBS neutron standards program, even though in principle it has the capacity to undertake and carry out such measurement itself. However, the Department of Energy laboratories are strongly programmatically oriented. The history of individual Department of Energy laboratories' concern for standard neutron cross sections is one of rapidly rising and falling interest. Periodically a laboratory's management recognizes the problems in its program caused by inadequate nuclear data standards and initiates programs to supply the needed standards. However, the measurements usually turn out to be far more difficult than expected and furthermore the bench scientists, recognizing that the main objective of the laboratory is a clearly stated programmatic one, work with somewhat less enthusiasm than on other projects. Over the past 15 years, the standards have slowly improved owing to their efforts.

The Department of Energy has long believed that many standards problems can be better handled at the NBS where the measurement of high-quality, high-accuracy standards is highly valued, and where the primary programmatic objective of the NBS is the establishment of standards. Through NBS programs the long-term and dedicated scientific effort can be brought to bear on the problem. It would be incorrect to assume that the Department of Energy efforts will stop because of increased NBS efforts. It is recognized that corroboration by the Department of Energy and foreign laboratories will be essential. Nevertheless, the NBS effort provides a base under the whole standards effort which is not provided by any other single laboratory or combination of laboratories of the Department of Energy. With the present NBS program providing the needed continuity to the standards efforts, one can now reasonably expect significant progress during the next five years leading to the resolution of the standards questions which have persisted for a long time.

2/3.C INDUSTRIAL RADIATION PROCESSING

The industrial radiation processing industry in the U.S. has become about a half-billion dollar a year business (1974), with an overall growth rate in recent years of about 20% per year. There are many problems that prevent a more spectacular growth, and there are many "dropouts," that is, many companies getting involved early in a new process and then withdrawing from competition as one or more successful companies develop the large market. This results in a highly proprietary approach to technological methods, R&D, etc., and eventually an almost monopolistic industry for nearly every type of successful process. Therefore, it is difficult to gauge measurement needs of these industries, where any failure and shortcoming, whether in program cost, product quality or rate of development, is carefully hidden from view. In essence, the industry at first glance does not need or want help or specific data in carrying out measurements of radiation quantities. With a deeper look, however, most of the companies need it badly, because of the very narrow profit margins that make or break a successful business venture, profit margins that could be significantly widened by a more efficient measurement capability. There are numerous examples of failures caused by insufficient market due to excessive costs and high prices that could have been lowered significantly by better selection of radiation parameters (wood-plastics, polymer synthesis, textiles, etc.).

Overseas competition in a number of successful industrial processes using radiation (e.g., production of flame-proof fabrics, vulcanization of rubber, product sterilization, water purification, graft polymerization, and waste control) is getting the upper hand, partly due to more intensive collaboration between government and industry (Japan, for instance, has over 500 government-trained applied radiation chemists and engineers now working in the radiation processing industry, compared to less than 200 in the United States). Part of the problem may be due to the limited measurement capabilities of U.S. industrial radiation users.

Industrial radiation processes of commercial interest include medical sterilization of surgical supplies, vitamins, pharmaceuticals; food sterilization and food shelflife extension; pest disinfestation of grains and crops; seed and bulb stimulation and mutation breeding for more productive crops and new types of flowers; sewage and waste treatment and recycling (sewage sludge decontamination by heat takes nearly 100 times the energy required by irradiation). Other processes of interest are synthesis of detergents; graft polymerization; polymer cross linking; polymer and hydrocarbon degradation; vulcanization of rubber; curing of coatings; polymer impregnation of materials; ion implantation; microelectronic fabrication; electron-beam welding and machining; research in radiation chemistry, physics, and measurements; curing of adhesives; and curing of textile fibers. A table summarizing information on the status of these processes is given in appendix E.

In the United States about 25 major companies are using cobalt-60 sources and/or accelerators for many of these radiation applications. Information on these operations which represents most of the industrial radiation processing activity, is given in Table 9.

Measurement instrumentation and dosimeters for the industry are provided by Far West Technology, Inc. (dye film dosimeters), Teledyne Isotopes (TLD dosimeters), and mostly British and French companies (liquid- and solid-phase chemical dosimeters). There are no commercial industrial processing dosimetry calibration laboratories in the U.S. Calibration users come directly to NBS. The quantity measured is nearly always absorbed dose.

The measurement system for Industrial Radiation Processing is not highly developed, partly due to the secrecy associated with proprietary nature of some of the processes. Some needs of the measurement system (as distinct from technology enhancement) have been identified: (1) development of further suitable radiation measurement systems and detectors; (2) provision of radiation measurement standards and calibration services; (3) provision of reliable experimental data on radiation penetration in materials, and (4) provision of radiation safety guidelines.

In response to these needs, NBS has prepared a new high radiation dose calibration service for industrial radiation users of large gamma-ray sources and charged particle accelerators. This should satisfy needs of many on a fee schedule basis. These calibrations are based on the thin-film calorimeter system developed at NBS, with the high-precision dye dosimeter system serving as a transfer method. Experimental measurements are being made of radiation penetration in materials, in standard materials and in layers of dissimilar materials, aimed at providing basic information on radiation penetration for industrial processing users. For example, recent measurements of electron penetration in various plastics and metals and interfaces of these materials have been made which are applicable to curing of surface coatings and sterilization of medical supplies. Provision of radiation safety guidelines is being made through ANSI Committee N43, "Equipment for Non-Medical Radiation Applications", for which NBS serves as Secretariat, and for which there are increasing demands for activity. In summary, provision of the high radiation dose calibration service, improved radiation dose measurement systems (better matching between dosimeter material and substances being processed), improved radiation penetration data, and support of ANSI Committee N43 will satisfy presently-identified needs of the measurement system for Industrial Radiation Processing. A modest increase in NBS program support is needed.

2/3.D DEFENSE

Introduction. Among governmental agencies, the Department of Defense is a prime user of radiation technology. With the increasing utilization of atomic and nuclear energy and technology for both propulsive and weapons

Table 9. Large radiation processing operations in the United States

Process	Company	Year of Initial Commercial Use	Radiation Source
Crosslinking of Wire & Cable Insulation	Raychem Corporation International Telephone & Telegraph Electronized Chemicals Corporation Western Electric Corp. Radiation Dynamics	< 1960	Accelerator
Specialty Copolymers	RAI Research Corporation Radiation Polymer Corp	< 1960	Accelerator & Cobalt-60
Heat-Shrinkable Film and Tubing	Raychem Corporation W. R. Grace Company (Cryovac Division) Electronized Chemicals Corporation	1960	Accelerator
Soil Release and Soil Resistant Fabrics	Deering Milliken Company	1966	Accelerator
Curing of Surface Coatings	General Electric Company The O'Brien Corporation Radiation Polymer Corp. ASHDEE, Div. of George Koch 7 Sons, Inc. Ford Motor Company	?	Ultraviolet[a] or Accelerator
Polyethylene Foam	Voltek, Incorporated	1970	Accelerator
Wood-Plastic Composites	American Novawood Corp. Atlantic-Richfield Chemical Corp. Radiation Machinery Corp. Radiation Technology, Inc.	1965	Cobalt-60
Ethyl Bromide Synthesis	Dow Chemical Company	1963	Cobalt-60
Controlled Degradation of Polyethylene Oxide	Union Carbide Corp.	~ 1968	Cobalt-60
Product (X) Synthesis (lubricants?)	Confidential	~ 1966	Cobalt-60
Sterilize Medical Supplies	Ethicon, Inc. of Johnson & Johnson Upjohn Co.	1957	Cobalt-60 & Accelerator
Curing Lumber and Wood Products (extending)	Weyerhauser Lumber Co.	1969	Accelerator
Vulcanization of Rubber	Firestone Radiation Research Radiation Dynamics	1968	Accelerator

[a]Non-ionizing radiation

systems, DOD has far-flung interests in the measurement and characterization of radiation fields and effects. Problems relating to personnel safety and environmental protection are similar to those encountered by non-military radiation users and are covered in a separate section of this report.

Although the prime users of radiation in the DOD are the military branches, the Defense Nuclear Agency (DNA) serves as a coordinator for radiation information for the Armed Forces. Other DOD agencies with a stake in radiation technology and measurements include the Defense Civil Preparedness Agency (DCPA), the Advanced Research Projects Agency (ARPA) which has the responsibility for nuclear monitoring (of foreign weapons tests), the Air Force Tactical Applications Center (AFTAC) which flies aircraft with detection systems aboard for nuclear monitoring of weapons tests, the National Security Agency (NSA), and the U.S. Army Natick Laboratory which develops radiation processing for military use.

2/3.D.1 X-rays, Gamma-rays, and Electron Measurements for Defense

DNA Survey of Needs. In 1968 a survey of the DNA laboratories and contractors was made by NBS to determine where NBS could best play a role in assisting members of the defense community. Although this survey was not a comprehensive one, that is involving all DNA laboratories and contractors, it did provide a basis for understanding the needs of users involved in nuclear weapons diagnostics.[1] This survey indicated the need for assistance in the calibration of detectors utilized in high gamma-ray flux radiation environments. Primarily, laboratories involved in nuclear weapons testing are interested in the detection of photons with energies between 1 and 100 keV and calibrate their instruments in steady state beams produced by the K-fluorescence of selected targets excited by the radiation emitted by low-energy d.c. x-ray machines. These sources provide low flux densities and impose the following limitations on the calibrations: (a) There are various detectors and detector systems that cannot be calibrated because their sensitivities are too low. (b) In most applications, the detectors are used in pulsed beams having flux densities that are at least 9 orders of magnitude higher than those provided by the steady state conditions. Because of these differences in the conditions of calibration and use, there are uncertainties in the calibration factors for the various detectors and detection systems.

NBS response to DNA survey of needs. In order to alleviate these difficulties, the NBS developed a program for DNA to develop standard monoenergetic x-ray beams in the energy region from 0.1 to 100 keV. These beams are both steady-state and pulsed, and the pulsed beams have an intensity at least 6-8 orders of magnitude larger than those currently available.

At present, the calibration accuracy within the system is of the order of 20-30%. The desired accuracy by the field users is in the region of 5% for nuclear diagnostics tests. Currently NBS is able to provide d.c. calibration services from 0.1 to 70 keV to an accuracy of 5% and pulsed sources near 1 keV to an accuracy of about 10%.

Contacts are continuously maintained between NBS and the major weapons diagnostics laboratories and preliminary calibration services are being done on several typical diagnostic detectors. It is anticipated that in the future this service will be offered to users outside the weapons diagnostic community.

Nuclear simulators. Large pulsed radiation sources are becoming more plentiful. With the reduction of effort in nuclear testing, large flash electron and photon sources are being constructed by DOD as nuclear simulators. Facilities such as the Aurora facility of the Harry Diamond Laboratory, the Casino facility at the Naval Ordnance Laboratory, Reba at Sandia Laboratory, and others produce nanosecond radiation pulses of high intensity. Detectors that will be utilized for diagnostic measurements on these machines will need to be calibrated in known high intensity fields.

Plasma physics. The field of plasma physics offers another class of users of this calibration service. Intensive efforts are now underway in DOD to understand the properties of plasmas generated both by high power laser and electron interactions with materials. The potential consequences of these experiments both from a military and civilian standpoint are enormous. Indeed, laser or electron beam-induced fusion experiments may provide a viable method for electrical power generation in the next several decades. In all these experiments, however, copious amounts of x-rays are

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[1]Laboratories surveyed included: Lawrence Livermore Laboratory (LLL), Los Alamos Scientific Laboratory (LASL), Sandia Laboratories (SL), Standord Research Institute (SRI), and the EG&G Laboratories at Santa Barbara and Las Vegas.

generated in the plasmas formed and the plasma diagnostics depend on the availability of calibrated detectors. NBS has initiated contacts with some of the major laboratories (both military and civilian)[1] regarding the calibration of these diagnostic instruments.

Dye dosimeters for megarad dosimetry. Department of Defense has a need for a simple, passive dosimeter which functions in the high-dose (megarad) range. Such a dosimeter is the radiochromic dye film dosimeter developed by W. L. McLaughlin of NBS and Lyman Chalkley (and is the same system discussed above for industrial radiation processing). Sandia Laboratories uses the dye films to measure the absorbed dose due to both electron and photon bombardment of various media exposed to intense radiation pulses. The U.S. Army Natick Laboratory uses the dye films to measure the absorbed dose in radiation processing. The National Security Agency is concerned with the effect of electron bombardment on extra-terrestrial enclosures containing sensitive equipment, and uses dye films for dosimetry in effects studies. The dye dosimeter, although linear in response (desirable) and capable of recording very large doses, does require calibration.

Calibration of dye dosimeters. To calibrate dye films, NBS has developed a twin microcalorimeter which is placed in electron and photon beams. After calibration of the twin calorimeter, the front calorimeter is removed and replaced with the dye film whose response is normalized to the rear calorimeter. This system is capable of accuracies of $\pm$ 10%. In this way the dose rate response of the dye film dosimeter is being measured at dose rates from 10^3 rad/s to 10^{15} rad/s for total doses in the range of from 0.5 to 10 Mrad. Experiments are currently under way to examine the transient radiation chemistry of the dye films.

In response to the need of the dye dosimeter users, NBS planned to offer calibration service to both military and civilian users (see also section 2/3.C). The calibration of these dye films is already being exploited by the military in a program NBS has undertaken with the National Security Agency, NSA. In order to investigate in the laboratory the problem of the effect of electron bombardment on satellites containing electronic equipment, NBS has developed in conjunction with NSA a simulation chamber for use with low energy electron accelerators. In this device the accelerator beam is scanned to provide a uniform electron radiation field 30 x 30 cm in area. A satellite mockup is placed in this field and rotated so that a uniform irradiation is provided over the entire surface of the module. The absorbed dose in the module is then measured in the enclosure by means of the radiochromic dye films. Measurements of the dose distribution in the module are anticipated to within $\pm$ 10% which is within the 20% accuracy required. At present, this program provides the only direct experimental data for complicated electronic enclosures.

It is anticipated that this program will provide data so that the electronics engineers can appropriately shield delicate and vulnerable electronic components. The potential economic savings are large since each pound of material lifted into orbit costs about $10 k. Even more important from a military standpoint, however, is the fact that each pound of shielding requires the removal of a pound of active devices from the satellite since the total payload is fixed by the available boosters.

In conclusion then, NBS is providing standard radiation fields and calibration services to a wide range of military users (only partially discussed here). Although the emphasis to date has been on the measurement of absorbed dose, it is anticipated that spectral and temporal measurements are going to be of interest in the future. In order to keep abreast of the needs in the military and defense laboratories, these contacts are being expanded to include the "new" class of military users, those involved in simulation devices, plasma generation and plasma fusion, radiation damage studies, and radiation processing. This effort has required a rather extensive reprogramming from the measurements of the basic interactions of electrons and photons with matter to the applications of these processes to detector calibration and the generation of well characterized radiation fields.

2/3.D.2 Radioactivity Measurements for Defense

Throughout the last several years the Department of Defense has been involved in several programs related to the monitoring of the detonation of nuclear devices on the international scene. Two agencies, in particular, have coordinated these programs. They are the Advanced Research Projects Agency (ARPA) and the Air Force Technical Applications Center (AFTAC). Historically the Nuclear Monitoring Office of ARPA was

[1]Lawrence Livermore Laboratory, Lawrence Berkeley Laboratory, Sandia Laboratories, Naval Ordnance Laboratory, Los Alamos Scientific Laboratory, Cornell University.

concerned with the development of the technical capabilities pertinent to the on-site inspection of underground nuclear device detonations. These concerns included efforts directed toward field measurements and laboratory studies. The former dealt with the assay of radioactivities trapped in or slowly released from the ground near the detonation, while the latter dealt with radioactivity decay data, fission yields and neutron reaction data. Towards the end of the 1960's the test ban negotiations indicated that the probability for a mutual acceptance of sufficient on-site inspection was rapidly decreasing to zero. The Nuclear Monitoring Office increased its research efforts in other areas, such as seismic sensors, gamma flash detection from satellites, and atmospheric radioactivity analysis. The latter area is also of interest to the AFTAC group, which has been concerned with similar monitoring, particularly of airborne debris from atmospheric nuclear detonations. In the early 1970's, the seismic detection capability was realized. With the increase of economic pressures and other technical problems, ARPA phased out the other programs. This left AFTAC with the responsibility for the measurement programs related to atmospheric radioactivity produced by nuclear detonations. To this end, military aircraft as well as ground-based stations are used to collect air samples (dust samples, also) for analysis of various radioactivities. Much information can be obtained about the type of nuclear device from the cloud and its fall-out. This effort continues primarily for military reasons, with a small amount of effort being put into research, mostly in wind pattern and atmospheric mixing studies.

Standards of radioactive gases (for example, ^{37}Ar, ^{85}Kr, tritium (HT), $^{14}CO_2$), and other radioactivity standards continue to be needed for instrument calibration. No new NBS action is required at this time.

2/3.D.3 Neutron Measurements for Defense

Neutron cross sections. One of the chief needs in the neutron measurements area for defense is for neutron cross sections (discussed in section 2/3.B.2 above). Weapons design information is classified but most cross section requests are not. Neutron cross sections are also needed for radiation transport through the atmosphere and through thick concrete shields (e.g. missile silos). At this time the Defense Nuclear Agency is funding only the measurement of neutron-induced gamma-ray production cross sections, however, the Division of Military Applications of Department of Energy has requested measurement of a large number of neutron cross sections, and is supporting evaluation of cross sections. The needs for standard neutron cross sections as a measurement base for measurement of neutron cross sections for applications, discussed in section 2/3.B.2 above, are equally valid here.

Neutron penetration information. The threat of biological damage due to neutrons from nuclear weapons is generally disregarded relative to the threat due to blast and gamma radiation. This is probably justified for weapon yields much greater than about 100 kT (equivalent tons of TNT explosive). However, for weapons with yields of a few kT or less, the relative threat of biological damage due to neutrons is substantial. One cannot rule out the possibility of the use in the future, particularly by terrorist groups, of very small weapons which have radiation as their primary hazard. Studies show that for a 40 kT weapon, lethal doses of neutrons can be received at distances of about 1400 m, where the blast overpressure is less than 15 psi (10^5Pa). Shelter adequate to survive the blast pressure does not necessarily guarantee sufficient protection from neutrons. Furthermore, covert explosions could be much smaller. For nuclear weapons of small yield, the neutron dose at a fixed overpressure level increases rapidly with decreasing yield. It is therefore important to be able to estimate the protection that ordinary buildings provide against neutrons. Many measurements producing this kind of information were made in the past. However, most reliance is now placed on theoretical calculations.

Nuclear reactors and weapons. As users of nuclear reactors (in submarines) and storers and transporters of nuclear weapons, the Department of Defense shares many of the same concerns as other radiation users: radiation protection, personnel monitoring, reactor instrumentation, environmental impact. These are covered in the appropriate sections elsewhere in this report.

2/3.E CHEMICAL ANALYSIS

Although other applications of radiation for chemical analysis, such as electron microprobe analysis are significant, by far the most important application is activation analysis. Activation analysis is important as an analytical chemistry method because: (a) its ultimate sensitivity is excellent for nearly every element, and for many elements its sensitivity is better than by any other technique; (b) non-destructive analysis is often possible; (c) several elements in a single sample can be determined; (d) it avoids problems of contaminated reagents;

(e) postirradiation chemical treatment is facilitated by freedom to use carrier techniques; and (f) it can even distinguish between different isotopes of the same element (Schulze, 1969). The growth in the field is shown by the increase from about 50 papers per year published in 1949 to about 800 in 1968, and the number has increased since.

Most activation analysis is done using thermal neutrons from nuclear reactors (80-90% of the field); sealed -tube or accelerator neutron generators producing 14 MeV neutrons account for 5-10%; photon activation analysis less than 5%; charged-particle activation analysis less than 5%; and ^{252}Cf spontaneous fission neutron sources, small but growing. The reactor-based thermal neutron activation analysis is centered around government agencies and national laboratories, with participation by a few commercial companies (Ford, Dow Chemical, General Telephone and Electronics and the solid-state electronics industry) and universities. The activation analysis field is limited in size because, although accurate, it is expensive. Thermal neutron activation analysis is usually the method of choice if available and capable of doing the job, since reactors run continuously and can irradiate many samples simultaneously. Sensitivities of 1 nanogram are not unusual, and sometimes parts per billion can be detected. Fourteen MeV neutrons are of limited use, chiefly for oxygen determinations. Thermal neutron activation analysis is not sensitive for elements with atomic number Z equal to 8 or less. Photon activation analysis (using linacs or betatrons) and charged-particle activation analysis (using p, d, ^{3}He, or alpha particle beams from cyclotrons) are important for C, N, and O determinations (sensitivity less than 1 μg). Oxygen in sodium (important for LMFBR application) has been determined at the few ppm level (Lutz, 1971). Photon activation analysis is also important for its great sensitivity for some elements: for example, F, Fe, and Pb (the latter is most important because of the environmental concern with lead).

Standards for activation analysis are chiefly Standard Reference Materials with major, minor, or trace elements accurately specified depending upon the application. Most activation analysis measurements are relative to a standard sample of similar composition to the unknown. Therefore a very good standard is an SRM of nominally the same composition as the unknown sample. Another approach is to use an internal standard, for example, a radioactivity solution standard which is dispersed throughout the material.

For thermal neutrons, the standard needs to be similar to the sample in thermal neutron absorption, epithermal neutron scattering and gamma-ray attenuation. Standards may also be needed to evaluate effects due to activation by fast neutrons present, possible trace elements in the sample, and radiolysis effects (Quinn, 1968). Examples of SRM's in unusual matrices to match samples include orchard leaves and bovine liver. In environmental samples it may be important to determine the natural radioactivity.

For fast neutrons and photon activation analysis, standards for the elements to be measured are needed: e.g., C, N, O, F, Si, P, Cr, Fe, Pb. For charged-particle activation analysis the sample needs to be almost identical in stopping power: for example, discs of selected metals containing known levels of the elements of interest.

Another class of radioactivity standards needed are point-source and mixed radionuclide gamma-ray standards, which are important for calibrating energy response and efficiency of Ge(Li) solid state detectors used as detectors for activation analysis because of their high resolution. Nuclear data on gamma-ray energies and gamma-ray emission rates are also important, but are probably also in reasonably satisfactory shape.

In conclusion, most standards needed for activation analysis are not ionizing radiation standards per se, but Standard Reference Materials. The chief ionizing radiation standards needed are radioactivity standards for gamma rays including those in solution and various matrices.

2/3.F RADIATION MEASUREMENT SYSTEM FOR SCIENCE

"Measurements for science" are considered here as those undertaken in order to obtain a better understanding of the physical or biological world; these measurements either produce new information or serve to prove or disprove the validity of basic theories relating to the systems on which the measurements are made. The radiations considered here are photons (energies > 1 keV), leptons (electrons, neutrinos, etc.), mesons, baryons, (protons, neutrons, etc.) and heavy ions.

Measurements considered here fall into two categories: (1) fundamental studies of the radiations themselves and their basic interaction processes (radiation and nuclear science), and (2) use of radiation as a tool for solving problems in other sciences (for example, biology, medicine, geology, chemistry, and archaeology). The measurement needs of these categories are quite different, and will be considered separately.

Radiation and nuclear science. As an example of how the measurement system enters into the determination of radiation properties and the effect of radiation on matter, consider the experimental determination of a nuclear cross section. There are at least five principal measurement quantities that must be specified in a direct experimental determination of a cross section. These are listed in Table 10 along with an indication of the standard reference data and measurements that must be made to determine each quantity.

In this example, few of the measurements rely on the existence of specific radiation measurement standards. They depend more on the standards associated with the SI-base unit system, the fundamental constants of nature, the existence of critically evaluated standard reference data, standard reference materials, and a few precision benchmark measurements of the basic physical properties of matter as well as of the response to radiation of instruments of specified design and construction. In this and other examples of fundamental measurements in nuclear and radiation science, dependence is greater on a wide range of physical measurement standards than on specifically ionizing radiation standards. In the case of most neutron measurements, however, this is not true -- perhaps the most difficult measurement is the establishment of the neutron beam fluence -- a major objective of the NBS Neutron Standards program.

Radiation as a measurement tool in the sciences. Radiation is widely used as an investigative tool in many sciences: biology, genetics, medicine, geology, archaeology, geology, metrology, space, chemistry, and so forth. The needs of the scientific investigators in these diverse fields are very much the same: (1) characterization and calibration of radiation sources and fields; (2) characterization and calibration of the radiation detectors; and (3) description of the interaction of the radiation with matter both in terms of fundamental cross sections and macroscopic properties such as attenuation, energy deposition, etc.

Table 10. Measurement quantities involved in a photon- or charged particle-induced cross section measurement.

Measurement standards involved are indicated in parentheses.

A. Energy scales and calibrations

1. Evaluated nuclear data (atomic mass, excitation energies of benchmark nuclear levels)

2. Deflection of charged particles in a magnetic field (atomic mass, proton magnetic moment, frequency, length)

3. Time-of-flight of neutrons (atomic mass, frequency, length)

B. Characterization of incident beam

1. Primarily from measurements made to describe radiation field

2. Beam fluence

a. Charged particles - charge collected (electronic charge, capacitance, voltage)

b. Photons - calibrated ionization chamber (P-2 chamber) (voltage, current, time)

C. Number of nuclei in beam (mass, mole, atomic masses)

D. Geometry of the experiment

1. Deflection angle - survey (length)

2. Solid angle - direct measurement of area and distance (length), indirect measurement (standard sources of radiation)

E. Response function of detector

1. Measurement with calibrated sources (standard sources)

2. Theoretical calculations based on standard reference data (interaction cross sections).

Not all the items listed in table 10 would be required for every measurement. Some items, for example the characterization of the incident beam, could require an even more extensive list of measurements.

In the biological sciences and radiation chemistry, it is normally assumed that effects observed are to first order dependent only on the energy deposited per unit mass within the medium with which the radiation interacts (absorbed dose). In general, the measurement techniques to determine this quantity directly in absolute units (joules/kg) do not exist, and there is a need for instrument calibration services in well-characterized radiation fields under carefully controlled and reproducible geometrical conditions. The measurement system here is closely allied to that of other applications of radiation and its interactions with matter.

Sources. Sources are characterized by type of radiation emitted, emission rate, and energy spectrum. Radioactive sources may be characterized by activity, half-life, and decay scheme. Accelerator and reactor sources may be characterized by energy and spectrum, beam current or power, beam divergence, flux density. The radiation field around a source may often serve as a Standard Reference Field.

Fields. Field description is in terms of the flux density or fluence, kerma rate, energy spectrum, and/or geometrical properties. Standard reference fields serve as standards for field quantities. Standard instruments are needed to measure radiation quantities in fields.

Detectors. Detectors need to be characterized in terms of their response ("dial reading") in a known radiation field, or efficiency, and also some detectors may be characterized in terms of their pulse height distribution for a given monoenergetic radiation source.

Interaction of radiation with matter. The microscopic or cross section description gives reaction probabilities, and angular and energy distributions of emitted particles. The macroscopic description of radiation interaction with matter yields information on absorbed dose distributions, energy spectra of radiations throughout the medium, and probabilities for radiation effects (changes in physical, chemical, and biological properties of materials).

In table 11 are shown some NBS activities contributing to the use of ionizing radiation as a measurement tool in the sciences.

Needs. The needs of the ionizing radiation measurement system for science are primarily for continuation of the standards, calibration, and data services now provided, with appropriate modifications as needs change. One gap which has become apparent is the need for systematic compilation and tabulation of charged-particle stopping power, range, and straggling and delta-ray production data particularly at low energies (below about 10 MeV). This should be done systematically in the sense that x-ray attenuation coefficients are tabulated by the X-Ray and Ionizing Radiations Data Center of NSRDS. The need derives from the need for better information on the interactions of pions, neutrons and heavier charged particles with biological materials, and from the need for better data for the technology of ion implantation in materials.

2/3.G ENVIRONMENTAL RADIOACTIVITY MEASUREMENT

Introduction. There has been great public concern over the widespread use of nuclear power, because of possible consequent radioactive contamination of the environment. A first step in the elimination of the unwanted radioactivity is its reliable measurement. In the past, many environmental monitoring laboratories have had poor control over their radioactivity measurements. The regulators of radioactivity at the national level, the Nuclear Regulatory Commission (NRC) and Environmental Protection Agency (EPA) as well as state health departments, have recognized the need to make environmental radioactivity measurements traceable to the national radioactivity measurements system for which NBS has a major responsibility. NBS as an independent agency without regulatory power but with standards responsibility and a reputation for reliable measurements capability, has therefore been asked by the agencies, to help to develop the "traceability" of environmental radioactivity measurements to NBS.

The schematic diagram of the low-level radioactivity "measurements system" is shown in figure 9. NBS has as its goal the establishment of traceability of the users (bottom line in figure 9, see appendix F, tables F-1, and F-2) through the quality control laboratories (second line). Occasionally, NBS will penetrate to the user level by the provision of standards and test samples.

To use a somewhat oversimplified statement, traceability may be established when an outside laboratory correctly measures test samples provided by NBS or when NBS measures standard samples of an outside laboratory and agrees with the assigned calibration.

Table 11. Some NBS contributions to ionizing radiation measurements for science

SOURCES AND FIELDS

Standard Reference Materials

- Over 80 calibrated radioactive sources

Standard Reference Radiation Fields

- Filtered low energy x-rays
- Thermal neutron flux
- Ra-Be (γ, n) standard neutron source
- ^{252}Cf spontaneous fission neutron source
- Intermediate-energy neutron standard
- ^{60}Co γ-ray beam
- ^{137}Cs γ-ray beam
- Filtered neutron beams

Characterization of Radiation Sources

- Spectrum of ^{60}Co teletherapy sources
- Bremsstrahlung and photoneutrons from electron-irradiated thick targets

DETECTORS

Standard Instruments
(Design specifications or prototypes for intercomparison and/or calibration measurements)

- Free air ionization chamber
- P-2 ionization chamber
- Absorbed dose calorimeter
- Precision Faraday cup
- Spherical graphite chambers as exposure standards

Detector Response Data

- Ionization to absorbed dose conversion for photon and electron beams
- Response function of NaI(Tℓ) detectors to x- and γ-rays
- Response of Si detectors to electrons

INTERACTION OF RADIATION WITH ATOMS, MOLECULES, NUCLEI

Benchmark Measurements

- Radiation width of 15.10 MeV level in ^{12}C
- C total neutron cross section
- Form factor of the proton
- Form factor of ^{12}C

Standard Reference Data

- Evaluated data on "atomic" interaction of photons
- Evaluated data on nuclear interaction of photons
- Kerma factors for neutrons

INTERACTION OF RADIATION WITH BULK MATTER

- Development of methods of calculating penetration, diffusion, slowing down of high energy radiation (moments, Monte Carlo, numerical methods)
- Gamma-ray, neutron, and electron transmission
- Energy degradation spectra for electrons, secondary particles from neutrons
- Critical data tabulations (electron and charged particle stopping power and range tables, depth dose distributions)

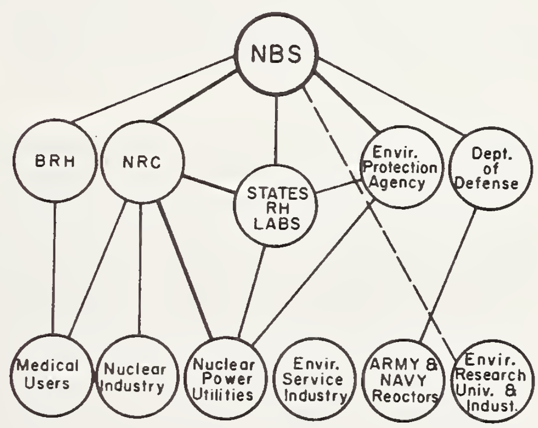

Figure 9. Structure of the environmental radioactivity measurement system.

Traceability at the international level. At the international level, NBS maintains traceability to the international radioactivity measurements system through "round-robin", and other, intercomparisons with national laboratories in other countries. International agencies such as BIPM and IAEA sometimes sponsor such efforts which NBS supports strongly. These efforts not only serve to help evaluate the "state-of-the-art", but also give more certainty to NBS values when these values are given to laboratories within the U.S. NBS will sometimes invite a foreign laboratory, which has a particular measurement expertise, to collaborate in solving a particular measurements problem. This has been the case in the development of the NBS environmental-radioactivity freshwater-sediment standard for which Dr. Miettinen in Finland agreed to measure the iron-55 content. At different times, NBS has been asked, or has asked laboratories outside the U.S., to serve as referees in cases of dispute. Recently, NBS was asked to make a survey of European laboratories engaged in environmental radioactivity measurements, to explore possible expansion of joint international efforts, especially as they may relate to the solution of the energy crisis.

Traceability of the Nuclear Regulatory Commission (NRC). The NRC, either directly or through contracts with a number of state health laboratories, monitors the discharge of radioactivity from nuclear power reactors and fuel reprocessing plants. It, therefore, has a strong interest in the radioactivity measurement capabilities of these states, the nuclear power (and related) industry, and the NRC quality control laboratory - Department of Energy's Health Services Laboratory, Idaho Falls. The NRC requires, as a standard provision of its contract with about 25 states, that their measurements be "traceable to NBS."[1] These states verify results of NRC licensee measurements related to the discharge of radioactivity and often impose additional restrictions of their own. Many state laboratories are not yet expert enough to monitor measurement accuracies of NRC licensees. Thus, the NRC (HSL) furnishes necessary services to contract states (round-robin intercomparisons, etc.) for achievement of some form of traceability to NBS and to improve their capability. To facilitate standardization of these state laboratories, the NRC is distributing intermediate-level standard samples, which are, or will be, traceable to NBS. In addition, at the request of the NRC, NBS has provided these states with intermediate-level gaseous standards of ^{133}Xe and ^{85}Kr.

The major element in the NRC traceability program is the continuing measurements program between the Health Services Laboratory in Idaho and NBS. Each year the HSL is required to measure a number of NBS test sources and report results which should fall within predetermined limits of the NBS values.

Traceability of the Environmental Protection Agency. The Environmental Protection Agency (EPA) is charged with monitoring and regulating environmental radioactivity "outside the fence." The EPA performs round robin intercomparisons with its monitoring laboratories. The "milk surveillance network" is a well-known example of a measurements sub-system in this field. The program is managed from their Las Vegas laboratory (NERC-LV) with which NBS is engaged in a traceability study. As does NRC, EPA is providing intermediate level standards to user groups. During the past several years, many secondary standards have been measured at NBS, many NBS test sources have been sent to NERC-LV. NERC-LV has also received a number of standard sources for instrument calibrations.

The EPA has also asked that NBS make available to the public, through the SRM program, a number of solution standards of alpha-particle emitters (Table F-3). These standards will be needed for environmental surveillance programs at fast breeder reactors, coal-burning power plants, and other associated processing facilities.

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[1] ARTICLE II - SCOPE (of NRC state agreement);
The STATE and the Commission shall engage in a cooperative program for measuring quantities and concentrations of radioactivity and radiation levels in the environment of Commission licensed activities located within the STATE and selected by the Commission. The principal objectives of the program are to 1) provide reasonable assurances that effluent analyses and environmental measurement made by the licensee under Commission requirements are valid and 2) achieve and maintain traceability to the National Bureau of Standards of the radioactivity measurements made by the licensee, the STATE and the Commission laboratory involved in this contract.

NBS interaction with the users. NBS interacts directly with the users of environmental radioactivity standards (Table F-1 of appendix F) by providing SRM's and test sources through the SRM program and, to a lesser extent, by providing calibration services of user standards. Table F-2 lists operational nuclear-power reactors and many scheduled for operation which use (or do not use) NBS standards. In addition standards are supplied to the 4 major reactor manufacturers, roughly 12 nuclear service corporations, and many universities performing radioactivity measurements. Standards are also required by the other facilities in the nuclear-fuel cycle, such as: uranium mines, fuel-fabrication plants, and fuel-reprocessing plants.

The capital investment and operating costs required to maintain an environmental surveillance program at a reactor are quite high. One observer estimates that it costs $250,000 to equip an environmental laboratory for a single power reactor (multiple units at the same site normally use a single laboratory) and that operating costs, including manpower, are about $150,000 per year. The magnitude of these operations affects the NBS Standards program in two ways. First, the laboratories are asking for NBS Standards for the instrument calibrations. They are increasingly unwilling to use secondary standards to calibrate gamma-ray spectrometer systems which cost in excess of $35,000. Secondly, the utilities are turning to environmental consulting groups, whose analytical services are often cheaper and more convenient than maintaining an in-house measurements capability. Neither the NRC or the EPA has any direct control over such laboratories at the present time. However, most of these companies are using NBS standards to calibrate their instruments (and to increase credibility with their customers).

The standard reference materials available include mixed gamma-ray solution standards (Cavallo, et al, 1973), alpha- and beta-particle-emitting solution standards, and radioactive noble gas standards. NBS has issued a fresh-water-sediment SRM, which is certified for a number of alpha- and beta-particle- and gamma-ray-emitting radionuclides. Tables F-2 and F-4 in appendix F indicate the wide use of radioactivity SRM's by the nuclear industry. Most of the users listed in Table F-2 are also interested in gaseous standards for calibration of gamma-ray spectrometers. In a limited distribution of ^{133}Xe gas standards (table F-4), NBS was able to supply standards to representatives of each type of power reactor in the U.S.: PWR, BWR, and HTGR.

The second method of NBS interaction with users is by means of test sources. In 1973 NBS distributed mixed-radionuclide test sources containing gamma-ray emitters and in 1974 a mixed test source containing ^{89}Sr and ^{90}Sr - ^{90}Y. A total of 27 laboratories, with representatives from each user group in table F-1, participated in these intercomparisons. The results have been published (Coursey, Noyce and Hutchinson, 1975).

The impact of NBS standards on the measurements system is best illustrated by examining the environmental-surveillance network in a small geographic area. Figure 10 shows who uses the NBS radioactivity standards in four states in the south. All of the regulators in this area are using NBS environmental radioactivity standards as are all the operating reactors and the soon-to-be operating fuel reprocessing plant. The independent consultants and universities are also using NBS standards to calibrate their detectors for field measurements at the reactor sites (as shown by the dashed lines on the diagram). Chemists or health physicists representing the reactors under construction have talked with NBS personnel about availability of NBS standards.

It should be noted, however, that the use of NBS standards by these laboratories does not insure traceability of their measurements to NBS. Actual measurement competence of each laboratory must be demonstrated by its measurement of unknowns (distributed by NBS or laboratories traceable to NBS). Four of the laboratories shown in the figure participated in the intercomparisons mentioned previously.

2/3.H MISCELLANEOUS RADIATION APPLICATIONS

Introduction. In addition to the specific areas of application mentioned in previous sections of this report, there are a large number of uses of ionizing radiation that are difficult to group under one simple classification. Most of the applications are industrial, although not exclusively of that type. The nature of the source of radiation covers a wide range, and the conditions under which the source is used are often extreme. In some cases, the users the users are highly regulated

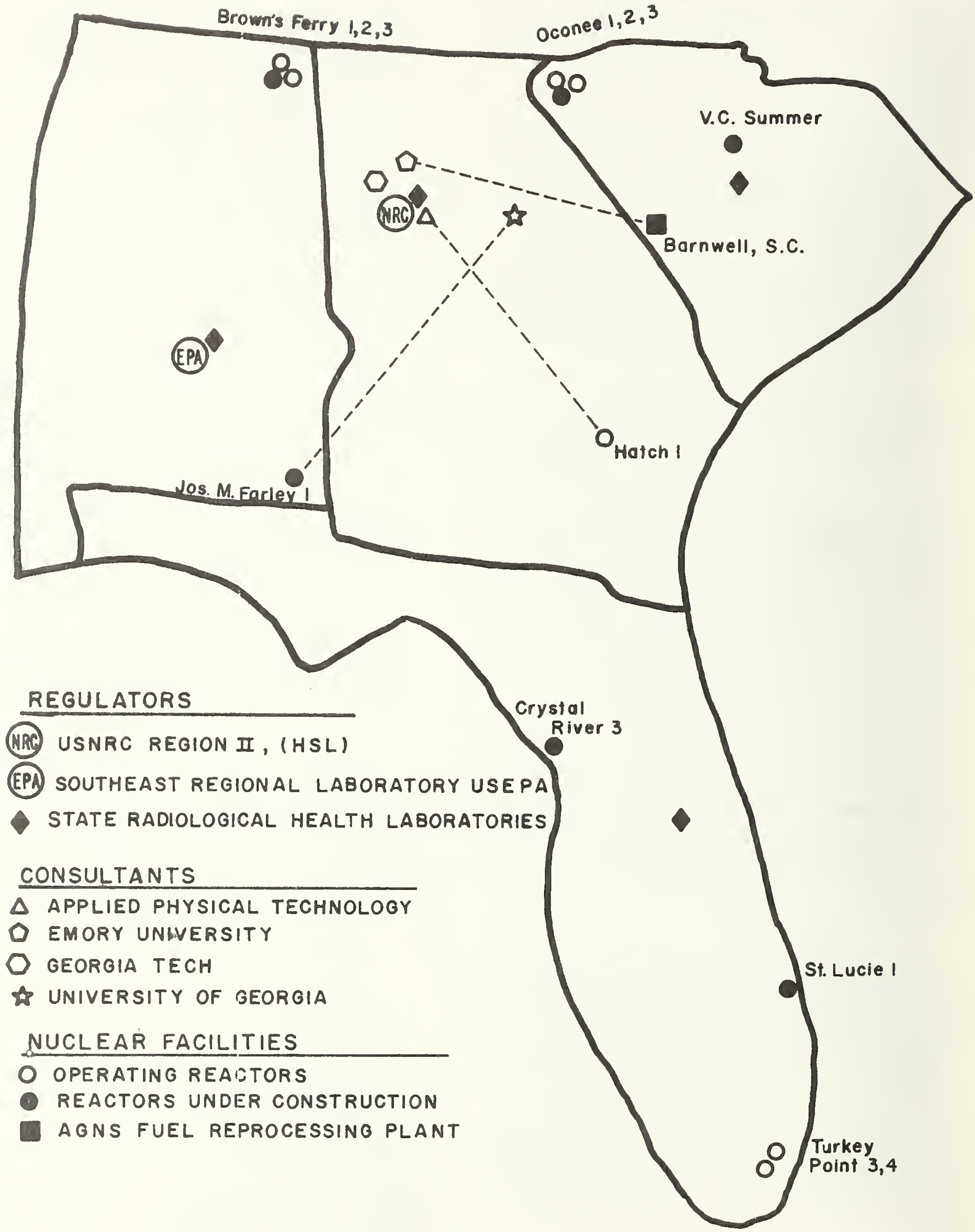

Figure 10. Environmental radioactivity measurements system in the southeastern United States.

while, in other cases, there is little or no regulation. Safety of personnel is a primary concern, but a significant number of accidental exposures do occur.

Measurement of the radiation quantities is often not very critical, although the primary purpose often is to measure a non-radiation quantity by means of radiation. In spite of localized problems associated with companies founded primarily on speculation, the radiation applications industry as a whole shows a significant growth rate.

There are many types of devices that make use of radiation in miscellaneous applications, but the major types are the following: (1) radiographic equipment, (2) gauges, (3) irradiators, (4) oil-well logging apparatus, (5) self-luminous products, (6) smoke detectors, (7) static eliminators, (8) heat sources. Although each of these devices will not be discussed in detail, their common characteristics will be presented generally.

Users. To present a comprehensive survey of the users of the devices listed above would require many pages of material that would have only secondary relevance to this study. However, to illustrate the range of uses for only one of these devices, table 12 lists the industries that make use of radiation gauges. As shown in table 13, multiple applications of these devices are common in many industries.

Table 12. Industries employing radiation gauging devices

Chemical & Pharmaceutical	Plastics
Glass	Tobacco
Cement & Cement Products	Paper and Allied
Petroleum Refining	Aeronautical
Electric Power Products	Electronics
Steel	Laboratory Use
Non-Ferrous Metals	Mining
Waste Treatment	Paint
Food & Beverages	Ceramics
Rubber	Textiles

A similar analysis of uses for each device could be presented in this manner, and the conclusion one would reach is that such equipment is used in the majority of industries for a variety of purposes. In some cases, devices such as gauges and radiographic equipment are crucial elements in process control and quality assurance programs. Gauges, for example, are used to measure properties like thickness, weight, density, moisture content, level, and sheet profile. Many gauge installations are of custom design, for specific applications in specific environments. An excellent example of the wide range of use parameters encountered in radiation applications is the application of radiographic equipment. This type of equipment is used widely in nondestructive testing. Selection of a particular device is based on five principal factors: radiation quality, radiation output, source size, range of operation, and reliability. Table 14 shows the relationship between voltage and radiographic application for x rays to achieve efficient penetration. In special applications, such as inspection of pressure vessels for nuclear power reactors, energies required are much higher. One steel company uses a 25 MeV betatron for inspection of flued heads, and 12 MeV linear accelerators are being purchased for routine inspection procedures by another company.

Table 13. Applications of radiation gauging devices in selected industries

Metals	Plastics
Cold Rolling	Calendars
Hot Rolling	Extruders
Classifying	Blown Film
Pickling	Lamination
Coating	Coating
Raw Materials	Casting
Raw Materials Processing	Raw Materials
Paper	**Rubber**
Pre-digester	Calendars
Digester	Tread
Post-digester	Tire Inspection
Paper Machine	
Coaters/Laminators	
Mill Roll Inspection	

Some companies are in the business of supplying both field and laboratory inspection and testing services to all segments of industry. One such company provides services by twelve divisional and district offices from Alaska to the Gulf and Atlantic coasts. Foreign operations are carried out through a Canadian subsidiary and also through cooperative ventures in Europe and South America. The company's in-house capability covers all forms of nondestructive testing, visual inspection, and vendor surveillance programs. Additionally, concrete and physical properties tests are performed on a field-project, joint-venture basis. The area of greatest demand for service has historically been nondestructive testing of weldments, usually by radiography, performed during field construction and shop manufacturing operations. To meet this demand, the company manufactures its own portable x-ray machines and accessory equipment to outfit its own fleet of trucks as mobile field laboratories. This fleet of more than 200 mobile units supplied from an inventory of more than 400 x-ray machines and 100 gamma-ray cameras makes the field operation the largest of its type in the world.

Table 14. Relationship between voltage and radiographic application

X-ray tube potential or photon energy	Typical Applications
50 kV	Wood, plastics, textiles, leather, grain. Diffraction and microradiography.
100 kV	Light metals and alloys. Fluoroscopy of food stuffs, plastic parts and assemblies, and small light alloy castings.
150 kV	Heavy sections of light metals and alloys, and thin sections of steel or copper alloys. Fluoroscopy of light metals.
250 kV	Heavier sections of steel or copper. (Fluoroscopy is not generally used at this voltage).
1 to 2 MeV	Radiography of heavy ferrous and nonferrous sections.

Other major users of radiation devices, as a class, are the military services. In 1922, radiographic equipment with a Coolidge x-ray tube that could operate at 200 kV with a current of 5 mA was installed at the Army Ordnance Arsenal at Watertown, Massachusetts. With the installation of this equipment, pioneer efforts were made which led to the first real accomplishments in industrial radiography. In 1929 the Naval Research Laboratory did the first casting radiograph using radium. Radiography received a great impetus from World War II, and during those years it was actually formalized into a science. The advent of complex systems such as jet-powered aircraft and rocket-powered ballistic missiles emphasized the need for innovative radiation technology utilization. Radiographic inspection of critical structural elements in military aircraft is required periodically as standard procedure. This application, which requires extremely portable equipment, presents a unique set of design parameters.

There are many additional users of radiation devices, including universities, government agencies, and law enforcement agencies. Government laboratories such as NASA are not only large users of radiographic equipment, but have also contributed significant advances in the technology of radiography. Use of x rays for baggage inspection is becoming more widespread each day in this country.

Manufacturers. Data on the size of the radiation source and radiation device industries are difficult to obtain because many individual companies prevent disclosure of their figures. For purposes of discussion, it is convenient to categorize manufacturers by their products as follows:

1) Isotopic radiation sources
2) Machine radiation sources
3) Devices employing isotopic sources
4) Devices employing machine sources.

There are approximately 30 principal suppliers of radioactive sources, according to a 1974 report by the USAEC (AEC, 1974). In November 1973, the Bureau of the Census reported total shipments of sealed and other radiation sources for industrial applications had a value in 1972 of $15 million. This represents a growth of about 21% over the previous year.

Estimates relating to the manufacture of machine radiation sources are not available generally. This category would include power supplies, x-ray tubes, and accelerators. It appears, however, that about half a dozen companies share most of the business among themselves.

The Bureau of the Census, in the same report mentioned above, presented a total figure for the sum of 1972 shipments of radiographic, radioteletherapy, process irradiation devices and systems, and nuclear self-illuminating materials and devices. That total value, which was $3.5 million, represented a growth of almost 60% over the previous year.

The USAEC, in its 1971 report on the nuclear industry, listed 26 principal suppliers of industrial radioisotope gauges and gauging systems. Estimated total sales by these companies in 1972 was $53 million, with an annual growth rate of 15%. Slightly over half of this total was sales by only one of the companies.

It is estimated that 20,000 industrial x-ray sets were in use in 1972, which represents a growth of 30% in 3 years compared to an earlier estimate. Thus it appears that a high growth rate is typical in the radiation device industry as a whole. This conclusion is supported by an examination of the use of radiation in industry as reflected by literature references, which shows an almost exponential growth rate.

Regulators. At the federal level, there are three regulators of industrial radiation equipment and its use. The first and foremost is the U. S. Nuclear Regulatory Commission (see section 2.4.4). NRC regulations applicable to industrial use of radioisotopes are listed in Table 15. The Occupational Safety and Health Administration (OSHA) was set up as a result of the Williams-Steiger Occupational Safety and Health Act of 1970. This act gives the Secretary of Labor the authority to issue such mandatory standards and enforcement rules and regulations as are necessary to furnish employees a place of employment which is free of recognized hazards. The responsibilities of OSHA for ionizing radiation relate only to those ionizing radiation sources in the workplace not covered under NRC regulations, such as natural activity, x-rays, and isotopes other than those produced by nuclear reactors. The third regulatory agency is the Bureau of Radiological Health which, under the Radiation Control for Health and Safety Act of 1968, has been delegated responsibility to protect the public from unnecessary exposure to radiation from electronic products.

Standards and Calibration Laboratories. At the moment, it appears that the accuracy required for radiation measurements associated with manufacture and use of these radiation devices is relatively low. Requirements for accuracy in radiation protection measurements are often greater than those for measurements associated with radiation application. Calibration of radiation protection instruments is achieved by returning the instrument to the manufacturer or by the use of a calibration source purchased from NBS or some other manufacturer of such sources.

Except for radiation protection purposes, a highly accurate characterization of the radiation quantities apparently is not necessary for applications considered here. In the use of radiation gauges for measurement of thickness, for example, calibration of the device is achieved by inserting a piece of material whose thickness is known to high accuracy and then making appropriate adjustments in the readout or control system. In x-ray and radioisotope radiography the ultimate objective is a good radiograph. This is achieved by adjusting x-ray tube voltage and current, by choosing appropriate exposure times, by selecting the proper film, screen, developer, etc. In radioisotopic radiography, the most important operational parameter is time.

Table 15. NRC regulations applicable to industrial use of radioisotopes

10 CFR Part 20	"Standards for Protection Against Radiation"
10 CFR part 30	"Rules of General Applicability to Licensing of Byproduct Materials"
10 CFR Part 31	"General Licenses for Byproduct Materials"
10 CFR Part 32	"Specific Licenses to Manufacture, Distribute, or Import Exempted and Generally Licensed Items Containing Byproduct Material"
10 CFR Part 33	"Specific Licenses of Broad Scope for Byproduct Material"
10 CFR Part 34	"Licenses for Radiography and Radiation Safety Requirements for Radiographic Operations"
10 CFR Part 36	"Export and Import of Byproduct Material"
10 CFR Part 40	"Licensing of Source Material"
10 CFR Part 70	"Special Nuclear Material"

The most stringent accuracy requirements for measurements appear to be at the manufacturing, rather than user, level. Approximately 25 companies are listed in the 1973 Nuclear News Buyer's Guide as providers of calibration services. A number of these also are manufacturers of radiation sources and devices.

Other Interested Groups. Two professional societies have been active in the field of radiography for a number of years. They are the American Society for Non-Destructive Testing (ASNT) and the American Welding Society (AWS). Both are involved in the writing of engineering standards related to various aspects of radiographic equipment and its use.

The American Nuclear Society (ANS), because of its general interest in applications of radiation, must be considered an interested group. Although this society emphasizes matters related to nuclear reactors, it is not limited to that area.

Needs. The chief measurement need relates to radiation safety in the use of the radiation equipment necessary for the various applications. This would seem to call for all regulators to be traceable to NBS; adequate survey and personnel monitoring (see next section); and promulgation of standards and codes of good practice to tell users how to operate their equipment safely. Documentary Standards in this area are prepared by ANSI Committee N43 (Equipment for Non-Medical Radiation Applications) and with the National Council on Radiation Protection and Measurements (see section 2.2.1.1 above). An appropriate NBS response would be increased support of those two groups.

2/3.I PERSONNEL MONITORING

2/3.I.1 Nature of Activity and Present Status

The term personnel monitoring as used here means the recording of the radiation response of devices worn by individuals for the purpose of inferring the approximate radiation dose received by them in the course of their duties. Personnel monitoring for protection of workers against radiation is a need common to all users of radiation whether they work in medicine, industry, nuclear energy, in universities, or in defense. Personnel-monitoring devices usually are carried on the body (attached to collar, shirt pocket, belt, or lab coat). In special circumstances they are worn on the wrist or as finger rings. They usually consist of photographic film in a holder (film badge) incorporating certain personnel-identification data, or of thermoluminescence material in a similar arrangement (TLD badge). Most industries, hospitals, and clinics purchase personnel-monitoring services from at least 14 commercial suppliers. Government laboratories and military installations usually have their own services.

Personnel-monitoring badges are changed and read at intervals of typically one month, with many establishments using three-month periods for workers unlikely to be exposed to radiation in the normal course of their activities. For workers whose normal duties bring them in contact with radiation, weekly, biweekly, or more frequent changes may be made. In the event of an accident or suspected radiation dose, a reading may be obtained immediately and a new badge issued. The longer exposure periods bring certain problems: if a procedure or apparatus is producing some personnel exposure, considerable doses could be received before a high reading calls attention to the problem. Also, particularly with photographic film used for fast-neutron monitoring, there may be severe latent-image fading especially in the presence of heat and humidity, with a corresponding underestimation or even nondetection of the dose received. Badging intervals are, of course, normally based on experience and are usually conservative. In addition, warning devices such as "chirpees" may be carried by personnel working in potentially hazardous areas to alert the individuals as to the existence of a hazard, but, as a rule, they do not lead to a permanent record of dose received.

Personnel monitoring differs from survey or area monitoring (also used in personnel protection) in which instruments are used to determine the radiation levels in a room and to warn if the radiation levels are unsafe for occupancy. In area monitoring, usually no attempt is made to record the total dose received by the individual.

2/3.I.2 Basic Problems and Needs

A major problem in personnel monitoring is that the response of the monitoring devices as a rule does not parallel the presumed biological effect of radiation in man. The extent of the discrepancy depends critically on the type of dosimeter used, and the kinds and energies of the radiations. For this reason, it is important for suppliers of personnel-monitoring services to have as much information as possible regarding the nature of the radiation fields to which the workers carrying the personnel-monitoring devices may have access, and to have features incorporated into the devices which provide for some discrimination between exposure to different types and energies of radiation. A further problem in personnel monitoring is that in many instances the radiation field at the personnel dosimeter may not be the same as that at the critical organ (or organs), either because of the orientation of the radiation field relative to that of the person wearing the dosimeter, or because of the location of the critical organ relative to that of the dosimeter. In some instances, multiple badging is helpful, but often the sole solution of these problems is to make estimates of the errors stemming from each of the difficulties and to adopt dosimeter geometries insuring that whenever possible the errors are on the "safe side," i.e., that they lead to an overestimation of the dose received. (See, e.g., ICRU Reports 19 and 20, 1971.) A detailed discussion of these basic problems of personnel dosimetry, touching on the very philosophy of radiation protection, goes well beyond the scope of these remarks. It is true, however, that proper dosimeter calibration, though not sufficient to guarantee satisfactory estimates of the dose received by radiation workers, is a necessary prerequisite for such estimates.

Neutron personnel monitoring presents special difficulties. This is due in part to the state of the technology of neutron dosimetry, and in part to the problem that whenever neutrons are present, gamma-rays are present as well. This necessitates often difficult mixed-field dosimetry. In film-badge monitoring for neutrons, nuclear track emulsions are used. Dose is evaluated by counting the number of proton recoil tracks observed in a fixed number of microscope fields. In addition to being subject to fading, these personnel monitors are insensitive to neutrons below about 0.5 MeV, an energy range in which much of the neutron dose from modern nuclear reactors is found. In an attempt to find a better neutron monitor, a number of laboratories are developing and using so-called "albedo neutron dosimeters" which have pairs of Li-6 and Li-7 containing TLD detector elements in a moderating shell to provide good low-energy neutron response. For testing whether these monitors do, in fact, give the proper response, a need existed for standard reference neutron fields especially in the energy region below 1 MeV (but a few higher energies as well). NBS has responded with a program, initially with Department of Energy support, to provide monoenergetic calibration fields in the required energy ranges using reactor beam filters which give monoenergetic neutron fields of 2, 25, and 144 keV, and Van de Graaff accelerator neutron fields in the energy range above 30 keV. These fields have been developed at NBS and are now available to the designers of dosimeters and the suppliers of personnel-monitoring services for checking the neutron response of their detectors.

Another problem is concerned with the reliability of commercial companies who supply personnel-monitoring service to organizations not connected with the Federal Government. These organizations are normally under the regulatory control of State public health departments, and, in the case of radioisotopes, of the Nuclear Regulatory Commission. Therefore, the following important question arises: How does the radiation user or the regulatory agency know that the measurements made by the commercial monitoring company chosen are, in fact, reliable and sufficiently accurate to furnish a basis for an estimate of the dose received by radiation workers? As will be seen later, he frequently cannot know. As a result, the Nuclear Regulatory Commission, the Bureau of Radiological Health, and representatives of the Conference of Radiation Control Program Directors have expressed their concern about the performance (extent of reliability and accuracy) of commercial personnel-monitoring services, and have asked NBS for advice and assistance in solving problems existing in this area. This led to the initiation by NBS of a "base-line study" of the current performance of at least the commercial suppliers and one military personnel-monitoring service. This study was carried out by Battelle-Northwest under contract with NBS, which in turn received some funds for this work from the Bureau of Radiological Health. The NRC later added a similar study for NRC contractor laboratories, also performed at Battelle-Northwest, in parallel with the NBS-initiated work.

One approach to a permanent solution to this measurement problem would be to have a measurement-assurance service provided by NBS or by a laboratory whose measurement standards are traceable to those of NBS. The laboratory furnishing this service would expose personnel-monitoring devices to known doses of radiation (preferably without the supplier of the devices being aware of the test), and reported doses of the personnel-monitors could be compared to actual doses given. This approach would establish whether or not the calibration standards of the supplier of the service are traceable to those of NBS; but to do the job with a number of badges sufficient for obtaining statistically valid results would require a rather expensive operation.

The Nuclear Regulatory Commission presently is working on a change in the requirements for personnel monitoring by its licensees, based on the above approach. It will result in the licensees having to select a supplier of personnel-monitoring services from a list of suppliers certified on the basis of the results of tests carried out by a laboratory (or laboratories) under NBS supervision. While the NBS function would be subsidized by the Nuclear Regulatory Commission, it is envisaged that the bulk of the cost of the program would be carried by the commercial suppliers themselves.

2/3.I.3 Size and Importance of Personnel Monitoring Activities

Estimate of size. At present, there are at least 14 companies (probably a few more) providing either film badge or TLD personnel-monitoring services for others (see appendix G). Information on the numbers of persons "badged", i.e., required to wear personnel monitors, is given in table 16. The total number was obtained from an estimate in a report of the Environmental Protection Agency (Klement *et al*, 1972).

Table 16. Estimates of workers monitored (1969-70)

Service Provided By	Number of Persons
Commercial personnel-monitoring services	590,000
Companies and government laboratories providing their own services	100,000
Defense Department, Army, Navy, Airforce	80,000
	770,000

These figures are not inconsistent with figures for 1971 for AEC contractors and covered licensees who reported monitoring some 208,000 individuals (Fourth Annual Report of the Operation of the U.S. Atomic Energy Commission's Central Repository of Individual Radiation Exposure Information, September 1, 1972), since not all radiation workers are under AEC (now National Regulatory Commission) surveillance.

Commercial film-badge processing has grown steadily from around 2.5 million badges in 1963 ($1.25M) to 5.8 million badges in 1970 ($4.4M) (AEC, 1971), a growth rate of 13% per year in badges, with the medical users being the biggest customers. TLD devices are gradually replacing photographic film for technical reasons (no need for darkroom and development procedures, fast, simple readout, less dependence of response on photon energy, higher sensitivity to intermediate and low-energy neutrons, less fading in many instances). The TLD device's intrinsic cost is higher than that of film (about 10 cents per film, $1 per TLD device), but TLD devices usually can be used many times, while photographic film is used only once. Also, if radiation hazards are low, it is possible to change TLD devices less frequently because of less severe problems with fading. About 15% of the commercial personnel-monitoring business is carried out with TLD devices at present.

For the sake of completeness it should be mentioned that the radiation industry needs area survey and radioactivity measuring instruments as well as personnel-monitoring systems. The dollar volume of this instrumentation presumably is distributed among the user applications (medical nuclear instrumentation, reactor instrumentation, etc.), and not readily identifiable. The source and calibration facilities required are similar to those for personnel-monitoring, although often less accuracy is required.

It is expected that all commercial suppliers of personnel-monitoring services will continue to grow rapidly due to the growth of the nuclear industry generally, of nuclear medicine with the particularly high growth rate of 25% per year, and of the nuclear electric power industry, quite small at present, but with major growth scheduled.

Government laboratories and companies providing their own services (mostly Government contractors) predominantly use TLD devices. The military services are currently using film badges, but are looking for better personnel monitors (usually TLD). These groups, representing about 200,000 persons monitored, are staying roughly constant due to lack of real growth in Government organization budgets.

Regulation of personnel-monitoring. The chief organizations concerned with the regulation of personnel-monitoring are the Nuclear Regulatory Commission, the Occupational Safety and Health Administration of the Department of Labor, and the state and local government radiation control offices. In addition the Bureau of Radiological Health of the Food and Drug Administration is generally concerned with minimizing radiation exposure to the population, which includes exposure to radiation workers.

In nearly every state, the state health department is designated as the agency responsible for radiation protection with the authority to adopt regulations. The states discuss common problems in radiation control at the National Conference on Radiation Control which meets annually, and recently has been attended by several NBS representatives each year. This group is particularly concerned with the question of obtaining demonstrably reliable personnel monitoring. A workshop on the progress made in this direction was held in the spring of 1975.

A list of some of the regulations and guides for personnel monitoring promulgated by such organizations as the American National Standards Institute (ANSI), the National Council on Radiation Protection and Measurements (NCRP), and the NRC is given in table 17. The standard for film-badge performance is Criteria for Film Badge Performance, American National Standard N13.7-1972. Under review at the present time is a similar ANSI standard for thermoluminescence dosimeters (TLD). In addition standards or recommendations cover performance specifications for pocket dosimeters, administrative practices in radiation monitoring, and radiation-exposure record keeping.

Table 17. Some standards and guides for personnel monitoring

Sponsoring Organization[1]	Standard or Guide
AEC	The Establishment and Utilization of Film Dosimeter Performance Criteria, USAEC Report BNWL-542 (1967) by C. M. Unruh, H. W. Larson, T. M. Beetle, and A. R. Keene.
ANSI	Administrative Practices in Radiation Monitoring (A Guide for Management), American National Standard N13.2-1969.
ANSI	Dosimetry for Criticality Accidents, American National Standard N13.3-1969.
ANSI	Performance Specifications for Direct Reading and Indirect Reading Pocket Dosimeters for X- and Gamma Radiation, American National Standard N13.6-1966 (R1972)
ANSI	Criteria for Film Badge Performance, American National Standard N13.7-1972
ANSI	Practices for Occupational Radiation Exposure Records System, (reaffirmation and redesignation of N2.2-1966), American National Standard N13.6-1966 (R1972).
ICRU	Radiation Protection Instrumentation and Its Application, ICRU Report 20 (1971).
NCRP	Radiological Monitoring Methods and Instruments, NBS Handbook 51 (1952). This report is out of date; a new report is in preparation by NCRP, but it is not known when the new report will be available.
PHS	Standards of Performance for Film Badge Services, U.S. Department of Health, Education, and Welfare, Public Health Service Publication No. 999-RH-20 (Sept. 1966).

[1]AEC United States Atomic Energy Commission (no longer in existence)
ANSI American National Standards Institute
ICRU International Commission on Radiation Units and Measurements
NCRP National Council on Radiation Protection and Measurements
NRC Nuclear Regulatory Commission
PHS U.S. Public Health Service, Department of Health, Education, and Welfare

2/3.I.4 Structure of the Radiation Measurement System for Personnel Monitoring

A schematic drawing of the radiation measurement system for personnel-monitoring is given in figure 11.

Direct Users. All users of radiation must provide personnel monitoring for workers who might be exposed to radiation doses above the very low levels permissible for the general public. The problem of personnel monitoring, therefore, exists across the board for all the employers of the estimated 800,000 radiation workers. In figure 11, the users are separated into two categories: (1) The larger group of users, medical, industrial, nuclear power, etc., who buy their personnel-monitoring services from commercial suppliers. Their chief concern is to have an adequate service to provide a radiation-exposure record to their workers which meets the regulatory requirements placed on them by the state or local government and/or by the NRC. (2) In addition most of the government laboratories and the military services provide their own personnel-monitoring services, or have certain designated laboratories which provide the services for the others.

Suppliers of monitoring services. A list of personnel monitoring service suppliers is given in appendix G. The sizes of the businesses vary widely -- from as small as 400 personnel badged per month to the order of 100,000. The larger services computerize their data handling for efficiency and for keeping track of the rather large body of permanent records.

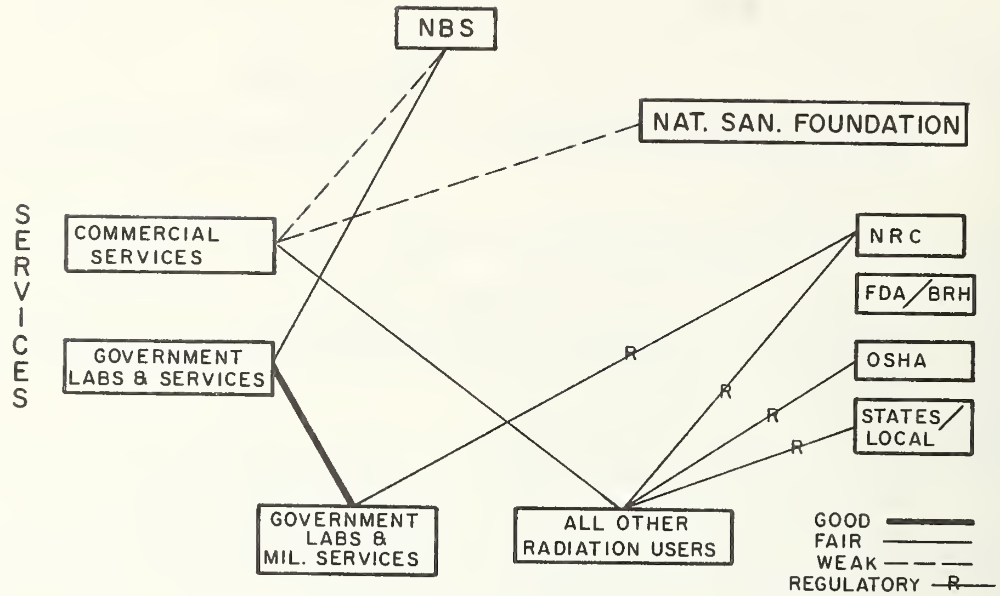

Figure 11. Structure of the personnel monitoring measurement system

In addition to a wide variation in size, there is also a wide variation in calibration procedures. Some organizations have NBS-calibrated beta-ray, gamma-ray, and neutron sources. Others use sources calibrated locally with NBS-calibrated dosimeters, usually Victoreen R-meters.[1] Other organizations use the source strength given by the source manufacturer (which may in some cases be a nominal strength). Others own sources which have been calibrated against sources in neighboring institutions whose calibration is believed to be traceable to NBS calibration standards. Others own no sources at all but occasionally make calibration checks against sources owned by a neighboring institution, typically a university. Similar variations exist with respect to the calibrations with x-ray photons (usually bremsstrahlung). It is desirable for any personnel-monitoring organization to have check sources since these can be used to provide calibrations of a particular batch of photographic film (including development procedure) or a batch of TLD material. Estimates of accuracy claimed by the managers of the commercial services range from about 10% to 30% for x and gamma rays, much worse for neutrons. (Measurement-assurance testing experience indicates that such estimates are often much smaller than the actual errors).

The organizations which have received the Seal of Approval (i.e., which "pass" the test) of the National Sanitation Foundation, which carries out measurement-assurance tests on a limited scale with radiation type and energy known to the participants, were within ranges of about 67% to 150% of the given dose for x and gamma rays, with somewhat broader ranges for neutrons.

Standards and calibration laboratories. Two of the chief standards laboratories in the personnel-monitoring measurement system are the National Bureau of Standards and the National Sanitation Foundation (see figure 11). In addition standards groups in some organizations assist the monitoring services by providing calibrated sources to establish the calibration of the personnel monitoring devices.

The chief function of the National Bureau of Standards in the system at present is through calibration of sources and instruments for source calibration which establish the measurement scale for the monitoring services. In this way calibrations are provided for x-ray, gamma-ray, and neutron sources. For beta-ray calibrations, the film badge services use typically Sr^{90} -Y^{90} plaques or natural uranium slabs. Unfortunately, NBS priorities have been such that no calibration service has been developed for this type of source. NBS recently has received funds from BRH for the development of an extrapolation ion chamber that could be used for such a service.

[1]Mention of particular brand-names of commercial equipment here does not constitute NBS endorsement (or criticism) of a particular product.

The first measurement-assurance irradiations of film badges were provided by NBS about 20 years ago under AEC sponsorship (Ehrlich, 1973). These tests led to the recognition by the USAEC that a permanent personnel-monitoring testing laboratory should be established. The USAEC also sponsored a measurement-assurance study at Battelle-Northwest Laboratory and a set of final performance criteria.

Concurrently, the U.S. Public Health Service sponsored a similar study at a private testing laboratory, the National Sanitation Foundation. The National Sanitation Foundation has now been performing tests of personnel monitoring services on a commercial basis for over five years. A description of the NBS measurement assurance service and related standards is given in Barber, Standards of Performance for Film Badge Services, (see table 17). Of the 14 commercial services interviewed, eight had participated and received the NSF Seal of Approval. Most felt that this testing service, which is performed about once a year, was not particularly helpful to them technically, did not provide a very critical accreditation, and the smaller services complained about the high cost (quoted variously as \$1100 to \$1800) eating into small profits.

The National Sanitation Foundation does not at present have radiation facilities of its own, and uses equipment located at and belonging to the University of Michigan. The National Sanitation Foundation also does not have radiation-qualified staff of its own, but depends upon consultants and graduate students from the University of Michigan. However, it is interested in expanding its personnel-monitoring testing capabilities.

The Conference of Radiation Control Program Directors of the States has expressed concern over the adequacy of the present system of testing personnel-monitoring services: (1) not all services are tested (shown by a "weak" link in figure 11); (2) the National Sanitation Foundation does not have radiation competence and equipment of its own; (3) quarterly checking of the monitoring services, including "blind checks", would give better assurance of competent performance than annual testing; and (4) the calibration of the sources used by the National Sanitation Foundation is not currently traceable to NBS standards, no sources or instruments having been calibrated in the last five years (indicated by no link in figure 11).

The professional society chiefly concerned with personnel radiation-monitoring problems is the Health Physics Society, and its international equivalent, the International Radiation Protection Association (IRPA). In addition NRC-related organizations participate actively in personnel monitoring workshops.

2/3.I.5 Conclusions

Personnel-monitoring services are important to the health and safety of about 800,000 radiation workers. They represent a commercial business of about \$7 million per year plus perhaps \$3 million in-house governmental services. The personnel-monitoring services verify the safe operations in a much larger sphere: nuclear medicine, diagnostic and therapeutic radiology, nuclear electric power, non-destructive testing, science, chemical analysis, oil-well logging, etc., which run to several billion dollars (AEC, 1971).

One of the major problems is that the individual radiation user does not have assurance at the present time that the personnel monitoring service provided to him is satisfactory, although many of the suppliers of such services probably are competent. Of the 50 or so suppliers in total, most undergo no measurement-assurance testing at all, and those that do are tested by a small organization whose measurements are not traceable to NBS standards. The Conference of Radiation Control Program Directors of the States, the Nuclear Regulatory Commission, and the Bureau of Radiological Health are all aware of these problems, and are actively cooperating with NBS to find a solution. The solution being considered is to have one or more personnel-monitoring testing laboratories operate under NBS oversight, and be required to be traceable to NBS.

There is a need for improved neutron personnel monitors which perform satisfactorily in the low neutron energy range below 1 MeV. The action called for by NBS is the establishment of monoenergetic neutron calibration facilities in this energy range and at a few higher energies, so that the developers and users of the new neutron personnel monitors can adjust their dosimeters to optimum response, and verify that the monitors are indeed satisfactory for all important neutron energies.

3. IMPACT, STATUS AND TRENDS OF MEASUREMENT SYSTEM

In view of the rather lengthy discussions in section 2/3 on the various applications of radiation and the measurement communities interested in them, the present section will include only short summaries on the Measurement System for Ionizing Radiations as a whole.

3.1 Impact of Measurements

3.1.1 Functional, Technological and Scientific Applications

Ionizing radiation is a very powerful tool for accomplishing many different objectives. This powerful force for good, like other phenomena in nature, is not without some hazards. It seems clear that the public wants the benefits, but is insistent that the radiation hazards be kept to a minimal, acceptable (or negligible) level. An NBS-traceable ionizing radiation measurement system is important, both for the precise measurements needed in nuclear power and medical applications, and also to provide the standard of measurements which regulatory agencies, radiation users, and the public can all agree on.

The goals of ionizing radiation measurement are: (a) medical -- more successful radiation therapy of cancer, better medical and dental diagnosis for less radiation exposure; (b) nuclear power -- abundant, relatively cheap supplies of power from primarily domestic sources using fission now and probably fusion in the future; (c) industrial radiation processing -- improvement of products and sterilization of products in an energy-efficient, frequently economic way; (d) defense -- effective defense including maximum protection of the armed forces and civil population; (e) chemical analysis -- a highly sensitive, accurate method for analytical chemistry; (f) science -- radiation is a powerful means for investigating the fundamental properties of particles, atoms, atomic nuclei, molecules, liquids, and solids, and for studies across the entire spectrum of physical and biological sciences; (g) environmental protection -- sensitive detection methods leading to protection of the public both from radioactivity and from other pollutants (such as lead) in the environment; and (h) miscellaneous radiation applications -- industrial process control, non-destructive testing, oil-well logging, heat sources, smoke detectors, and so forth.

3.1.2 Economic Impacts -- Costs and Benefits

A good measurements system for ionizing radiation results primarily in improved health and safety benefits for the general population. It is very difficult to quantify the value of these benefits in standard economic terms. For example, one patient in four entering the hospital undergoes nuclear medicine diagnostic procedures; and 65% of the civilian non-institutional population of the United States had one or more x-ray examinations in 1970 (Department of Health, Education and Welfare, 1973) to help determine the course of the patient's treatment. Thus the measurement of ionizing radiation impacts a significant and important portion of the health care delivery industry (around $100 billion per year).

Similarly, a reliable and sufficiently accurate ionizing radiation measurement system, both in the plant and in the environment surrounding the plant, is absolutely necessary for the viability of nuclear power as a source of energy for the nation. Here only a small fraction of the $102 billion committed for nuclear power by the electric utilities (AEC, 1974) is assignable to radiation, yet adequate protection of the public from stray radiation must be demonstrated before the reactor is allowed to operate. Personnel monitoring of workers is also important.

Cases where economic analysis is quantifiable are in the areas of industrial radiation processing ($500 million per year for the industry), and miscellaneous radiation applications (about $100 million). Radiation measurement is a significant part of these industries.

3.1.3 Social, Human, Person-in-the-Street Impacts

The benefits of a good system of ionizing radiation are primarily social. Let us cite some examples.

Improvement of Cancer Therapy. Based on normal incidence of cancer, one person in four will get cancer during his lifetime. Of these, more than half will be treated by radiation therapy. While radiation therapy is sometimes palliative only, cure is frequently attempted. The principal need for accurate measurements arises in connection with photon and electron beams being used for treatment. In addition to the control of the radiation delivered to individual patients, dosage must be known if the results of treatments are to be compared between hospitals -- a procedure essential if experience is to be shared, so that rapid progress can be made. Evidence now points to the narrow margin between success and failure in relation to dose delivered, a margin now put at $\pm 5\%$ for curable tumors. Under-dose will lead to recurrence, over-dose to damage to normal tissue and resulting complications. In order to achieve the ±5% in treatment, it is imperative that the primary standards at the head of the calibration chain be known to 1 or 2% or better.

Neutrons and other heavy particle radiations offer the hope of improved success in radiation therapy. But the ability to measure these "new" radiations is less than for x rays and electrons. Standards and transfer instruments will be needed if clinical trials are successful and the use of these radiations becomes widespread.

Reduction of dose in the use of x rays for diagnosis. Since medical diagnostic x rays represent roughly 90% of population exposure to man-made ionizing radiation, one of the ways to reduce population dose (and thus the possibility, however small, of cancer induction) is to systematically measure and control the dose of x-rays used in taking diagnostic radiographs to the lowest level giving acceptable radiographs. Cases where x-ray exposure is unnecessarily high can be corrected. A further enhancement, more in the nature of technology development than measurement system, would be to develop diagnostic radiology systems with better pictures for less dose. Such developments might permit x-ray examinations on a more routine basis, permitting discovery of problems before they become serious, thus greatly improving medical care.

Nuclear power. At the rate that our fossil fuel sources are drying up, notably gas and oil, despite vigorous conservation measures, it is frequently reported that a new source of energy will be needed towards the end of the century. Nuclear energy, at present from fission reactors, is the only major source available to us with present technology. Nuclear energy from fusion reactors, if the technology can be developed, would represent an essentially inexhaustible source of energy. The nation may decide not to build breeder reactors due to the large quantities of plutonium, a very dangerous material, involved. Even so we will be concerned with the environmental impact of breeder reactors, because other countries are going ahead with them. It is also important to remember that all nuclear energy power sources are also intense sources of radiation, including "clean" fusion power. Radiation measurements both for design and operation of the power plants and for protection of workers and the environment, will be needed.

Radiation workers. Radiation workers, mostly in hospitals and clinics, but also in electric power companies, manufacturing industry, government laboratories, and universities, have the right to work in a safe workplace. This requires good radiation protection discipline, ability to accurately measure radiation fields continuously, monitoring. If the worker is to be protected, personnel monitoring must be demonstrably reliable -- hence must be traceable to NBS.

Environmental pollution -- lead. Lead from automobile exhausts is one of the chief contaminants of air, particularly around superhighways and tunnels, for example Photon activation analysis is the most sensitive method for determining lead. Proper calibration is needed so that these measurements provide a basis for action by proper authorities.

Environmental polution -- coal-fired power plants. Coal-fired power plants are larger sources of radioactivity in normal operation than some nuclear plants, and in addition they put large quantitites of ash into the air which contain elements such as fluorine which may damage vegetation in the neighborhood of the plant. Both radioactivity and activation analysis measurements are needed to monitor the safe operation of these plants.

Non-destructive testing -- air travel. When a commercial airplane undergoes a periodic overhaul, certain key parts are radiographed to ensure that no cracks have started to develop. These measurements must be made under controlled conditions at demonstrably low radiation levels for the x-ray technicians and other workers.

3.2 Status and Trends of the System

A strength of the measurement system for ionizing radiation is that many well-developed standards exist, as do sophisticated conscientious users of radiation. A weakness is that many users in the field are not achieving the accuracy of measurements they need. This has led to a strong trend of transfer of calibrations out to users. In turn this has led to a very vigorous NBS activity in measurement assurance, establishment of secondary standards laboratories (sometimes lead laboratories of other government agencies), and development of high-quality transfer instruments.

Another trend is the increased interest of regulatory agencies to determine compliance on the basis of NBS-traceable measurements, and to write NBS-traceability into regulations. Industry, particularly when it feels regulation may be approaching, is also showing interest in proving that its measurements are NBS-traceable.

A third trend is for outside groups to come to NBS for major standards-related programs. One example was the endorsement by AEC of the NBS neutron standards program. A second example is the assignment to NBS of major responsibility for atomic and nuclear data in the Controlled Thermonuclear Reactor (CTR) program of the Department of Energy.

External trends forcing changes in the system include: expansion of nuclear power; the breeder reactor program including the Fast Flux Test Facility (FFTF) now under construction, and preparations for and possible cancellation of the Clinch River breeder demonstration plant; higher priority for development of CTR and laser fusion systems; increasing concern for safeguarding nuclear fuel material on the part of the public and the Nuclear Regulatory Commission; expanding needs of regulatory agencies, especially State radiation control programs; expanding use of radioactivity in medicine; new radiations being proposed and tried for radiation therapy of cancer; with the increasing number of nuclear power reactors and coal-fired plants producing electricity, concern that the environment shall stay clean.

4. SURVEY OF NBS SERVICES

4.1 The Past

The Center for Radiation Research grew out of two activities begun in the 1920's, one in x-ray standards and the other in radioactivity standards. These soon developed satisfactory standards and served the community interested in medical applications of radiation. With the developments in atomic energy during the Manhattan project, NBS activity broadened to include radiation shielding, neutron measurements, and greater emphasis on radioactivity. Use of higher radiation energies in radiation therapy created a need for higher energy sources at NBS, and a betatron and synchrotron were obtained. Strong programs in radiation transport theory, nuclear theory, and photonuclear research were established. With the move to Gaithersburg in 1965, a 150 MeV electron linac was obtained as a high-intensity source for electron, photon, and neutron research and standards. Scientifically outstanding programs led to many new high-quality standards, and yielded much reference data.

The strength was that there were many standards, and they were of high quality. The weakness, in hindsight, was that although calibration services were available to all, they were used at the initiative of the user, usually the highest level user. Many users with real measurement problems were simply not reached.

4.2 The Present

4.2.1 Description of NBS Services

In order to avoid unnecessary repetition of material in section 2/3 we shall only briefly summarize NBS ionizing radiation measurement system services: (1) Calibrations: x-ray instruments 10-250 kV, ^{137}Cs, ^{60}Co; neutron sources, radioactive sources; gold foils in a standard thermal neutron field, instruments in high-intensity monoenergetic photon fields; (2) Measurement Assurance: radioactivity measurements at radiopharmaceutical, intermediate, and environmental levels; ferrous sulfate dosimeter for electron therapy and thermoluminescent dosimeter services for Co-60 teletherapy; personnel monitoring measurement assurance tests; ILRR program for fission rate measurements. (3) National Standards: free-air and cavity ionization chambers for x-rays and ^{137}Cs, ^{60}Co; graphite calorimeter for high-energy electrons; thin-film calorimeter for intense photon fields; radium-beryllium photoneutron source and ^{252}Cf spontaneous fission neutron source; thermal neutron flux density standard; P-2 ionization chamber for high energy photon energy fluence; Faraday cage for high energy electron beam current measurement. (4) Standard Reference Materials: over 80 radioactivity standards are issued through the SRM program. (5) Reference Data: two data centers, X-Ray and Ionizing Radiation, and Photonuclear; measurement of standard neutron cross sections, total neutron cross sections, electron scattering cross sections, photonuclear reaction cross sections, photofission cross sections, radionuclide decay scheme data (primarily gamma-ray emission).

NBS participation in standardization activities is described in appendix H.

4.2.2 Users of NBS Services

The subject is discussed at considerable length in section 2/3 which is organized by 9 user categories. Regulators, who are also users of NBS services, are discussed in section 2.4.4.

4.2.3 Alternate Sources of Calibration Services

Two kinds of alternate sources can be described: (1) the first is where the alternate source serves as central basis for the measurement system in lieu of NBS, and (2) where the alternate source plays the role of a secondary standards laboratory traceable to NBS, so the customer may go to the alternate source rather than to NBS. In general the first works very poorly, and the second very well.

As an example of case (1), in 1958 NBS turned much of its primary radioactivity standards production to industry. Such chaos resulted that a National Academy of Sciences-National Research Council Committee was formed to study the problem, and the committee recommended that central responsibility for radioactivity standards be returned to NBS (NAS, 1970). A second example is neutron standards which were worked on by both national laboratories and industry for a period of 20 years with many major problems never resolved. Major responsibility has now been given to NBS (with AEC, now Department of Energy, concurrence). While it is too early to say that the NBS program will resolve all problems, definite progress has been made.

Examples of alternative (2) working well include the medical Regional Calibration Laboratories (except for economic problems), and in environmental radioactivity measurements the quality control laboratories for NRC and EPA.

4.2.4 Funding Sources for NBS Services

Calibration services are funded on a reimbursable basis. Measurement assurance services are funded by the users or by government agencies. Development of standards is usually direct NBS (STRS) funding, although initial funding is often by other government agencies who need or wish to encourage the standards development. Standard reference materials development is through NBS funding (in part through the Office of Standard Reference Materials in NBS) while cost of production determines the price paid by the buyer of the standards on what is essentially a reimbursable basis. Data Center activities are chiefly funded by the National Standard Reference Data System, while data measurements are usually NBS funded. Other Government agencies funding ionizing radiation measurement work at NBS include Department of Defense, Nuclear Regulatory Commission, Energy Research and Development Administration (now Department of Energy), Bureau of Radiological Health, National Cancer Institute, National Aeronautics and Space Administration, and Environmental Protection Agency.

4.2.5 Mechanism for Supplying Services

As indicated in section 4.2.1, NBS services include calibrations, measurement assurance programs, radioactivity standards, and compiled standard reference data. Scientific publications constitute the major research output. Communication is also through attendance at scientific meetings and user-oriented meetings. There is also strong participation in schools and training programs (for example, workshops on Radioactivity Standards for Nuclear Medicine). NBS also participates in the writing of the documentary standards of the organizations discussed in section 2.2.1.

4.3 Impact of NBS Services

4.3.1 Economic Impact of Major User Classes

These impacts are discussed in sections 2/3.A through 2/3.I for the various user classes of ionizing radiation.

4.3.2 Technological Impact of Services

This also is discussed in section 2/3. Two technological impacts deserve special mention which come not directly from measurement services, but rather from the technical know-how which had to be developed to provide the wide variety of radiation services. The first is the development through NBS leadership of the Nuclear Instrument Module (NIM) system now used throughout the world for nuclear (and other) electronics. The second is the expertise NBS developed in accelerator technology through development of the needed intense multi-particle radiation source (the linac) which now has implications in CTR and other technology.

4.3.3 Pay-off from Changes in NBS Services

Some illustrative changes in NBS services with the resulting effects are given in Table 18.

4.4 Evaluation of NBS Program

The standards developed in the NBS Ionizing Radiation Measurement program are of high quality and relevant. A strong scientific program backs up the standards and makes it possible to move quickly into new fields. The program has been a leader in development of measurement assurance to users. Needed in the NBS program are: (1) much more measurement quality assurance, especially where

Table 18. Effect of changes in NBS services for ionizing radiations

Change	Effect
Establish Regional Calibration Laboratories for radiation calibrations for hospitals (with Am. Assoc. Physicists in Medicine).	Generally good, but not enough laboratories, and not yet enough business for them.
Establish measurement assurance service for high energy electron therapy.	Discovered hospital with a factor-of-ten error in their calibration before any patients were treated. Would have been overdose.
Withdrew from producing many radioactivity standards in 1958.	Chaos. Decision reversed.
Establish monoenergetic x-ray sources of very high intensity (d.c. and pulsed).	Instrument systems for field tests can be calibrated in the laboratory, which was impossible before.
Establish neutron standards program.	Definite progress made in this field. Final outcome hopeful but not yet certain.
Issue series of environmental radioactivity measurement standards, including mixed radionuclide standards.	Instant best seller to power reactor operators, states, regulatory agencies.

regulatory questions are involved; (2) more reaching out to help measurers with problems through assistance to the States, training, development of regional or secondary laboratories; and (3) some new measurement standards in crucial areas where they do not exist (examples are neutron standards for therapy and personnel monitoring, and standards for the CTR program).

The following are excerpts from recent National Academy of Sciences - National Academy of Engineering - National Research Council Evaluation Panel Reports on the NBS Center for Radiation Research:

> "The Panel unanimously feels that the CRR is being led by aggressive, competent management which is trying hard to respond to a national need considerably greater than that which can be handled with their present resources ...
>
> "The Panel was also pleased to see staff and management thinking in long range terms; this is most important for the future of the country and for the ability of a broad distribution of NBS personnel to understand their own objectives, therefore to be able to defend them but even more importantly, press for increasing the strength of NBS in the nation's scientific, commercial and political future ...
>
> "In another area, the Panel wishes to encourage NBS/CRR to continue its efforts to establish itself as the lead agency (in today's parlance) for all aspects of standardization and evaluation ..." [Report of the 1974 NAS-NAE-NRC Evaluation Panel].
>
> "The primary responsibility of the CRR unquestionably remains the provision of basic radiation standards and associated technologies in response to national need. This responsibility and the need is enormous and rapidly growing. The provision of an authoritative and objective standard basis is an essential response to rising public and private concern for the regulation, the safety and the economic effectiveness of a diversity of radiation technologies. The CRR is in a unique position to make that response. With this enormous responsibility and the constraint of finite resources: the CRR must be very selective of the most effective and key programs.
>
> "These should concentrate on the provision of the fundamental and underlying standards and technologies.
>
> In carrying out its responsibilities the CRR must strike a balance between near- and long-term objectives." [Report of the 1975 NAS-NAE-NRC Evaluation Panel].

4.5 The Future

It is always difficult to predict the future. Here is a list of possible events or trends which, if they do happen, will affect future needs in the ionizing radiation program of NBS:

(1) expansion of the use of nuclear power;
(2) expansion of the use of coal power;
(3) use of mixed-oxide (U and Pu) nuclear fuels in light-water reactors;
(4) industry-operated nuclear fuel cycle;
(5) development of large numbers of breeder reactors;
(6) largely as a result of (3), (4), and (5), greatly increased concern on the part of the Nuclear Regulatory Commission and public for safeguards of Special Nuclear Materials,
(7) successful demonstration of fusion power and construction of prototype fusion power plants;
(8) increased interest of regulatory agencies at federal, state, and local levels in traceability of ionizing radiation measurements to NBS;
(9) expanding use of radioactivity in nuclear medicine;
(10) development of a new generation of improved x-ray diagnostic equipment;
(11) continuing concern with minimizing x-ray dose to the population;
(12) linear accelerators replacing conventional x-rays and ^{60}Co as the preferred sources for radiation therapy;
(13) verification of the success of neutron cancer therapy leading to the use of new heavy-particle radiations in radiation therapy;
(14) industrial radiation processing and miscellaneous radiation applications will continue a rather steady growth;
(15) use of radiation for non-destructive testing of components and materials will become increasingly important.

The future program is thus likely to include: (1) standards and reference data for new technologies (e.g. fusion power, breeder reactors, safeguarding nuclear materials, new radiation therapy modalities, non-destructive testing, computer-assisted x-ray diagnostic scanning, nuclear medicine, industrial radiation processing); (2) development of transfer instruments and methods for transferring standards to the user, and fostering regional or other secondary calibration laboratories; and (3) measurement quality assurance programs of some kind, at least in every field where regulatory requirements exist.

5. SUMMARY AND CONCLUSIONS

The National Measurements System for Ionizing Radiations is large, important, and of prime importance in the development of nuclear power and medical applications of radiation, although there are many other applications. Many parts of the system do not now provide the accuracy needed for most efficient radiation application, or to adequately protect people and the environment. Some NBS actions shown in this report as needed to improve this situation are (note: impetus for these actions also has come from other sources than this report, and many of these actions are now underway):

(1) Develop a national radiation measurement calibration system to provide assistance chiefly to State radiation control agencies, but also to regional calibration laboratories and regulatory agencies.
(2) Institute a program of measurement assurance testing with quality control laboratories of NRC, EPA, and other regulatory agencies.
(3) Further development of the Regional Calibration Laboratory system for medical radiation is needed, including measures to make them economically viable.
(4) Primary absorbed dose standards need to be developed for high-energy (linac and betatron) X rays and fast neutron radiotherapy.
(5) Some system of quality control of radioactivity measurements needs to be extended throughout the approximately 8000 institutions doing nuclear medicine.
(6) Problems with dose calibrators used in nuclear medicine need to be straightened out, and appropriate sets of check sources provided.
(7) A major measurement assurance system for nuclear fuel materials accountability with strong NBS participation will be needed, barring major changes in U.S. energy policy, with state-of-the-art accuracy and real-time accountability.
(8) Standard neutron cross sections and standard reference neutron fields measurement programs are needed in support of nuclear fission power programs, especially the breeder reactor, and needs will grow with the fusion reactor program.
(9) Some new calibration services are needed in support of industrial radiation processing, but these do not constitute a major new program.
(10) Intense, pulsed and d.c. x-ray calibration sources need to be made available for defense measurements.

(11) New radioactivity standards, particularly in environmental matrices, and extended measurement assurance testing throughout the system is needed for environmental radioactivity measurements.

(12) A program is needed for systematic compilation of charged-particle stopping powers, ranges, straggling, and delta-ray production data below about 10 MeV.

(13) Support is needed for development of consensus standards for safety measures in the use of radiation equipment for various (mostly industrial) applications.

(14) A high-quality measurement assurance testing laboratory traceable to NBS is needed to provide personnel monitoring quality assurance.

(15) Monoenergetic neutron calibration fields are needed to test existing neutron personnel monitors and for use in developing improved neutron personnel monitors.

APPENDIX A. METHODOLOGY OF THE STUDY

The study was carried out essentially as ten separate studies, one on Regulators of Radiation, and nine on different radiation user groups (except that the ninth was on Personnel Monitoring, which applies to all users of radiation). These will be briefly discussed below.

Regulation of Radiation. Much documentary information is available from U.S. Government regulatory agencies, much of which is listed in the references. Of the Federal Government agencies (see section 2.4.4), we have held joint meetings, frequently laboratory visits, with all except DOT. An example of this was a meeting with the Bureau of Radiological Health attended by about 50 NBS scientists, including the NBS Director. We have carried out measurement assurance testing with NRC and EPA.

In regard to the state and local agencies, our chief contact to date has been attendance at several annual meetings of the Conference of Radiation Control Program Directors. In addition, committees of that organization have met at NBS. Visits were made to the Department of Radiation Control of the State of Maryland, and the Division of Radiation Control of New York City. An IBS staff member who collaborated in the study spent three months working with the Radiation Control Department of the State of California. In addition, we are very active in the consensus standards-setting organizations which provide a base for state and federal regulations (see appendix H).

Sources of background material for the main categories of radiation users

A. Medical

There are about 140,000 medical x-ray sets in the United States, and a similar number of dental x-ray sets. It would clearly not be possible to visit or contact any significant fraction of these. We have, however, contacted the two Regional Calibration Laboratories (at M. D. Anderson Hospital, Houston, and Memorial Hospital, New York) which provide calibrations to the hospitals in their regions, and visited the Memorial Hospital laboratory. We have also visited the Victoreen Instrument Co., Cleveland, which is perhaps the major supplier of radiation measurement instrumentation to x-ray departments and a major calibrator of such equipment. Representative hospitals have been visited, such as Washington Hospital Center, Washington, D.C., and M. D. Anderson Hospital, Houston, Texas. No x-ray equipment manufacturers have been visited, although the laboratories of the major tester of such equipment, the Bureau of Radiological Health (FDA) have been visited.

In the area of nuclear medicine, leading nuclear medicine departments of the about 8,000 hospitals and clinics doing nuclear medicine procedures have been visited: Johns Hopkins Hospital, Baltimore; Washington Hospital Center, Washington, D.C.; Mayo Clinic, Rochester, Minnesota. In addition, three seminars have been held at NBS recently on Radioactivity Measurement in Nuclear Medicine with representatives of radiopharmaceutical manufacturers, nuclear medicine physicians and technicians. NBS is participating actively with the College of American Pathologists in measurement assurance testing, and participating in Society for Nuclear Medicine meetings. We are in active liaison with two committees of the Atomic Industrial Forum on Radiopharmaceuticals and Standards. Visits have been made to one radiopharmaceutical manufacturer, Amersham-Searle, Arlington Heights, Illinois, and to 2 radiopharmaceutical dose calibrator manufacturers, Packard Instruments, Chicago, and Victoreen Instrument Co., Cleveland.

B. Nuclear Electric Power

1. Nuclear fuel cycle operations. In this area, a most through investigation has been carried out, including contacts with over 100 persons, attendance at 4 technical symposia sponsored by AEC in this field, and in-depth site visits to NRC's Division of Nuclear Materials Security and Directorate of Regulatory Standards. Discussions were held with representatives of all 4 major fuel manufacturers, 3 of the utilities with most experience in nuclear power, and 2 of the 3 fuel reprocessors.

2. Design data and reactor operations. Visits have been made to a number of national laboratories with programs in this area, including Brookhaven (which has the National Nuclear Data Center), Argonne, and Oak Ridge. A valuable source of information in this area has been membership on the Department of Energy Nuclear Data Committee which has close liaison with the Advisory Committee on Reactor Physics of the Department of Energy. A visit was made to the Oyster Creek Nuclear Power Plant of Jersey Central Power and Light. Participation in a recent conference on Nuclear Cross Sections and Technology and sponsorship of a conference on Neutron Standards and Applications were also helpful.

C. Industrial Radiation Processing

Of the major radiation processing operations in the United States, we have visited or have close working relations with about one-third (see table 9). These include Raychem Corporation, W. R. Grace Company, Electronized Chemical Corporation, Deering Milliken Company, Ethicon, Inc., Firestone Radiation Research Company, Weyerhauser Lumber Company. An announcement of radiation processing calibration services available from NBS has been issued and we expect that our involvement with these companies will increase.

D. Defense

The Defense Department is very large and contains many groups with differing interests in radiation. With respect to nuclear weapons and testing, the key organization is the Defense Nuclear Agency. Some years back NBS made a survey of needs for DNA in the area of radiation calibration which included visits to more than half of the Defense organizations and contractors concerned with weapons testing: Sandia, Los Alamos, Lawrence Livermore Laboratory, Sanford Research Institute, Ballistic Research Laboratories, and of course DNA Headquarters. In addition, nearly all the nuclear simulation facilities such as the Aurora facility of the Harry Diamond Laboratory, the Casino facility of Naval Ordnance Laboratory, Gamble I and II at Naval Research Laboratory, and the Reba facility at Sandia have been visited. In the rapidly growing field of plasma physics, we are in direct contact with perhaps 20% of the groups in the field. Other contacts with the Defense Department included Army food processing laboratory at Natick, Massachusetts (we have done measurements there); National Security Agency concerning effects of radiation on electronic components; Advanced Research Projects Agency (ARPA) and Air Force Technical Applications Center (AFTAC) (we furnish standards of radioactive gases to their laboratories and contractors); Defense Civil Preparedness Agency (an NBS staff member has been Chairman of the National Academy of Sciences Advisory Committee on Civil Defense, and we do radiation studies for them).

E. Chemical Analysis

This rather brief study used as background material the professional literature in this field and the results of discussions with participants.

F. Science

The section on the Radiation Measurement System for Science is based primarily on one of the collaborating author's over 20 years' experience working in the field of photonuclear physics on all aspects of the measurement, analysis, compilation, and evaluation of experimental data. The basic ideas were developed through discussion with professional colleagues both within as well as outside the Bureau which took place over a six-month period. These individuals have had a wide range of experience in high energy, nuclear, radiation and medical physics.

To determine needs for specific Standard Reference Materials, questionnaires are sent to the list of customers developed from previous sales of radioactivity standard SRM's. In addition, announcements of available SRM's were made in journals and through publications of the Office of Standard Reference Materials. In the other areas, communication is largely through journals and meetings of the scientific professional societies.

G. Environmental Radioactivity Measurement

In this area we are well-informed of the needs of users through contacts with federal and state agencies, and with reactor operators. These include discussions with and visits to the Health Services Laboratory in Idaho Falls, the Department of Energy Health and Safety Laboratory in New York, Argonne National Laboratory in Illinois, the EPA laboratory in Las Vegas (NERC-LV), Wood's Hole Oceanography Institute, and an AEC Regional Director's meeting in Chicago. We have visited two power reactors, Big Rock Point and Oyster Creek, and have made a telephone survey of power reactors. Over two-thirds of them are now referencing their radioactivity measurements to NBS environmental radioactivity standards. Contacts with NRC contract states are, at present, through the Health Services Laboratory. Contacts with the states are also made through the Conference of Radiation Control Program Directors.

H. Miscellaneous Radiation Applications

In this area we obtain much of our information through the NBS responsibility of providing the Chairmanship and Secretariat of ANSI Committee N43, Equipment for Non-Medical Radiation Applications, which is largely concerned with miscellaneous radiation applications. Visits include Ohmart Corporation, Cincinnati (producers of radiation gauges), and Kelly Field, Texas (x-radiography of airplanes). Other information was obtained from AEC studies of the nuclear industry.

I. Personnel Monitoring

Personnel monitoring services are provided by commercial monitoring service companies, by a few companies which provide their own services, and by government laboratories and the military services which usually provide their own services. We attempted to contact by telephone every commercial personnel monitoring service company. Fourteen were contacted and interviewed, six listed companies we were unable to contact. Three commercial companies providing their own monitoring services were contacted and interviewed, and one was visited (Dow Chemical Company, Rocky Flats Plant, Colorado). Ten major government laboratories (the majority of the government laboratories concerned with radiation) were contacted and their personnel interviewed. The four Defense Department agencies providing their own personnel monitoring services were contacted. In addition, a visit was made to the National Sanitation Foundation, Ann Arbor, Michigan, which provides measurement assurance services to those personnel monitoring services which desire to obtain the NSF "Seal of Approval". Discussions have been held with other federal agencies and with the states concerning NBS participation in an improved measurement assurance service for personnel monitoring. In summary, during this study NBS contacted the vast majority of the personnel monitoring services in the United States. We have also participated in the AEC (now Department of Energy) Workshop on Personnel Monitoring.

APPENDIX B. ORGANIZATIONS CONCERNED WITH RADIATION

Table B-1

List of organizations that may prepare nuclear documentary standards[1]

	Initials	Organization
	APCA	Air Pollution Control Association
	AACC	American Association for Contamination Control
	ABS	American Bureau of Shipping
	ACGIH	American Conference of Governmental Industrial Hygienists
	ACI	American Concrete Institute
	AIHA	American Industrial Hygiene Association
CRR-*	ANSI	American National Standards Institute
CRR-*	ANS	American Nuclear Society
	API	American Petroleum Institute
	ASCE	American Society of Civil Engineers
*	ASME	American Society of Mechanical Engineers
CRR-*	ASTM	American Society for Testing and Materials
	AWS	American Welding Society
	ANIM	Association of Nuclear Instrument Manufacturers, Inc.
	AIF	Atomic Industrial Forum
CRR-G*	BRH	Bureau of Radiological Health, Food and Drug Administration
	EEI	Edison Electric Institute
CRR-G*	EPA	Environmental Protection Agency
CRR-G	FRC	Federal Radiation Council (defunct)
CRR-*	IEEE	Institute of Electrical and Electronic Engineers
	INMM	Institute of Nuclear Materials Management
	ISA	Instrument Society of America
	MSSVFI	Manufacturers Standardization Society of the Valve and Fitting Industry
G	NAE	National Academy of Engineering
CRR-G	NAS	National Academy of Sciences
CRR-G*	NBS	National Bureau of Standards
CRR-*	NCRP	National Council on Radiation Protection and Measurements
	NEMA	National Electrical Manufacturers Association
	NFPA	National Fire Protection Association
G	NIOSH	National Institute of Occupational Safety and Health
CRR-G	NRC	National Research Council
CRR-G*	NRC	Nuclear Regulatory Commission
	NSF	National Sanitation Foundation
G*	OSHA	Occupational Safety and Health Administration
	SNAME	Society of Naval Architects and Marine Engineers
	UL	Underwriters' Laboratories, Inc.
G	USCG	United States Coast Guard
G	USDHEW	United States Department of Health, Education, and Welfare
G	DOL	United States Department of Labor
G*	DOT	United States Department of Transportation
G	USPO	United States Post Office Department

[1]Key: * = especially important to nuclear and/or radiation standards
G = government
CRR = CRR involvement.

Table B-2

List of biomedical organizations interested in radiation

* = important for standards
CRR = CRR involvement

	Initials	Organization
*	ACR	American College of Radiology
	ABR	American Board of Radiology
	ARRS	American Roentgen Ray Society
*	RSNA	Radiological Society of North America
	ARS	American Radium Society
	AMA	Section on Radiology of the American Medical Association
	CAR	Canadian Association of Radiologists
	AUR	Association of University Radiologists
	SCARD	Society of Chairmen of Academic Radiology Departments
	SPR	Society for Pediatric Radiology
	ASTR	American Society of Therapeutic Radiologists
*	ISR	International Society of Radiology
	IACR	Inter-American College of Radiology
CRR-*	AAPM	American Association of Physicists in Medicine
CRR-*	HPS	Health Physics Society
CRR-*	SNM	Society of Nuclear Medicine
	ASNR	American Society of Neuroradiology
	ARRT	American Registry of Radiologic Technologists
	ASRT	American Society of Radiologic Technologists
	CSRT	Canadian Society of Radiological Technicians
	AADR	American Academy of Dental Radiology
	AAD	American Academy of Dermatology
*	ADA	American Dental Association
	APHA	American Public Health Association
	AVMA	American Veterinary Medical Association
	AVRS	American Veterinary Radiology Society
	AUR	Association of University Radiologists
CRR-*	CAP	College of American Pathologists
	GSA	Genetics Society of America
	IMA	Industrial Medical Association
CRR-*	RRS	Radiation Research Society

APPENDIX C. INFORMATION ON MEDICAL RADIATION INDUSTRY

Principal suppliers of radioisotope teletherapy units and sources

Atomic Energy of Canada, Limited, Ottawa, Canada
Gamma Industries Div., Nuclear Systems Inc., Baton Rouge, Louisiana; and Port Norris, New Jersey
General Electric Company, Milwaukee, Wisconsin; and Pleasanton, California
Keleket/CGR Corporation, Waltham, Massachusetts
International Chemical and Nuclear Corporation, Irvine, California
Litton Medical Products Inc., Des Plaines, Illinois
Neutron Products Inc., Dickerson, Maryland
Phillips Medical Systems Inc., New York, New York
Picker X-Ray Company, Cleveland, Ohio
J. L. Shepherd & Associates, Glendale, California
Siemens Medical of American Inc., Union, New Jersey

Principal suppliers of clinical linear accelerators

Varian Associates
611 Hansen Way
Palo Alto, California 94304
Contact: Richard M. Levy, Product Manager, Radiation Therapy
415-493-4000

Applied Radiation (Subsidiary of Siemens, West Germany)
2404 N. Main Street
Walnut Creek, California 94596
415-935-2250

SHM Nuclear Corporation
570 Del Ray
Sunnyvale, California 94086
Contact: Robert C. Bellas, Jr., Corporate Development
408-245-3136

Atomic Energy of Canada, Limited
(affiliated with a French Company, C.G.R. Medical)
Commercial Products
P. O. Box 6300, Station J
Ottawa, Canada

Principal suppliers of medical x-ray equipment

Applied Radiation, 2404 N. Main, Walnut Creek, California 94596
CGR Medical, 2519 Wilkens Avenue, Baltimore, Maryland 21223
Capintec, 63 E. Sandford Blvd., Mount Vernon, N. Y. 10550
Cistron, 77 Tarrytown Road, White Plains, N. Y. 10607
Dunn Instruments, 1280 Columbus Avenue, San Francisco, California 94133
Edax International, Box 135, Prairie View, Illinois 60069
Enraf-Nonius, 130 County Courthouse Road, Garden City Park, New York 11040
Ercona, 2121 Bellmore Avenue, Bellmore, New York 11710
Field Emission, Box 58, McMinnville, Oregon 97128
General Electric, Medical Systems, 4855 Electric Avenue, Milwaukee, Wisconsin 53201
High Voltage Engineering, S. Bedford St., Burlington, Mass. 01803
Hyperion, Box 600, South Miami, Florida 33143
LogEtronics, 7001 Loisdale Road, Springfield, Va. 22150
Philips Medical Systems, 710 Bridgeport Ave., Shelton, Conn. 06484
Physiologic Interface, Box 211, King of Prussia, Pa. 19406
Picker, 595 Miner Road, Cleveland, Ohio 44143
Radiation Dynamics, 1800 Shames Drive, Westbury, New York 11590
SHM Nuclear, 568 San Xavier Ave., Sunnyvale, California 94086
Siemens, 186 Wood Avenue, Iselin, New Jersey 08830
Technical Instruments, 441 Washington Ave., North Haven, Conn. 06473
United States Radium, 1425 37th Street, Brooklyn, N. Y. 11218
Varian Associates, 611 Hansen Way, Palo Alto, California 94303

From Science, 28 Nov. 1972.

Principal manufacturers of dose calibrators

Capintec, Inc., 63 East Standford Blvd., Mt. Vernon, N. Y. 10550
Elsint, Inc., P. O. Box 297, Palisades Park, N. J. 07650
Nuclear Associates, Inc., 35 Urban Ave., Westbury, N. Y. 11590
Picker Corp., 333 State Street, North Haven, Conn. 06473
Rady Corp., P. O. Box 19161, Houston, Texas 77024
Searle Radiographics, Inc., 2000 Nuclear Drive, Des Plaines, Ill. 60018
Victoreen Instrument Division, VLN Corp., 10101 Woodland Ave., Cleveland, Ohio 44104

Principal standards and reference sources producers

Amersham/Searle Corp.
Atomchem Corp.
Baird-Atomic, Inc.
Beckman Instruments, Inc.
Bionuclear
Calatomic
Capintec Nuclear
Eberline Instrument Corp.
General Electric Co.
General Nuclear, Inc.
High Voltage Engineering Corp.
Industrial Nuclear Co., Inc.
International Chemical & Nuclear Corp.
Isolab, Inc.
Isotope Products Laboratories
Monsanto Research Corp.
New England Nuclear Corp.
Nuclear Associates, Inc.
Nuclear Equipment Chemical Corp.
Nuclear Materials and Equipment Corp.
Nuclear Radiation Developments, Inc.
Nuclear Supplies
Nucleonic Corp. of America
The Nucleus, Inc.
Ortec, Inc.
Packard Instrument Co., Inc.
Parkwell Laboratories, Inc.
Radiation Materials Corp., Inc.
Reactor Experiments, Inc.
J. L. Shepherd & Associates
E. R. Squibb & Sons, Inc.
Teledyne Isotopes
Tracerlab (Div. of ICN)
U. S. Radium Corp.
Universal Radioisotopes

From Radioisotope Directory, 1971
(Nuclear News)

Principal industrial suppliers of cyclotron radioisotopes

Abbott Laboratories, North Chicago, Illinois
Amersham-Searle, Arlington Heights, Illinois
Cambridge Nuclear Corporation, Subsidiary of NL Industries, Inc., Billerica, Massachusetts
International Chemical and Nuclear Corporation, Irvine, California
Mallinckrodt Chemical Works, St. Louis, Missouri
Medi-Physics Inc., Emeryville, California, and South Plainfield, N. J.
New England Nuclear Corporation, North Billerica, Massachusetts and Miami, Florida

From (AEC, 1974)

Accelerators used in neutron therapy studies

Type			
Cyclotron	M. D. Anderson Hospital Texas A&M	College Station, Texas	P. Almond
Cyclotron	Naval Research Laboratory	Wash., D. C.	R. Bondelid
Cyclotron	Univ. of Washington Physics Dept.	Seattle, Wash.	Peter Wootton
Cyclotron	Univ. of Chicago Argonne Cancer Hospital	Chicago, Ill.	L. Lanzl
Cyclotron (8-10 MeV)	Memorial Hospital	New York, N. Y.	J.S. Laughlin
250 keV(D,T)n	Univ. of Wisconsin	Madison, Wisc.	
Cyclotron 25 MeV(D,Be)	Cyclotron Corporation	Berkeley, Calif.	

Principal industrial processors of organic labeled compounds radiochemicals and radiopharmaceuticals

	Radio-Chemicals	Radio-immuno-assay Reagents	Radio-pharma-ceuticals
Abbott Laboratories, No. Chicago, Ill.	-	X	X
Aerotest Operations, San Ramon, Calif.	X	-	-
American Radiochemical Corp., Sanford, Fla.	X	-	-
Amersham/Searle, Arlington Heights, Ill.	X	X	X
Ames Co., Division of Miles Laboratories, Inc., Elkhart, Ind.	X	-	X
Bio-Chemical & Nuclear Corp., Burbank, Calif.	X	-	-
Bio-Rad Laboratories, Richmond, Calif.	X	-	-
Calatomic Inc., Los Angeles, Calif.	X	-	-
California Radiochemicals, Inc., Los Angeles, Calif.	X	-	-
Cambridge Nuclear Corp., Billerica, Mass., and Princeton, N.J. (Subsidiary of NL Industries, Ind.)	X	-	X
Curtis Nuclear Corp., Los Angeles, Calif.	X	-	X
Dhom Products Ltd., North Hollywood, Calif.	X	-	-
Diagnostic Isotopes Inc., Upper Saddle River, N. J.	-	-	X
Virgo Reagents, Electro Nucleonics Labs., Bethesda, Md.	-	X	-
General Electric Co., Pleasanton, Calif.	X	-	-
Gamma Industries, (Division of Nuclear Systems, Inc.) Houston, Texas, and Baton Rouge, La.	X	-	-
Imaj International, Inc., (Nuclear Medicine Division of Allergan Pharmaceuticals) Irvine, Calif.	-	-	X
Industrial Nuclear Company, Inc., Overland, Mo.	-	-	X
International Chemical & Nuclear Corp., Irvine, Calif.	X	-	-
Isolab Inc., Akron, Ohio	X	-	-
Iso-Med Inc., Hawthorne, Calif. (Division of New England Nuclear)	-	-	X
Kallestad Labs, Minneapolis, Minn.	-	X	-
Mallinckrodt Chemical Works, St. Louis, Mo.	X	-	X
Medi-Physics, Emeryville, Calif. and South Plainfield, N. J.	-	-	X
Miles Laboratories, Inc., Elkhart, Indiana	X	-	-
New England Nuclear, North Billerica, Mass.	X	-	X
Nuclear Associates, Inc., Westbury, N. Y.	X	-	-
Nuclear Dynamics, El Monte, Calif.	X	-	-
Nuclear Equipment Chemical Corp., Farmingdale, N. Y.	X	-	-
Nuclear Medical Labs, Inc., Dallas, Tex.	X	-	-
Schartz/Mann, Div. of Becton, Dickinson & Company, Orangeburg, N. Y.	X	X	-
E. R. Squibb & Sons, New Brunswick, N. J.	-	X	X
Teledyne Isotopes, Palo Alto, Calif.	X	-	-
Union Carbide Corp., Tuxedo, N. Y.	X	-	-
Worthington Biochemical Corp., Freehold, N. J.	-	X	-

From (AEC, 1974).

APPENDIX D. ASSESSMENT OF THE NUCLEAR FUEL MATERIALS MEASUREMENT SYSTEM

FINAL REPORT

ASSESSMENT OF THE NUCLEAR FUEL MATERIALS MEASUREMENT SYSTEM

John W. Bartlett

July, 1974

Center for Radiation Research
National Bureau of Standards
Washington, D. C. 20234

CONTENTS

EXECUTIVE SUMMARY

The most important finding of this study is that the nuclear industry needs a comprehensive, nationally-based measurement assurance system for fuel material measurements.

This need is derived primarily from Federal regulations designed to assure the tight control of special nuclear materials (SNM) that is required for protection of public health and safety. Business equity interests in shipper/receiver transfers involving nuclear materials can be satisfied by a measurement assurance system adequate for compliance with SNM control requirements.

Other sectors have recognized the need for nuclear fuels measurement assurance, and action is underway to implement this function. For example:

- International Atomic Energy Agency (IAEA) requirements, relevant ANSI standards, and the AEC's Division 5 Regulatory Guides all call for measurement assurance. The AEC is contemplating a measurement assurance regulation.

- The AEC has supported development of measurement technology commensurate with regulatory requirements.

- Through its Safeguards Analytical Laboratory Evaluation (SALE) program, the AEC has operated a prototype measurement assurance system.

These requirements and programs can be viewed as part of the groundwork for establishing a comprehensive measurement assurance system. To get from present conditions to a fully operational and effective system, the following major problems will have to be overcome:

- A complete framework of criteria, requirements and procedures will have to be established (via regulations, regulatory guides, and consensus standards).

- At present, state-of-the-art performance with highly sophisticated measurement technology is needed to meet regulatory requirements, i.e., there is very little margin for error. Field performance requirements approach NBS capability. Even a best-efforts operation may therefore fail to meet SNM control requirements. To avoid such inadvertent loss of SNM control, the accuracy capability of measurement systems should be improved.

- Current practice of periodic inventories followed by after-the-fact assessment of SNM control performance will have to be converted to real-time data acquisition and analysis.

- Current pressures for licensees to operate in-house measurement assurance systems will have to be converted to viable capabilities and practices.

This latter problem is the key issue for nuclear fuels measurement assurance. The measurement assurance function is the way to attain SNM control and to prove that adequate control has, in fact, been attained. Under present conditions, even if the industry succeeds in operating the measurement systems to the limit of capability, they have no resources other than their own to prove success. Moreover, they -- and the Nation -- run the risk that failure to attain SNM control will not be proved at all or discovered too late.

Nuclear fuels measurement assurance is therefore essential, and in-house licensee systems are necessary (they are analogous to redundant, quick-response, dedicated control systems). But the in-house system must be backed by capability to independently test and verify their performance. In short, a hierarchy of nuclear fuels measurement assurance is needed. The top of the hierarchy should have responsibility and capability to oversee and certify all measurement assurance functions within the system. Since SNM control is a national need and Federal Government responsibility, this "Supreme Court of nuclear fuels measurement assurance" should be affiliated with the Federal Government.

There are options for the structure of the nuclear fuels measurement assurance system hierarchy. For example, the Federal Government's keystone operation might deal directly with the licensee's in-house systems. Alternatively, intermediary functions (e.g., state- or industry-operated) might be preferred. Our preliminary investigation of this subject indicated numerous options and no clear-cut choice. Thorough evaluation of the alternatives will be necessary.

There also is need for thorough study to determine the scope and type of services to be provided by the measurement assurance system. At present, measurement methods are highly diversified. Standardization, automation, and new developments may tend to reduce the scope of service requirements; conversely, new fuel cycle technologies (mixed oxide, HTGR, LMFBR) will tend to expand them. In general, three types of functional requirements can be anticipated: service to existing technology, assistance to development of new technology, and leadership in reduction of new technology to practice. Specific activities and the level of activity in each area can be expected to change with time.

The needs for evaluation of hierarchy options and assessment of service functions can be summarized as a need for a major system design effort. Near-term initiation of such a project would be timely: the need for nuclear fuels measurement assurance is clearly recognized, a reasonably good information base has been established, and the industry is just beginning a surge of growth and diversification.

With a system design project identified as the next appropriate step toward nuclear fuels measurement assurance, it is necessary to define who should do the project and how Federal Government responsibility for the operational system should be implemented.

Since the Federal Government has ultimate responsibility for nuclear fuel measurement assurance, it should lead the systems design effort. Two organizations have relevant expertise and responsibilities: the AEC, with its regulatory and development responsibilities for nuclear power, and NBS, with its responsibilities for the national measurement system. These responsibilities are complementary; the AEC focuses on development of capability, and NBS aims at maintenance of capability during operations. In an area such as nuclear fuel material measurements where requirements and operational capability are evolving rapidly on broad fronts, the two sectors of responsibility overlap.

Joint interaction between AEC and NBS aimed at implementing a design study project would, therefore, be appropriate. These interactions should be initiated at the policy level. They should include the fundamental issues of scoping and allocation of Federal Government responsibilities.

These AEC/NBS interactions should also consider areas such as effluent monitoring, dosimetry, radiation medicine, and quality assurance which are also measurement-oriented functions and share many measurement assurance requirements and measurement technologies with nuclear fuels. Long-run economies and better public safety might be obtained if a comprehensive measurement assurance system embracing all areas were the initial goal.

ASSESSMENT OF THE NUCLEAR FUEL MATERIALS
MEASUREMENT SYSTEM

INTRODUCTION

This document reports the results of a comprehensive survey and evaluation of factors concerned with measurements for nuclear fuel materials.

The study is representative of NBS efforts to establish a rationale for Federal Government, and NBS in particlar, involvement in industry's measurement activities. Nuclear fuel materials were selected for study through recognition that developments in nuclear power technology and regulation might have major impact on the Government's measurement-related responsibilities.

Nuclear fuel material measurement activities are impacted by many factors. For example, accuracy of measure for a ton of coal or a barrel of oil is dictated primarily by economic forces associated with trade equity; accuracy of measure for nuclear fuels is additionally affected by stringent health and safety requirements and the highly sophisticated technology involved in its use. As a result, this assessment of the measurement system for nuclear materials had to consider a broad range of regulatory, technical, and business interests. Extended discussion of these factors is given in the appendices; the report highlights the key items.

Information summarized by this document was obtained primarily by interaction with representatives of nuclear industry corporations and associations, the AEC and personnel in its prime contractor laboratories, and NBS personnel currently engaged in programs related to nuclear fuel material measurements. Over 200 interpersonal contacts were made. The literature of current events in nuclear power was also an important source of information.

As the report shows, the need for security and control of special nuclear materials dominates nuclear fuel measurement activities. The measurements are part of a comprehensive safeguards system wherein requirements and technology are evolving rapidly as a result of increased interest in and resources applied to nuclear materials control.

The report therefore does not dwell on technical details; we can expect that current measurement practices and methodology will rapidly evolve to improved levels of capability. The major thrust of this report is to aid effective development of measurement-related activities through description of the in-context role of nuclear fuel material measurements.

FACTORS SIGNIFICANT TO NUCLEAR FUEL MEASUREMENTS

Industry Characteristics and Status

Nuclear power is entering a period of rapid growth and diversification expected to make it the mainstay of U. S. electrical generating capacity by the turn of the century. The present status is analogous to the beginnings of the automotive industry. The challenges faced are analogous to those of the aircraft industry: develop a high-risk, complex technology into a safe, reliable capability to serve a large consumer market economically.

In comparison with fossil-fueled systems, nuclear power is highly complex. A sequence of fuel preparation operations (mining, milling, conversion, enrichment, and fuel element fabrication) is necessary. Also, spent nuclear fuel (the "ashes") contains residual fissile materials economically worthy of recovery (fuel reprocessing and recycle). Despite these complexities, fuel costs for nuclear power are so comparatively low that the overall system is economically competitive with fossil-fired systems. Comparative environmental impact and safety characteristics of these energy supply technologies are being debated.

The commercial U. S. nuclear power industry currently uses slightly-enriched uranium dioxide as the reactor fuel. This fuel is used in two basic types of power plants: pressurized water and boiling water. Both are designated as light-water cooled reactor (LWR) concepts. In the future, the number of reactor concepts in commercial use is expected to diversify. High-temperature gas-cooled reactors (HTGRs) and liquid metal cooled fast breeder reactors (LMFBRs) are expected to come into commercial use before the turn of the century. The HTGR and LMFBR systems promise more efficient use of fissile fuel resources than an all-LWR economy.

An aspect of this diversification that is of potential significance to fuel measurements is the fact that the LWR, HTGR, and LMFBR fuel cycles require different technologies. Measurements and material standards needed for each may therefore differ. From this point of view, still another fuel cycle requiring different measurement capabilities and material standards can be identified: the LWRs will, in the future, probably use mixed-oxide fuels, i.e., mixtures of uranium and plutonium oxides. The safety and economics of this "recycle Pu" fuel cycle are currently being evaluated by the AEC.

The U. S. nuclear power industry is currently experiencing growth pains. In perspective, both key components of the industry (i.e., the AEC and the industrial licensees) are on steep learning curves. Many licensees and would-be licensees are entering the arena for the first time; competence levels of the participants vary widely. All, however, are facing a drive for upgrading safety and reliability that is producing instabilities and adversary situations.

License requirements are changing rapidly and escalating ("ratcheting"); retrofitting is being demanded; some basic policy decisions (involving recycle Pu, private ownership of enrichment plants, and waste management) that will have strong impact on business decisions have not been made; manpower and quality assurance are major problems; a massive effort to develop consensus standards is underway; proposals to reduce lead times are being debated and the intervenors clamor ever louder. The net result is a strong preoccupation with day-to-day problems.

An action that impinges strongly on measurement interests is the recent revision of regulations concerning security and accountability of nuclear fuel materials. In an attempt to prevent theft and subsequent consequences, requirements for nuclear materials control have been tightened to the point where some licensees may find it difficult or impossible to stay in business. The consequences of this regulatory action are not yet fully visible; the AEC initiated review of licensees' compliance plans early in 1974, and licensees are in process of developing compliance capability.

Planning and action toward these fuel material control requirements has been in progress for many years. In recognition of the need for measurement capability to make compliance feasible, the AEC funded R&D on measurement technology during past years. They reported and described the products of these programs at technical symposia held in 1973.

Measurement Technology

Measurement technology sufficient to enable current nuclear industry operations to achieve compliance with regulations exists. Existence does not necessarily, however, imply practical availability and use. The technology is highly sophisticated; many licensees simply do not have the skilled manpower needed to use it. Most of such talent is in the national laboratories.

Instrument vendors are expected to commercialize the technology and supply the industry. They also can be expected to go as far as possible in meeting industry's desire for rapid, automatic, and fool-proof systems. The business is highly competitive; new systems can be developed and marketed in a matter of months. In the near future, however, production capacity may limit the rate at which industry can obtain the systems they need for compliance.

Delivered measurement systems will have to be backed by technical assistance and service capabilities. Some industry representatives think the services available today are not what they should be. If indeed the services do not keep pace with need, many of the instruments might be used inadequately or improperly.

Measurement Assurance

Measurement assurance provides methods and services to test the accuracy of measurements. Calibrations, insertion of "unknowns" into the work load, and diagnostics to uncover bias are typical measurement assurance functions.

As routine practice, operations in the nuclear industry will maintain an in-house measurement assurance program. At present, however, there are no comprehensive national guidelines for these functions; each operator does what he thinks is best. Current practice ranges from minimal instrument calibration procedures to comprehensive (but still in-house) nuclear fuels measurement assurance (NFMA) systems. There is no nationally-based, hierarchical NFMA system.

A nationally-based NFMA system is implictly required by the regulations and regulatory guides for fuel materials accountability. An NFMA system is also called for in present and anticipated ANSI standards and the International Atomic Energy Agency (IAEA) agreement for member states. To date, however, the structure and functions of an NFMA system have not received much attention. For example, the IAEA agreement calls for an international system of standards and measurement control which does not exist.

A prototype of a national NFMA system now exists. It is the Safeguards Analytical Laboratory Evaluation (SALE) program operated and administered by the AEC. Under SALE, working standards, unknowns, etc., are issued under authority of the AEC's New Brunswick Laboratory (in process of moving to Argonne). The working standards and other materials used in SALE, which embraces all AEC labs but only 24 licensees, are backed by standard reference materials (SRM's) issued by NBS. The SALE program therefore provides "NBS traceability," i.e., a chain of measurement assurance based on the best materials standards available, to some of the industry. However, the AEC was expected not to fund licensee participation in SALE after FY 1974.

Guidance for Measurement Practice

Procedures and methods for nuclear fuel material measurements are guided by ANSI standards and the AEC's Division 5 Regulatory Guides. These sources of guidance are complementary; the regulatory guides reference the ANSI standards and add supplementary recommendations.

The standards and guides are at present far from complete as a basis for measurement operations. A massive standards development effort is underway; present schedules anticipate substantial completion over approximately the next two years. Similarly, about half of the anticipated Division 5 Regulatory Guides have been issued.

The Division 5 guides currently available include some on assay methodology but emphasize physical security of special nuclear materials. Future guides will place more emphasis on assay techniques, including non-destructive assay. They also will include a guide entitled "Measurement Control Program for Materials Accounting in Nuclear Materials Processing Plants." This guide will focus on measurement assurance. The title implicitly indicates it will be aimed at the licensees' in-house measurement assurance operations. If so, a nationally-based hierarchy of nuclear fuels measurement assurance will be left to be a subject of future action.

The standards and regulatory guides inherently delegate responsibilities and problems of implementation to the users. This is, of course, conventional practice. This "policy of non-interference" may not, however, be appropriate for nuclear material processing plants. For one thing, the regulatory requirements for SNM control are so stringent that the measurement systems must be routinely operated at or near state-of-the-art capability. This means that the licensee has very little margin for error; mechanical and human deficiencies must be essentially non-existent.

The difficulties associated with achieving good measurement performance are paralleled by the potential difficulties associated with failure to achieve it. Not only is the licensee at risk with respect to compliance, but until proven otherwise, the Nation is at risk from escape or theft of nuclear material. Note also that the proof of materials control must include a high level of measurement competence. For example, it should in practice be possible to demonstrate that an acceptable (re compliance) quantity of material unaccounted for (MUF) is not the result of offsetting bias and accounting errors.

For the reasons outlined above, it appears that guidance for nuclear fuel materials measurement practice should extend beyond the norm. The regulatory guides are a step in this direction, but even they do not provide the proof of performance that is needed. Nuclear fuel materials measurements <u>must</u> be accurate in order to preclude adverse consequences. The only way to achieve real-time testing and verification of accuracy is with an active measurement assurance system that itself can be proven to be functioning properly.

<u>Equity in Trade</u>

The numerous operations in the nuclear fuel cycle produce several exchange points where a shipper transfers fuel material to a receiver. Both parties in a transfer are required to measure the mass and composition of material involved (see Regulatory Guide 5-28).

In present industry operations, the need to satisfy regulations on fuel materials accountability is most stringent, i.e., the monetary value of "lost" material is comparatively negligible. When the reactor operator purchases fresh fuel, his interest in the dollar value of the fuel material is submerged in his interest in the in-service integrity and performance of the fabricated fuel elements. Similarly, his concern for values to be reclaimed from spent fuels are at least matched by the reprocessor's need to demonstrate SNM accountability. In general, equity interests will be adequately served within the total framework of accountability requirements and contractual agreements.

Since the U. S. currently has no operational commercial reprocessing facilities, relatively few opportunities for equity in trade problems have arisen. (A current, critical need is to maintain good data on spent fuel in storage.) In the future, problems may arise due to pooling of fuel materials. For example, one reprocessor anticipates operation so that fuel owners do not "get their own atoms back." The fissile content and dollar value of spent fuel is dependent on fabrication and exposure history; we can expect no two batches of spent fuel to be the same. Arrangements will therefore have to be made to assure that the fuel owner receives values from the mixed-pool reprocessor's product appropriate for the values in the spent fuel he supplied. Various contractual devices are available to achieve this equity, but actual achievement will depend on capability to make high-accuracy measurements on the fuel materials involved.

ASSESSMENT OF FUEL MEASUREMENT STATUS AND NEEDS

The most significant items among the factors significant to nuclear fuel materials measurements can be summarized as follows:

- The need for SNM control and accountability dominates nuclear fuel material measurement activities.

- Current measurement technology must be utilized at or near state-of-the-art limits in order to achieve compliance with SNM control requirements.

- To avoid after-the-fact evaluation of measurement performance and to avoid even the possibility of escape or diversion of nuclear materials, real-time verification of measurement accuracy is necessary. However, such capability does not now exist.

- Testing and verification of accuracy are functions of measurement assurance. The need for measurement assurance is widely recognized in standards and other guides to measurement practice, but only the first steps toward an adequate measurement assurance system have been taken.

On this basis, the most important characteristic of the nuclear fuels measurement system today is the need for a comprehensive, nationally-based measurement assurance system.

The first step toward adequate nuclear fuels measurement assurance, i.e., development of in-house programs, is an important one. Such systems are essential for the real-time control that is needed to fulfill the intent of the regulations.

The in-house systems cannot, however, stand alone. If they are not backed with a hierarchy of authority and capability, the operators have no independent way to demonstrate that the measurement systems under their control are functioning properly. They -- and the Nation -- run the risk that failure to attain SNM control will not be proved at all or will be discovered too late.

The Federal Government has ultimate responsibility for SNM control. Delegation of responsibility for first-line control to licensees is an essential feature of the Federal responsibility. But responsibility to prove satisfactory operation of the entire system cannot be delegated. The Federal Government must therefore maintain a capability dedicated to oversight and independent proof testing of the SNM control activities in the industry.

A hierarchy of nuclear fuels measurement assurance with ultimate responsibility and capability within the Federal Government should therefore be implemented. The Federal capability should embrace all measurement practice and be highly responsive to, if not in fact lead, new developments in measurement technology.

The nuclear fuels measurement assurance system hierarchy can evolve by design from current operations such as the AEC's SALE program and the licensee's in-house measurement assurance programs. Part of the design development effort should be aimed at improvement of the data acquisition and data analysis systems. Current practice of periodic inventories to measure MUF permits at best after-the-fact discovery of deficiencies rather than the real-time accuracy verification that is essential for positive SNM control.

Improvement of data systems should include attention to improvement of the dangerously small margin between practical limits of capability and performance requirements. To assure SNM control by having measurement uncertainties that fall within the range of regulatory requirements, the accuracy capability of measurement systems should be improved. Studies aimed at determining requirements for improved accuracy are currently underway at Brookhaven National Laboratory.

Development of technical and administrative capabilities for SNM control will have to be accompanied by development of appropriate guides to practice. Needs for SNM control are current, but the essential standards and guides will not be available for several years if present schedules are followed. The problem is complicated by the fact that measurement technology is evolving so rapidly that the standards and guides may be out of date when issued.

Another critical underpinning for successful operation of a measurement assurance system is availability of reference standards for instrument calibration. Development of automated, non-destructive assay systems is creating new needs for these reference standards. Geometry as well as composition is important for such standards. It is also, of course, essential that the standards be certified. A licensee may develop his own reference standards, but there must be an independent capability to certify them. This capability obviously must lie outside and above the licensee in the measurement assurance hierarchy. This outside capability must also anticipate need for services to certify licensee use of reference standards it develops.

In summary, this study's assessment of the current measurement system for nuclear fuel materials is that a comprehensive measurement assurance system with keystone operations in the Federal Government is needed. The system should be aimed at measurement control and verification for real-time data acquisition and data analysis. Design and operation of the measurement assurance system must incorporate consideration of requirements for reference standards and guides for measurement practice.

PATHS TO IMPROVED PERFORMANCE

Participants and Responsibilities

Since the Federal Government has ultimate responsibility for control of nuclear fuel materials, it should lead development of the measurement assurance system.

Two organizations have relevant expertise and responsibilities: the Atomic Energy Commission, with its regulatory and developmental responsibilities for nuclear power, and the National Bureau of Standards, which is responsible for the national measurement system. Development of a national measurement assurance system for nuclear fuel materials would involve extension of past activities in both organizations.

AEC and NBS responsibilities and skills are complementary. The AEC focuses on development of capability, and NBS aims at maintenance of capability during operations and provision of reference standards needed for practical use of measurement systems. Since functional requirements and technology for nuclear fuel material measurements are evolving on broad fronts, the AEC and NBS sectors of responsibility are both needed for effective development of a measurement assurance system.

Development of the measurement assurance system should include licensee participation. The licensees will have to maintain comprehensive in-house measurement assurance capability. Problems in designing these functions and linking them to the national hierarchy will be minimized if the licensees participate throughout the development process. The licensees can also contribute expertise on practical in-service considerations such as personnel capabilities. Ways the users of the measurement system can contribute to its development are outlined below.

Identification of Measurement Assurance Needs

A major problem to be faced by developers of a national NFMA system is determination of the scope and type of services to be provided. Four generic types of services can be anticipated: (1) calibrations; (2) round-robins to check performance; (3) corrective-action assistance; and (4) development of working standards. Specific service requirements in each category will be difficult to assess and may be large in scope because the various licensees each have individual approaches to measurement. In other words, needs for services approach being as numerous as licensees and operations in the fuel cycle. Even if standardization significantly reduces the broad spectrum of measurement methodology currently in use, implementation of the recycle-Pu, HTGR, and LMFBR fuel cycles will tend to expand the spectrum.

Aside from standardization and diversification effects, two factors will govern NFMA service needs: longevity of methods in use, and addition of licensees and their facilities to the industry. With the exception of the utilities' power plants, proliferation of licensees and facilities is projected not to be great. For example, two or three additional reprocessing plants can be expected to meet needs to the turn of the century. Expansion and diversification of fuel fabrication capacity will probably occur largely at existing sites and with existing licensees. Thus, accrual of new licensees and unique measurement methods is expected to be minimal.

Standardization and new products from instrument vendors will probably tend to shrink NFMA service needs from present dimensions. The advantages of real-time measurement systems will outweigh the capital costs of installing them. Thus, the longevity of current systems may be brief; basic NFMA service needs may soon be less than would be estimated for current practice. In-depth assessment of needs will be essential, however.

The best way to assess NFMA service needs accurately is to obtain input from the users. One way to do this is with Delphi-type questionnaires. Another, which was considered for inclusion in this study's activities, is a workshop. Use of the workshop concept in this study was abandoned after discussion with experts on such functions. They pointed out that the only way to get the information sought is to (a) avoid competition-induced inhibitions by having only one company present, and (b) include all company interests (e.g., management, finance, technology, production) in the discussions. With these ground rules, numerous workshops would be needed, even if relatively few representative companies were selected.

Whatever the technique selected, assessment of NFMA service needs will be a major task. The assessment must be conducted by experts. The assessment methodology will have to accommodate and reflect the current and dynamic state of nuclear fuels measurement technology.

Selection of Measurement Assurance System Structure

The national measurement assurance system for nuclear fuel materials will necessarily have two basic components: the licensees' in-house systems, and a "Supreme Court of measurement assurance" operated by the Federal Government. Between these extremes, alternative structures of activities and responsibilities within the hierarchy are possible. A basic task for development of the national system is to select the preferred hierarchical structure.

The basic function of the hierarchy is to provide a chain of accuracy testing and verification that stretches from user measurements to the best-available standards. An important constraint is that calibration and other technical services will usually have to be taken to the user, i.e., the measurement systems are not portable.

"Best-available standards" may be working standards or NBS-issued SRM's. Working standards for which physical geometry as well as composition (elemental and isotopic assay) are important and have a key and growing role in the nuclear industry. Major responsibility for such standards currently lies with the AEC's New Brunswick Laboratory; these standards are based on SRM's.

Alternative participants in the national hierarchy include NBS, the AEC (e.g., via extension of its SALE program), state-operated facilities, Federal Government-operated regional facilities, and industry-operated facilities (one or more locations). In each case, the Federal Government would have responsibility to certify the intermediaries which would in turn certify and service licensee operations.

State-operated intermediaries would at present suffer the disadvantages of uneven or non-existent competence. Industry-operated facilities would have to be developed from scratch but would probably be most responsive to user needs. Regional Federal facilities could be set up within the national laboratories but might be ponderous and bureaucratic. In summary, no concept for delivery of NFMA services at present has a clear-cut advantage.

This study's exploration of the licensees' viewpoints on the structure of the measurement assurance hierarchy suggested that they would be largely indifferent to the origins of NFMA authority. They would follow whatever procedures are necessary to obtain and maintain their licenses. They would expect, however, that delivered services would be appropriate to their needs.

Measurement Assurance System Design Project

Development of a national measurement assurance system for nuclear fuel materials measurements will require a project dedicated to (a) design of the system, and (b) definition of procedures and resources required for its implementation.

Since AEC and NBS share authorities and expertise for nuclear fuel measurements and measurement assurance, they could share the project effort.

Three major project tasks can be anticipated, details of which could be developed by AEC/NBS interaction prior to initiation of the program:

1. Definition of measurement assurance service needs. This task is aimed at determining the functional requirements for the measurement assurance system. Users of the services should participate in the assessment effort.

2. Selection of the measurement assurance system structure. Activities in this task will be directed at defining and evaluating alternatives for the structure of the measurement assurance system.

3. Detailed design of the measurement assurance system. This task will identify facilities, staff, equipment, organization, activities, costs and cost recovery methods for the measurement assurance system selected by Task 2. It will also develop a blueprint for implementation.

Our preliminary estimate is that this project will require two years for completion at an annual cost on the order of $250,000.

This program and related measurement assurance activities should be implemented through AEC/NBS dialog at the policy level. These policy discussions should establish a base and framework for continuing policy and operational interaction in areas such as nuclear fuels measurement assurance where the AEC and NBS have collaboration responsibilities.

Related Areas

Activities for this study of the nuclear fuel materials measurement system produced exposure to other measurement operations in the nuclear industry. For convenience, these may be classified as effluent monitoring, dosimetry, radiation medicine, and quality assurance.

Although these measurement systems were not studied in depth, we observed that they have many characteristics in common with fuel material measurements. For example, measurement technology such as gamma ray spectroscopy is widely used. The most comprehensive elements of commonality are that all areas (a) depend on good measurement performance for effective fulfillment of responsibilities; (b) have measurement activities guided by a body of codes, procedures, and standards; (c) have compliance requirements aimed ultimately at protection of human health and safety; and (d) are in one way or another a national concern.

These commonalities -- especially the requirements to protect public health and safety -- indicate that measurements for effluent monitoring, dosimetry, radiation monitoring, and quality assurance should also be backed by a national measurement assurance system. Accuracy requirements in these areas are not as stringent, or in some cases even as feasible, as for nuclear fuels. However, good measurement performance within the appropriate framework is just as important as for nuclear fuels. There is substantial evidence that in conventional practice measurement performance in these areas is not all it can be or should be. The deficiencies can be eliminated with measurement assurance systems.

Although this study has been focused on nuclear fuel materials measurement assurance, we infer that there is across-the-board need for measurement assurance systems for radiation-oriented measurements. Consideration should therefore be given to expanding the recommended measurement assurance system design project to include all measurement categories. This approach could be expected to effect long-run economies, but it would of course expand the resources required for the near-term design activities. However, because of commonalities in the measurement categories, the incremental costs of the expanded effort should be significantly less than the benefits obtained.

ACKNOWLEDGMENTS

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Many people contributed their time, expertise, and viewpoints to this effort. The study would not have been possible without their help.

APPENDIX A [1]

NUCLEAR POWER: PRESENT AND FUTURE

This appendix provides details on the structure and anticipated growth and diversification of the nuclear power industry under the following headings:

Installed Capacity
Nuclear Fuel Materials
The Nuclear Fuel Cycle
Waste Management and Transportation
Fuel Element Fabrication
Role of Measurements

Installed Capacity

Nuclear power plants currently supply less than 10% of the Nation's demand for electrical energy. Rapid expansion of installed capacity is forecasted, however. Projections differ in detail, but the consensus order-of-magnitude estimates are that new plants, each with capacity of approximately 1000 MWe, should come on line at a rate of about one per three weeks through the 1980's and one per week through the decade of the 1990's. Total installed nuclear capacity by the year 2000 is estimated [(1)] to be on the order of 1000 GWe, corresponding to about 1100 units. Forty-five units are on-line today. Estimates of future installed capacity are tending downward, in recognition of licensing and intervenor delays and reduced demand.

Major incentives for nuclear energy as the principal source of future electrical power are expectations of lower cost and lower pollution in comparison with fossil-fired plants. Risks are assumed to be acceptable, and no major new substitution technology (e.g., solar or fusion power) is foreseen for at least 20 years.

Nuclear Fuel Materials

Present U. S. nuclear power plants operate with uranium dioxide as the fuel material. Future reactors will, however, probably use a diversity of fuel materials. The diversity is highly significant to measurement interests because of differences in fuel assay requirements (elemental and isotopic combinations) that will exist.

The four major types of nuclear fuels expected to be in use are:

- UO_2 (present technology) for water-cooled reactors (LWR's)
- recycle Pu (mixed U, Pu oxides) also for LWR's
- U-Th fuels for gas-cooled reactors (HTGR's)
- Pu fuels for sodium-cooled breeders (LMFBR's)

Estimates of when and how much the advanced concepts will come on line vary widely. In practice, implementation will depend on economic forces in the industry. There is consensus, however, that all four types will be in use by the turn of the century.

[1]Of Bartlett (1974).

The Nuclear Fuel Cycle[2]

Nuclear power is distinguished from fossil power by the nuclear fuel cycle. The cycle exists (Figure A-1) because spent fuel removed from the reactor contains unused and "bred" fuels economically worthy of recovery. These fuel materials are recovered in reprocessing plants and recycled to either the enrichment plant (uranium) or the fuel fabrication plant (plutonium) for use in future generations of fuel elements.

The fuel cycle is not in use today; there are no U. S. reprocessing plants in routine, commercial operation. One is, however, in design, and one that previously operated is shut down for modifications to increase capacity. Another that was expected to be in service this year now appears inoperable. Future viability of the fuel cycle and reprocessing is indicated by the fact that estimates of need for additional reprocessing capacity (above that which currently planned plants can provide) by the mid-1980's are widely accepted.

Each type of reactor (LWR, HTGR, LMFBR) expected to be in commercial use requires its own technology in each fuel cycle operation. Measurements and material standards will therefore be different for each type of reactor and its associated fuel cycle.

Waste Management and Transportation[3]

At present, radioactive wastes are generated at relatively low levels. Shipments of spent fuels and waste are relatively infrequent; the spent fuels are retained in storage basins at the reactor sites pending operation of the reprocessing plants.

In the future, however, generation of wastes will accelerate at a rate commensurate with the growth of operational capacity throughout the fuel cycle. Transport of radioactive materials will accelerate even more rapidly because each operation generates several types of waste, and handling procedures differ for each type.

A major area of concern (reflected by rapidly growing R&D budgets) is the so-called high-level waste produced at reprocessing plants. This waste contains the highly radioactive fission products from spent fuel. Present plans call for solidification and shipment of this waste to central repositories. These repositories will be few in number (perhaps only one). The frequency of shipments from the reprocessing plants will be high, and distances to be traveled will probably be large.

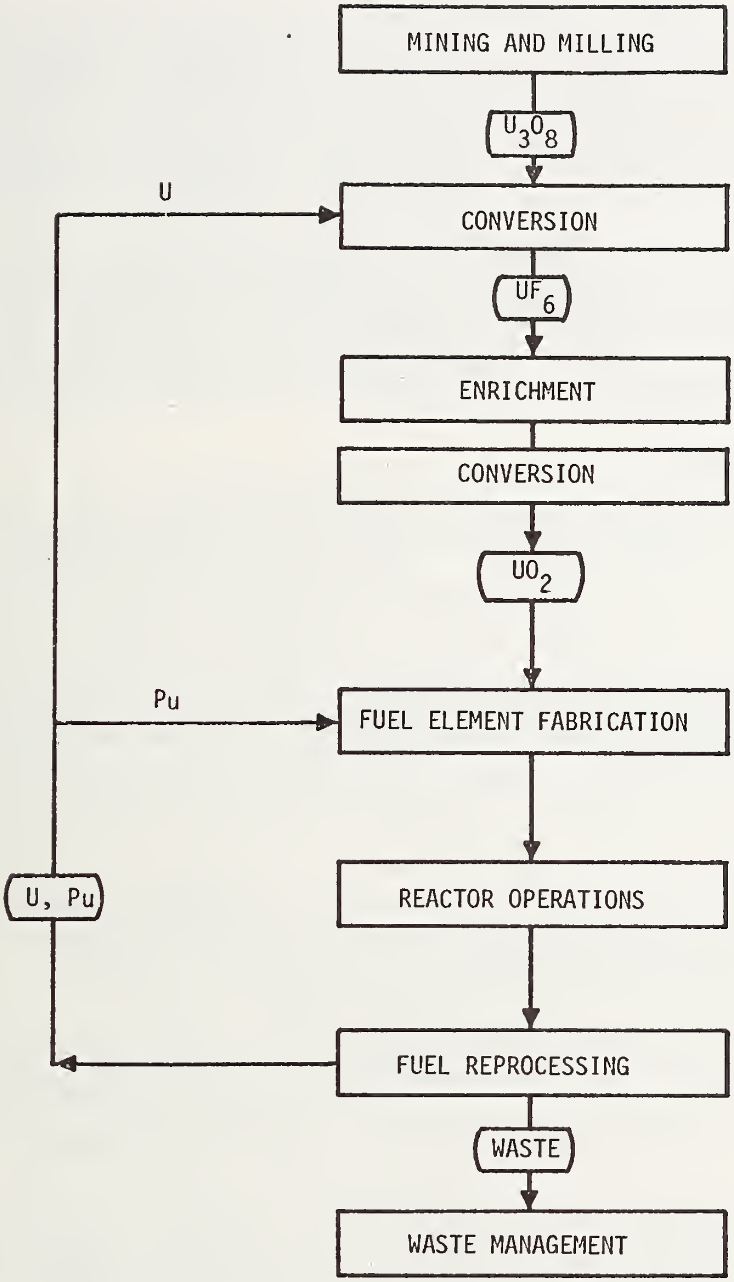

Figure A-1

Operations in the Nuclear Fuel Cycle

An unresolved problem associated with the high-level waste is its actinide content. With present reprocessing technology, the waste will contain actinide elements in concentrations sufficient to dominate the potential long-term biological hazard. They also extend the persistence of hazard from the order of a thousand years (fission products alone) to millions of years. A decision to limit the actinide content of high-level waste to extremely low levels could pose the most challenging technology and measurement problems in the industry.

Low-level wastes will be generated in volumes and masses much larger than those for high-level waste. They frequently contain low concentrations of actinides inhomogeneously distributed. Actinide assay is essential, however, for material balance and accountability purposes. Such measurements are extremely difficult to make with good accuracy; errors are typically on the order of ± 50%. Development of working standards and improved accuracy is a major challenge for the future.

Fuel Element Fabrication

This operation in the fuel cycle is given special consideration because of its pivotal role in operational reliability and shipper/receiver equity.

A key action in the nuclear industry is the contract between the utility and the fuel supplier. From the utilities' point of view, megawatts are purchased; the total is specified in terms of reactor power rating, capacity factor, and fuel endurance (burnup achieved, in megawatt-days per metric ton, MWD/T) prior to removal of fuel from the reactor. The fuel fabricator translates these specifications into a core design which is defined in terms of the spatial distribution of fissile material in the core, fissile concentrations in the individual fuel pellets, and mechanical integrity of the as-fabricated fuel elements.

In the absence of external problems such as non-nuclear plant outages, achievement of specified power outputs depends on how well the fuel fabricator does his job in core design and fabrication. Theoretical core design is now a highly-sophisticated and highly-accurate process; the major problem is to convert theory into materials and operational hardware.

Modern computer-based core design techniques permit specification of axial and radial gradients in fuel loadings (fissile concentrations in the fuel pellets). Construction of a core in accordance with such specifications requires fabrication of pellets with different fissile assays and location of these pellets in the right place in the core. This is a complicated and difficult task.

A BWR-6 core (standard GE design), for example, will contain approximately 14 million fuel pellets with on the order of a dozen different assays. These pellets are distributed in over 48 thousand fuel rods arrayed in 756 fuel elements. Each type of fuel pellet must be put in its proper place in this array.

If inventory and accountability procedures necessary to assure proper placement of the fuel pellets are assumed adequate, the next major problem is to fabricate the fuel elements with integrity to avoid failure during design-life service. This is one of the major operational and contractual problems in the industry today. Fabrication shortcomings are expected, tolerated, and the linch pin of contractual agreements. The usual "level of acceptable failure" is 1%. General Electric is seeking assured reliability of 99.95%; even at this level of quality, the typical BWR-6 core will contain approximately 70,000 substandard fuel pellets and 240 failed fuel rods.

Fuel element failure in service in indexed by measurement of fission product concentrations in the reactor coolant. Such measurements are therefore the basis for potential contract disputes. Accuracy of measurement on a given coolant sample may be high, but such samples are of questionable reliability as an index of core phenomena. Since millions of dollars are at stake in a decision to shut down, remove failed fuel, and seek restitution from the fuel supplier, these coolant measurements have a key role in the operational economics and reliability of nuclear power.

Assays of fuel pellets in the as-fabricated core are important not only to in-service performance but also to subsequent shipper/receiver transactions in the fuel cycle. The fissile content of spent fuel at discharge (total value of several million dollars per discharged batch) is calculated using the as-loaded assay values as a starting point. These calculated results are the basis for shipper/receiver equity transactions between the utility and the reprocessor.

At the GE reprocessing plant at Morris, Illinois, (which is the one apparently inoperable) these calculated values were expected to be the sole basis for utility-reprocessor contracts (the reprocessor usually guarantees 99.5% recovery of fissile values). The basis for this approach was an attitude that the assays of the as-fabricated core are the most accurate fuel assay values in the fuel cycle.

Other reprocessors will rely on assay of as-received spent fuel after dissolution as the basis for their contractual obligations. The problems with this approach are similar to those for the coolant assays. Although measurements on the sample can be highly accurate (a factor of ten better than the burnup-based calculated values), the sample may be unreliable because of peculiarities of plutonium chemistry. High-accuracy calibration of the accountability tank volume is also difficult to achieve.

Role of Measurements

The above expositions illustrate the fact that fuel materials measurements are fundamental to the economics and reliability of nuclear power. They are also, as discussed below, fundamental to safety as interpreted by safeguards and accountability requirements. An important present and future concern for all aspects of the nuclear industry is therefore the capability to make measurements of requisite reliability.

Present fuel materials measurement technology can, in principle, meet most existing needs (the major exception is low-fissile-content waste). In other words, when existing measurement methods are used properly in the existing framework of fuel cycle operations, materials specifications, regulatory requirements, and standards, they can produce data with accuracy sufficient for needs.

There are, however, current problems in achieving proper use. Skilled manpower is in short supply. Opportunities for human error are numerous. Instrument availability is sometimes limited. Costs are high and inimical to good measurement practice. The net result is that current performance is very uneven. Some operations consistently produce reliable data; others rarely do.

These barriers to good measurement performance will persist in the future unless improved measurement systems are developed. Industry is pressing (and being pressed by regulatory requirements) for measurement systems that are more economical, reliable, and fool-proof. There is need and desire for increased use of non-destructive assay (NDA) techniques and real-time data acquisition and analysis. The instrument suppliers are moving to respond to these demands. Their response will, however, have to include development and delivery of capability to meet new demands stemming from introduction of HTGR and LMFBR fuel cycles, tighter specifications and regulations, and overall rapid expansion of the industry. This delivery of in-service measurement capability will have to be preceded or accompanied by appropriate R&D and preparation of reference materials standards.

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APPENDIX B[1]

THE INSTITUTIONAL ENVIRONMENT

The nuclear industry is currently far from maturity and stability. All aspects of industrial operations and the external constraints are on learning curves. Institutional interactions are therefore highly dynamic. They will have major impact on future industrial operations and Federal Government programs.

The basic driving force for actions and reactions that may ultimately impact programs concerning nuclear fuel material measurements is the current concern with nuclear materials safeguards and accountability. In the absence of this pressure, there would be no story to tell; industry would give measurements and measurement assurance no more attention than economically necessary. The drive for nuclear materials accountability will, however, make fuel materials measurements one of the industry's major concerns and costs.

The pressure for accountability has several sources. To the U. S. nuclear industry, the most visible are the AEC regulatory requirements. Recently promulgated regulations set material-unaccounted-for (MUF) and limit of error on MUF (LEMUF) requirements that are much tighter than previous requirements. The industry will be able to meet these requirements only if elaborate inventory and accounting procedures are installed and the best of current measurement technology is used to the limit of its capability.

The new regulations permitted licensees initially to submit plans for compliance in lieu of immediate compliance. Most, if not all, licensees exercised this option. The AEC started review of these plans early in 1974. Indications are that strict enforcement is intended, to the extent that operations incapable of achieving compliance will be allowed or forced to shut down.

Consensus standards such as produced by ANSI are another source of pressure for improved measurements. These standards can be said to represent reduction of regulatory requirements to practice. A massive effort to develop consensus standards for all aspects of the nuclear power industry is underway. Output and progress are slowed, however, by the fact that these standards are developed primarily as a result of moonlighting activities of the participants. On a relative basis, development of the consensus standards relevant to fuel materials accountability and measurements has just begun.

A third force for improved accountability is the International Atomic Energy Agency (IAEA). In the past, an IAEA role has not been highly visible in the U. S. Visibility that has existed can be described as negative: U. S. industry views IAEA laxity in comparison with our AEC as a cause for loss of competitive position on overseas markets.

Present and anticipated accountability requirements from all sources contain a common thread that is potentially of great importance to fuel material measurements. That is, requirements implicitly or explicitly call for a measurement assurance system.

The basic function of the measurement assurance system would be to validate fuel materials measurements data and thereby demonstrate compliance with regulatory requirements. Basic components of such a system are (a) means to test and verify the accuracy of data obtained with each specific measurement apparatus, and (b) programs and procedures for periodic testing of measurement performance (e.g., unknowns, round-robins, etc.).

[1]Of Bartlett (1974)

A licensee can, in principle, operate his own measurement assurance system. In fact, such systems are a part of the compliance requirements. These in-house activities should, however, be regarded as secondary systems. A primary system which is nationally -- or internationally -- based and of unquestioned reliability is necessary to fully demonstrate industry-wide compliance and materials accountability. This "Supereme Court of measurement assurance" must be operated or at least backed by authority and competence within the Federal Government. If IAEA regulatory tie-ins are significant, international measurement assurance tie-ins should be equally significant.

A prototype of a national measurement assurance system now exists. It is the Safeguards Analytical Laboratory Evaluation (SALE) program operated and administered by the AEC. Under SALE, working standards, unknowns, etc., are issued under authority of the AEC's New Brunswick Laboratory (in the process of moving to Argonne). The working standards and other materials used in SALE, which includes only 24 licensees, are backed by Standard Reference Materials (SRM's) issued by the National Bureau of Standards. The SALE program therefore provides "NBS traceability," i.e., a chain of measurement assurance based on the best materials standards available, to some of the industry.

Since SALE reaches only some of the licensees affected by 10 CFR 70 requirements, it would have to be expanded to serve as the national measurement assurance system. Furthermore, it or any similar system will have to be diversified as recycle Pu, LMFBR, and HTGR fuel cycles come into commercial use. These fuel cycles will require new, additional SRM's and measurement technology.

Industry contacts made during this study revealed no opposition to the concept of a national measurement assurance system. Reactions did, however, range from "What is it?" to acceptance. Conspicuous by its absence was any sense of urgency to implement such a system.

Lack of urgency could be the result of several factors. One obvious possibility is that institution of a measurement assurance system will produce cost and manpower headaches (for both the industrial and governmental sectors) that are seen to be avoided as long as possible. For industry, the full impact of the tighter regulations and the AEC's attitude toward enforcement has not yet been felt. For the AEC, until recent publicity on nuclear materials control, the pressures of current business and existing commitments impeded a detailed look at measurement assurance. For NBS, application of the concept to nuclear fuel materials could require new activities and programs.

Many institutional entities have interest in nuclear fuel materials control and therefore, presumably, nuclear fuels measurement assurance. Major interests include:

- AEC Regulatory. The Directorate of Regulatory Standards promulgates regulatory guides (Division 5) that provide the basis for selection and use of measurement systems.

- AEC Operations and Development. The newly-formed Division of Safeguards and Security will administer R&D for physical security and nuclear materials control techniques and equipment. The fact that this Division was formed despite pending major organizational changes (i.e., formation of ERDA) is indicative of the importance of nuclear materials control.

- American Nuclear Society (ANS). Represents the technical interests of the nuclear industry. Deeply involved in development of nuclear standards.

- American National Standards Institute (ANSI). Work on development of nuclear industry standards is extensive and expanding. Many of the standards, especially those promulgated by the N-15 Committee of ANSI, deal with nuclear materials control and measurements.

- Institute for Nuclear Materials Management (INMM). This organization is the focus for technical expertise related to nuclear materials control and measurements.

- Atomic Industrial Forum (AIF). Represents the commercial interests of the nuclear industry. Also maintains in-house technical expertise.

- Electric Power Research Institute (EPRI). Represents the interests of the utilities (not the fuel suppliers, reprocessors, etc.). Interests are therefore focused on reactor site measurements such as effluent monitoring and shipper/receiver equity for fuel.

- The states. Twenty-four states are "agreement states," i.e., they have regulatory responsibilities delegated by the AEC. These states exercise regulatory control over some 9,100 licensees compared with about 9,000 materials licenses under AEC jurisdiction.

- Federal Legislative Branch. An indication of the expertise and interest that can come from this sector is provided by the following excerpt from a speech made by Senator Abraham Ribicoff before the U. S. Senate on May 28, 1974:

> "It should be noted that while the job of safeguarding commercial nuclear materials is enormously important, the job itself is manageable and well within the bounds of available technology. There are now 568 AEC-licensed facilities which are authorized to possess a total of 1,041,000 pounds of explosive plutonium and enriched uranium. But 99.8 percent of the authorized weapons-grade material is located in 97 facilities. Of these, 27 were fuel facilities where theft is considered a problem, because the nuclear materials are in a form that can be easily handled. The remaining 68 facilities are reactor sites where the fuel is highly radioactive, making theft unlikely. Furthermore, of the 27 fuel facilities, only 19 are listed by the AEC as major facilities. Thus, the present commercial safeguards efforts against theft can be focused on less than 20 major facilities, and this figure is expected to grow by another 20 by the 21st century."

Not all sectors share Senator Ribicoff's confidence that nuclear fuel materials control is "manageable and well within the bounds of available technology." Exhibit B-1, excerpted from the June 1974 issue of Nuclear Industry (published by the Atomic Industrial Forum), reflects the AEC's concern for need to upgrade nuclear fuel material control capability. Of special interest is the item referring to expedited consideration of a proposed new regulation for a measurement control program. Such action would, in effect, mandate a national measurement assurance system for nuclear fuel materials.

In summary, it is clear that the institutional environment for nuclear fuel materials measurements is in a state of evolution and contains many constituents. It is equally clear that control of special nuclear materials is currently a "hot issue." The glare of publicity may diminish, but action toward development of a national measurement assurance system for nuclear fuel materials is certain. The AEC has lead responsibility, but other institutional entities might assist the effort. Within the Federal Government, the National Bureau of Standards has expertise and responsibilities that complement those of the AEC.

EXHIBIT B-1

(from Nuclear Industry, June 1974)

AEC Grapples with a Dozen Safeguards Studies, Policy Papers

As the question of safeguards and handling of special nuclear material continued in the forefront of Senate moves on the bill to create ERDA and a nuclear regulatory commission (see story on p. 3), AEC was plunging into a massive review of the subject.

As this issue of *Nuclear Industry* went to press the Commission was grappling with more than a dozen staff and contractor studies and policy papers on various aspects of the safeguards problem. One of them, the so-called Rosenbaum Special Safeguards Study released last month (see NI for May, p. 3), was the subject of a staff assessment which was itself released this month.

On the central recommendation of the Rosenbaum report, that the adequacy of safeguards systems should be judged in terms of "design basis incidents" analogous to the design basis accidents for safety analysis, the staff agreed that the concept "can and should be applied to materials protection." But it said that "applying a risk probability value with the same meaning and significance to materials and plant protection as to a reactor accident appears extremely difficult."

Despite that difficulty the staff recommended that a "family of design basis incidents" should be developed.

"The elements and subsystems of the physical protection systems which are designed to accommodate the design basis incidents should be evaluated, as a first step," for vulnerability to a single failure, said the staff. "Alternative or redundant subsystems should be incorporated as appropriate to assure that failure of any critical component or subsystem will not result in the inability of the security system to successfully respond to a design basis incident."

Still unclear in the staff report, as in the original study, was the nature of a "design basis incident." Carried to an extreme, such a concept might involve developing specific hypothetical scenarios in which diversion or theft of special nuclear material was attempted, and demonstrating that safeguards systems would frustrate those attempts. Because of the unpredictability and variability of possible terrorist activities, such a formalistic approach would face considerable opposition.

The staff report was more specific on the question of developing "blackhat" scenarios of attempted diversion. Such "gaming analysis" has great utility and value, and should be encouraged on a continuing basis, the staff said. But the Rosenbaum recommendation that the resulting "Threat scenarios could form the basis for a simulated but dynamic testing of a licensee's SNM [Special Nuclear Materials] safeguards," was rejected by the staff.

"Threat scenarios should be developed and systems weaknesses analyzed without using 'blackhat' teams to actually attempt to steal SNM," the staff assessment said. "Such tests should not be conducted, for they not only could densensitize the guard force to the point where a real threat would not be recognized, but also could result in the loss of life."

The staff recommended that "vulnerability studies underway at present should be expanded to include 'blackhat' gaming in the areas of transportation and fuel processing plant security. In addition, in-house technical staff should be expanded to perform 'blackhat' analyses of licensee security programs as part of the licensing review process, and to use 'blackhat' studies as input to the development of new regulations. . . . Moreover, the results of these 'blackhat' exercises should be used in the development of regulatory inspection strategies."

On the question of a Federal guard force, recommended by the Rosenbaum report, the staff temporized. Because of the "increasing terrorist activities in the United States and elsewhere," the staff said, "we believe that a reassessment should be made of whether the level of protection needed is not greater than that which can reasonably be expected from a private organization, which must rely upon local law enforcement authorities to provide assistance in the event of a squad-sized attack."

The staff noted that a study of the relative merits of Federal guard forces and private guards assisted by local authorities was underway at Brookhaven National Laboratory.

Perhaps the most far-reaching recommendations from an industry point of view concern methods of inventory and materials control. The Rosenbaum study recommended that the current Material Unaccounted For (MUF) method of keeping track of nuclear material be abandoned and a system of accountability and double-checking be instituted that would allow daily accounting of material.

The staff agreed that changes should be made in the accountability program. "The need for improving material balance accounting in terms of timeliness and in both an absolute and a relative per cent basis is recognized," the staff assessment said, "and the staff is aware of the limitations of requiring periodic inventories expressed in terms of MUF and LEMUF (Limit of Error of MUF) concepts."

Additional staff papers "proposing new regulations for fundamental material controls, measurement quality control and design criteria are being developed," it added, "and will provide for much of the upgrading of material control recommended" by the Rosenbaum study.

The staff made a number of recommendations in the accountability area:

• Expedited consideration of a proposed new regulation, "Measurement Control Program for Special Nuclear Materials Control and Accounting," and development of a computer-based accounting system which would operate in "real time" rather than retrospectively. Development of this Real Time Materials Control (RETIMAC) program "should be initiated immediately," the staff said.

• Expedited approval of the proposed new regulations for Fundamental Nuclear Material Controls.

• A study of an "integrated system of internal controls including the use of tamper-safing techniques, redundancy measures, counting techniques, and modern methods of data interrogation and analysis."

• More effort in the analysis of diversion paths for each of the types of plants in the fuel cycle.

The Rosenbaum study and the staff review of it were only two of a large number of studies and activities in the safeguards field now going on. In a letter to JCAE Chairman Melvin Price (D-Ill.), AEC Chairman Dixy Lee Ray listed 15 categories of ongoing activities in safeguards. Among the more significant:

• A safeguards policy paper and a study of regulatory goals and objectives.

• A policy paper being prepared by the staff to define the interface between ERDA and NEC in the safeguards area.

• Revision of the Nuclear Material Information System (NMIS) to enable more prompt reporting of licensee inventory anomalies, and a policy of action to be taken when a licensee exceeds the new MUF limits.

• A study of the impact of the Nuclear Material Security Bureau which is currently a part of the Senate bill forming ERDA and NEC.

• Development of Safeguards Design Criteria for reprocessing plants, fuel fabrication plants and nuclear power plants.

Another activity noted by Chairman Ray was the request for legislation to allow AEC to establish clearance programs for licensees with employes handling special nuclear material.

As explained by Regulatory Standards Director Lester Rogers at a JCAE hearing this month, the legislation, part of an omnibus bill amending the Atomic Energy Act, would clearly give the Commission authority to set up such a program. Present provisions of the Act apparently give AEC some authority in this area, but a recent Supreme Court decision prohibiting security clearance programs for merchant vessel personnel casts a cloud on that authority, Rogers said.

"If the legislation is enacted," Rogers testified, "we would establish a clearance program of various levels ranging from no clearance to a full field investigation. . . . We anticipate that the cost of clearance investigations—\$7.50 for an 'L' clearance and about \$750 for a 'Q' clearance—would be borne by the licensee."

APPENDIX C[1]

INDUSTRY VIEWPOINTS AND CONCERNS

Nuclear industry viewpoints concerning fuel material measurements are dominated by two factors: compliance and costs. These subjects are closely related; at present, for example, the costs of compliance are a major concern. The new 10 CFR 70 regulations will, for most special nuclear materials (SNM) licensees, require large expenditures for physical security equipment, measurement systems, personnel, and personnel training.

Problems in any or all of these sectors could inhibit achievement of compliance. For example, measurement equipment may be in short supply because of high demand and limited production capability. The highly skilled people needed to operate the measurement systems and manage the SNM control system are in short supply. And the capital and operating costs required to implement improved SNM control systems will, at best, have at least a short-term effect on profitability (the 10 CFR 70 regulations effective in December 1973 permitted deferred compliance only for installations facing changeover costs in excess of $500,000).

As suggested above, shipper/receiver equity for nuclear fuel materials is not a major concern at present. Achievement of SNM control compliance will assure accuracy as good as or better than business equity requirements. Reactor operators, for example, appear to be satisfied if the reprocessor's spent fuel assay is "in the ballpark" with calculated values. The reprocessor must have a highly accurate assay of incoming material in order to achieve compliance with SNM accountability requirements.

One area of shipper/receiver equity not now a concern but possibly so in the future is the isotopic assay of spent fuel. The fissile content of spent fuel is a function of burnup history during reactor exposure; since economic worth is a function of fissile content, dollar value of the spent fuel is also dependent on burnup history.

Experience to date suggests that few, if any, reactors will have the same burnup history (for example, 22 reload cores have been designed; no two are the same). However, the reprocessors will probably run continuous or semi-continuous operations so that no fuel owner gets his own atoms back. How, then, is equity achieved and the total fuel need of the industry met, especially if or when plutonium recycle becomes widely used? (Pu isotopic ratios change markedly with cycle.)

There are various ways to minimize problems from this source (e.g., cash payments or credits; campaigning cores with similar calculated assays in series). The topic will, however, require management attention and economic analysis in the future.

As discussed from a slightly different viewpoint in Appendix A, the reactor operator's primary concern is in-service endurance of the fuel. Accuracy in assay of the fresh fuel is a part of this concern, but mechanical integrity is a larger part. Shutdown due to fuel element failure will cost the reactor operator several hundred thousand dollars daily in lost revenue and maintenance costs. In contrast, typical contracts limit the fuel supplier's liability to the cost of the failed fuel element (about $50,000). The reactor operator therefore has a large stake in fuel element quality assurance. Most utilities maintain strong in-house capability or hire consultants to thoroughly check quality assurance during fuel element manufacture.

[1] Of Bartlett (1974).

On the other side of the fuel supplier/user interface, the supplier's longevity in business is dependent on his reputation for product quality (reflected in reload core orders), his achievement of compliance, and process economies. The fuel supplier therefore also has a large stake in the quality of his fuel elements. To assure quality and effect economies, the fuel suppliers employ a comprehensive capability for in-process fuel material measurements. This measurement capability must also, of course, satisfy SNM accountability requirements.

The fuel supplier's measurement capability must include non-destructive assay (NDA) of fuel elements when fabrication is completed. Ideally, for economic reasons, this NDA capability should be available throughout the manufacturing process. This desire for rapid, on-line NDA measurement capability is a major driving force for the evolution of improved measurement systems.

A rarely mentioned but widely prevalent concern in the nuclear industry is availability of manpower to properly operate the measurement systems. The sophisticated technology requires sophisticated capabilities somewhere in the system. Ideally, this sophistication should not be required on the production line; rather, it should be in a backup system responsible for accurate calibrations, etc. Such capabilities are inherently a requirement for a measurement assurance system.

A currently-unresolved issue is entry of private industry into the uranium enrichment business. The private sector is interested in taking on this function but believes government assistance in covering the risks of transition will be essential. Some sectors of the government disagree. If the debate is finally concluded with private sector operation of enrichment plants, the licensees will have materials control and measurement responsibilities analogous to those the AEC now has for the enrichment plants it operates. If centrifuge rather than gaseous diffusion separation technology is used, measurement methodology and practice may differ from current operations.

APPENDIX D[1]

NUCLEAR INDUSTRY MEASUREMENTS AND THE NBS ROLE

Measurement Users and Methods

Table D-1 lists the nuclear fuel materials measurers and the key measurements they make. Reactors are not included because they calculate rather than measure fuel burnup (these calculations are, however, the basis for shipper/receiver comparisons between the reactor and the reprocessor). AEC prime contractors (12 in number) are also not shown since they usually have in-house capabilities sufficient to provide needed measurement assurance services. Their measurements are similar to those of the fuel fabricators and reprocessors.

As shown in Table D-1, relatively little proliferation of sites is forecasted. That which is shown primarily reflects addition of LMFBR and HTGR operations. Expansion of capacity will usually occur at existing sites.

Table D-2 lists the methods used to make the measurements. In practice, there will probably be as many variations of these methods in use as there are users. There are, for example, several hundred analytical procedures for U and Pu assays. Rapid, automated systems will be used as much as possible.

All of the fuel materials measurements involve just four basic quantities:* mass assays of U and Pu, and isotopic distributions for these same two elements. Waste control measurements may not require isotopic distribution determinations; safeguards and equity measurements usually will.

Ranges of values for these quantities -- particularly the Pu isotope distributions -- are of primary interest to measurement technology. As previously noted, elemental and isotopic compositions of spent fuels will depend on reactor exposure and number of recycles.

The data shown in Table D-3 indicate that ranges of values for future LWR fuels will be quite similar to present values. Anticipated assays for fresh and spent fuels are all within the ranges for current fuels and primary standards. The HTGR fuels will also be in the range of current capability. Data similar to those of Table D-3 are not available for LMFBR fuels, but these systems are not expected to be in commercial operation until near 1990. Performance capabilities of LMFBR fuels are to be determined in the Fast Flux Test Facility (FFTF) which is scheduled to begin operation in 1976.

An unresolved question concerns the changes in Pu isotopic distribution that will occur with repeated cycles and their impact on equity and measurements to assure equity. Proprietary calculations to estimate these changes

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* One additional measurement, Thorium, is required for HTGR fuels

[1] Of Bartlett (1974).

TABLE D-1

MEASURERS OF NUCLEAR FUEL MATERIALS

Operation	Total Number* To 1985	Total Number* 1985-2000	Key Measurements
Enrichment	AEC-Owned	3	I.C.** of Product, Tails
Fuel Fabrication	10	15	I.C. of Receipts, Blends, Scrap, Waste, Pellets NDA of Fuel Rods and Elements
Fuel Reprocessors	3	5	Mass, I.C. of Receipts and Product Actinide Content of Waste
Service Labs	30	30	Same as Fuel Fabrication, Reprocessing (Referee Service)
Instrument Vendors	50	50	Calibration of Products

* Estimates based on AEC, industry projections

** I.C. = Isotopic Composition. All measurements for U and/or Pu compounds, mixtures

TABLE D-2

NUCLEAR FUEL MATERIALS MEASUREMENT METHODS

Measurement	Where	Method(s)
UF_6 Enrichment Product	Enrichment	Quant. Anal.*, Mass Spec.
UO_2, PuO_2, Powders	Fuel Fabrication	Quant. Anal., Mass Spec.
Powder Blends	Fuel Fabrication	Quant. Anal., Mass Spec.
Fuel Pellets	Fuel Fabrication	Quant. Anal., Mass Spec. Neutron Interrogation, Gamma-Ray Spectroscopy, Calorimetry
Fuel Rods	Fuel Fabrication	Gamma-Ray Spectroscopy Neutron Interrogation
Spent Fuel Assay	Fuel Reprocessing	Quant. Anal., Mass Spec., X-Ray Fluorescence
Recovered U, Pu (as nitrates)	Fuel Reprocessing	Quant. Anal., Mass Spec.
High-Density, High-Fissile Scrap and Waste	Fuel Fabrication Fuel Reprocessing	Calorimetry, Quant. Anal., Mass Spec.
Low-Density, Low-Fissile Waste	Fuel Fabrication Fuel Reprocessing	Calorimetry, Gamma-Ray Spectroscopy

* Many methods for quantitative analysis are available. See reference 1.

TABLE D-3*

THERMAL REACTOR CHARACTERISTICS[1]

	BWR		PWR		HTGR	AGR	
	Thru 1980	After 1980	Thru 1980	After 1980		Inner Core	Outer Core
Thermal Efficiency (%)	34	34	33	33	39	42	
Specific Power (MWth/MT)	26	28	38	41	82	13	
Initial Core (Average)							
Irradiation Level	17000	17000	24000	24000	54500	13000	
Fresh Fuel Assay (Wt% ^{235}U)	2.03	2.03	2.63	2.63	93.15	1.49	1.78
Spent Fuel Assay (Wt% ^{235}U)	.86	.86	.85	.85	([4])	.75	1.00
Fissile Pu Recovered (kg/MT)[2]	4.8	4.8	5.8	5.8	([4])	2.5	
Feed Required (ST U_3O_8/MWe)[3]	.625	.580	.591	.548	.456	.737	
Separative Work Req. (SWU/MWe)[3]	200	185	224	208	311	188	
Replacement Loadings (Annual rate at steady state and 80% Plant Factor)							
Irradiation Level (MWD/MT)	27500	27500	33000	33000	95000	20000	
Fresh Fuel Assay (Wt% ^{235}U)	2.73	2.73	3.19	3.19	93.15	2.10	2.54
Spent Fuel Assay (Wt% ^{235}U)	.84	.84	.82	.82	([4])	.59	.87
Fissile Pu Recovered (kg/MT)[2]	5.9	5.9	6.6	6.6	([4])	4.0	
Feed Required (ST U_3O_8/MWe)[3]	.191	.191	.205	.205	.113	.176	
Separative Work Req. (SWU/MWe)[3]	89	89	99	99	77	73	
Replacement Loadings (Annual rate at steady state, 80% plant factor, and plutonium recycle.)							
Fissile Pu Recycled (kg/MWe)	.174	.174	.167	.167			
Fissile Pu Recovered (kg/MT)[2]	10.3	10.3	11.4	11.4			
Feed Required (ST U_3O_8/MWe)[3,5]	.158	.168	.179	.179			
Separative work Req. (SWU/MWe)[3]	70	70	80	80			

[1] MWth is thermal megawatts, MWe is electrical megawatts, MWDt is thermal megawatt days, MTU is metric tons (thousands of kilograms) of uranium, and ST U_3O_8 is short tons of U_3O_8 yellowcake from an ore processing mill. One SWU is equivalent to one kg of separative work.

[2] After losses.

[3] Based on operation of enriching facilities at a tails assay of 0.3%. For replacement loadings, the required feed and separative work are net, in that they allow for the use of uranium recovered from spent fuel. Allowance is made for fabrication and reprocessing losses.

[4] All spent fuel and fissile production (primarily ^{233}U) are recycled on a self generated basis. Only one recycle of ^{233}U is assumed.

[5] Include natural uranium to be spiked with plutonium; 0.0037 ST U_3O_8/MWe for BWR and 0.0067 for PWR.

*Reproduced from WASH-1139 (72), "Nuclear Power, 1973-2000" may have been made but appear not to have been published; AEC calculations of this type (but not for this purpose) have been initiated as part of their waste management studies.

The data cited in Table D-3 and discussed above are confined to the primary fuel materials (i.e., fresh and spent fuel). The industry will also have to make many measurements on other fuel-bearing materials which can be classified as process inventory, scrap, and waste. The major impetus for such measurements is special nuclear material control (see Appendix B).

Measurement methods used for these non-primary fuel-bearing materials will be as shown in Table D-2. Guidance in selection and use of measurement systems is provided by the AEC's Division 5 Regulatory Guides.

As indicated by Table D-2, measurement methods for primary and non-primary fuel materials are essentially the same. However, there is one important difference: impurities and inhomogeniety of the non-primary materials greatly complicate application of the measurement methods. For example, Pu is frequently present in waste at the ppm level; under these circumstances, the accuracy of gamma ray spectroscopy and neutron interrogation can be as low as ± 50%.

The greatest operational effect of the measurement difficulties associated with the non-primary fuel materials is that they mandate a proliferation of reference materials standards. They also lead to other methods to minimize problems (e.g., scrap volume reduction and densification via incineration).

<u>Current NBS Services to Nuclear Fuel Measurements</u>

NBS currently provides 16 standard reference materials that are different mixtures of uranium isotopes and one reference material containing four Pu isotopes.[1] In view of the projection that spent fuel uranium compositions will in the future not be significantly different from those of the present, the currently available uranium reference materials may be sufficient for future needs.

Additional Pu standards may be needed to accommodate different Pu isotope distributions in future fresh or spent fuels. Specific needs can be identified only as a result of in-depth study, and the need is probably at least ten years away. Needs for standards in support of waste management are similarly proscribed.

NBS is currently participating, with the AEC and the nuclear industry, in a study to assess future needs for standard reference materials to support nuclear fuel materials measurements. This study is near completion; it is expected to provide a firm base for future NBS activities related to nuclear material SRMs.

The situation for materials standards other than SRM's is quite different. Working standards have historically been provided by the AEC's New Brunswick Laboratory or the users themselves; NBS has not been involved. To date, the industry has not developed consensus standards that would reduce problems and minimize needs for working standards (for example, there is no standardization of the paint cans commonly used to contain low-density, low-fissile waste).

In general, the problem is to develop consensus written standards and appropriate materials standards for the non-destructive assay (NDA) techniques used in the nuclear industry. NDA techniques are expected to dominate the industry in the future because they are essential for real-time measurements and data analysis (see Appendix B).

The need for standards in support of non-destructive assay was recently expressed by Dennis Bishop of General Electric Company. Bishop was reported[2] to say that industry can produce satisfactory working standards and NBS and NBL provide some primary standards, but there is presently no facility where industry can confirm values of its working standards.

Current NBS services to the nuclear industry also include provision of radioactivity standards (e.g., the ^{137}Cs standards used in fuel burnup evaluations). NBS also has, for many years, provided technical expertise to assist AEC programs. At present, NBS personnel are assisting the AEC's safeguards studies.

Potential NBS Support of Nuclear Fuel Materials Measurements

The infrastructure by which NBS can service a national measurement system for nuclear fuel materials is illustrated by Figure D-1. NBS services should have impact at a level involving local regulatory functions (designated "local" because regulation has been delegated to many states) and suppliers of instruments and other measurement-assisting materials. The national laboratories are also a primary recipient of NBS services; as shown in Figure D-1, they may operate or include some of the fuel cycle operations.

Measurement capabilities are supplied to three basic types of operations in the nuclear industry: the various fuel cycle operations, waste disposal sites, and service laboratories. The service laboratories are of special interest. Traditionally, they have supplied services such as dosimetry measurements. In the future they may be called on for materials control measurements either as a referee or for routine measurements. The possibility of a significant role for these laboratories exists because equity assurance may require frequent referee measurements and because facilities for U and Pu measurements are expensive to install and operate (i.e., fuel cycle operators may find it cheaper to buy the service rather than to maintain their own capability). However, most measurements will have to be done at the fuel cycle facilities because they have materials control responsibility and the radioactive materials cannot be transported economically.

Ideally, all measurements for all sites and all functions shown in Figure D-1 will be traceable to NBS standards. Problems that challenge capability to achieve this goal are outlined below.

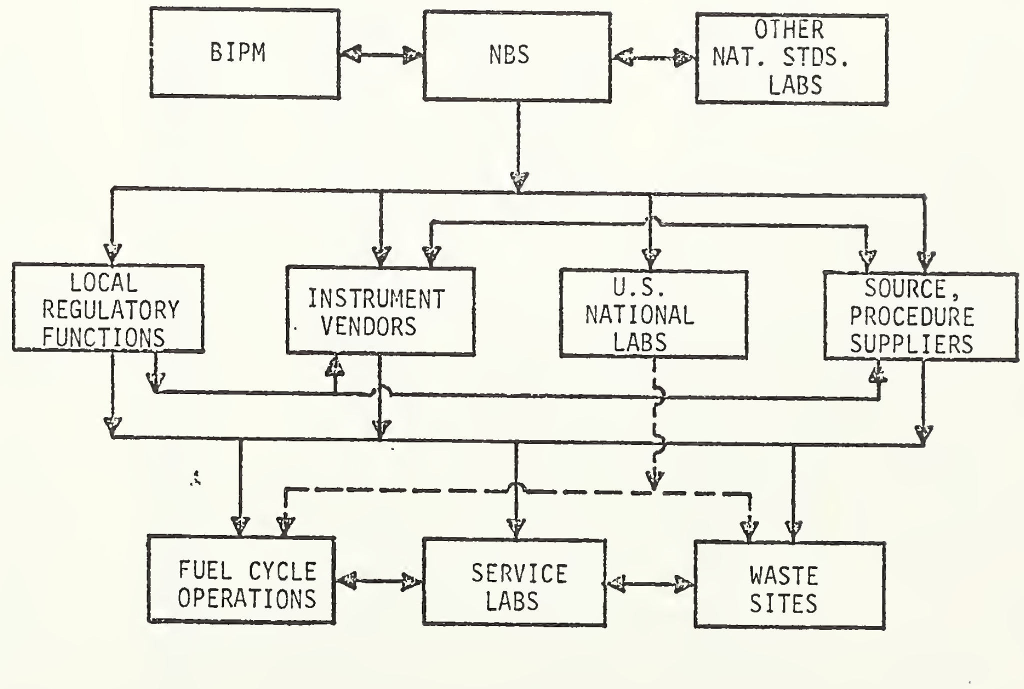


Figure D-1

Possible NBS Interactions for Nuclear Industry Measurements and Standards

If NBS provides measurement services throughout the nuclear industry, the total demand may be enormous by the turn of the century. As shown in Table D-1, there will be numerous facilities of each basic type in the fuel cycle. The number and type of primary standards and other NBS services required in support of these operations may actually be even larger than would be supposed because of the multiplicity of types of operations (e.g., fabrication of UO_2, mixed oxide, HTGR, and LMFBR fuels). Each type of each operation may require its own standards and reference materials, and each has many types of measurements to make.

An indication of the potential scope of requirements for NBS services is provided by Figure D-2, D-3, and D-4. Each shows, with differing emphasis, some of the demands for measurements in the fuel cycle operations. Similar types of diagrams could be developed for each of the functions defined in Figure D-2.

Figure D-2 summarizes the basic alternatives for fuel materials and reactor types in the nuclear power industry. The three reactor types shown in dotted lines are under development but are not expected to be major segments of the industry. The LWR, LMFBR, and HTGR systems will all be important; each requires its own type of support operations.

Figure D-3 illustrates the basic types of measurements needed for the four major fuel cycle operations. As can be seen, each block of measurements requirements is actually a three-dimensional matrix involving measurement type, facility type, and the number of facilities shown in Table D-1.

Figure D-4 shows details of measurements for fuel reprocessing sites as recommended by the draft of ANSI standard N15.13. This standard breaks the four basic measurements defined in Figure D-3 into 14 specific types of measurement for each plant. Similar measurements would be needed for each type of reprocessing plant.

As indicated by these diagrams, a large number of operations will make many types of measurements that should be traceable to NBS primary standards. Achievement of this performance will require that the NBS services be available and that the infrastructure be adequate.

REFERENCES

1. Clement J. Rodden, ed. "Selected Measurement Methods for Plutonium and Uranium in the Nuclear Fuel Cycle," U.S. Atomic Energy Commission, 1972.

2. _Nuclear News_, August 1973, pp. 68-69.

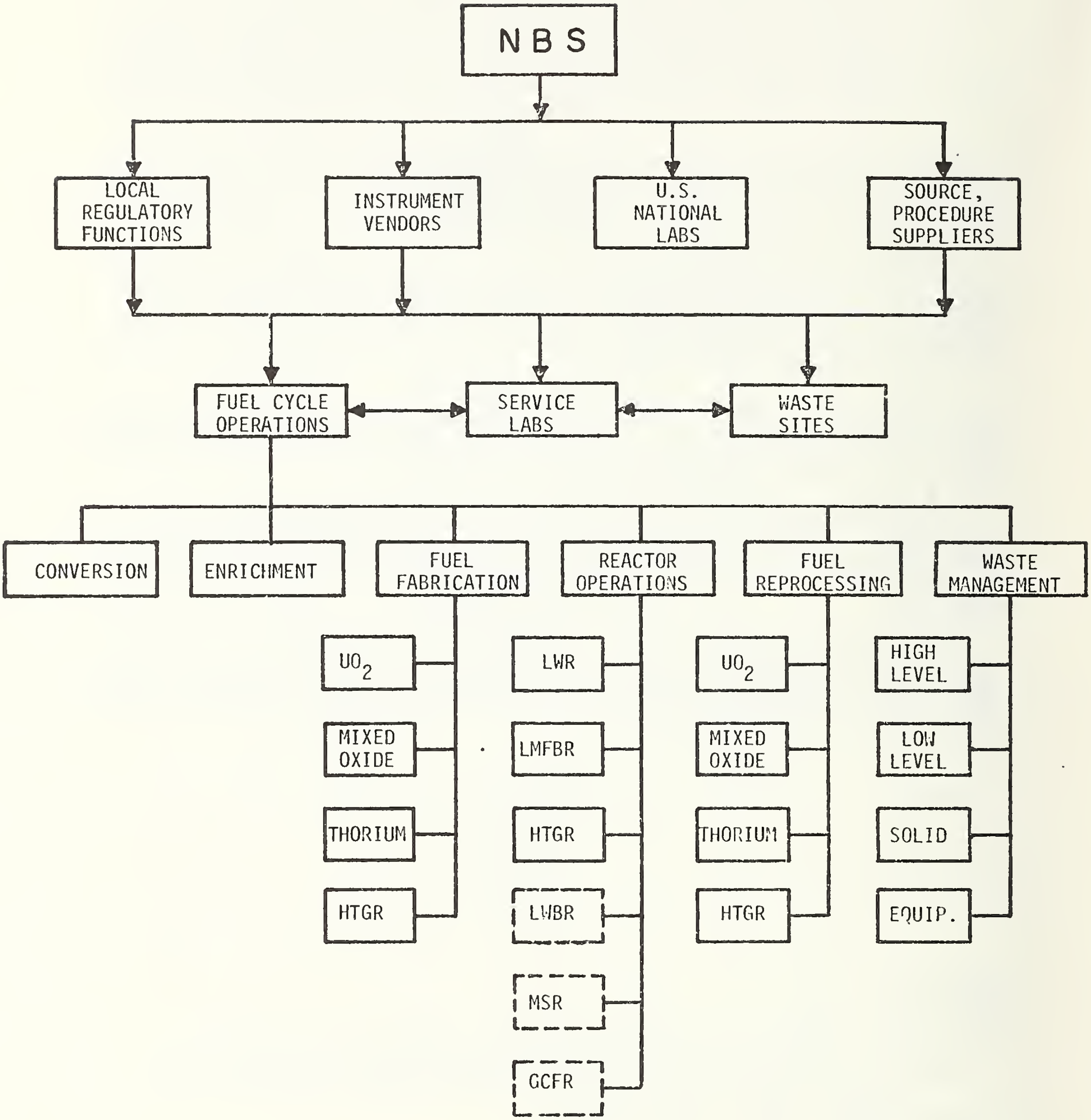
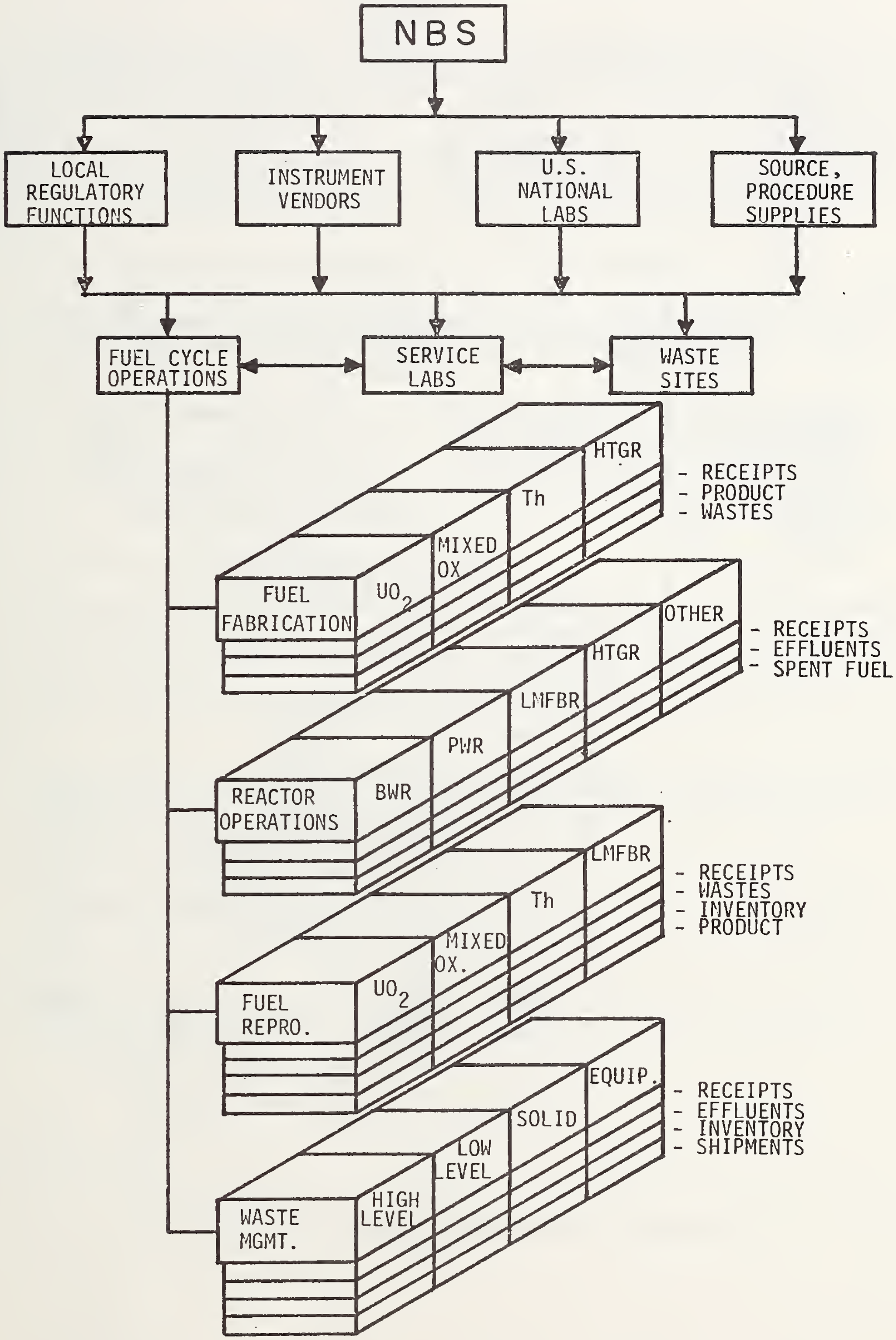


Figure D-2

Basic Fuel Cycle Options and Alternatives

Figure D-3

Major Fuel Cycle Measurement Needs



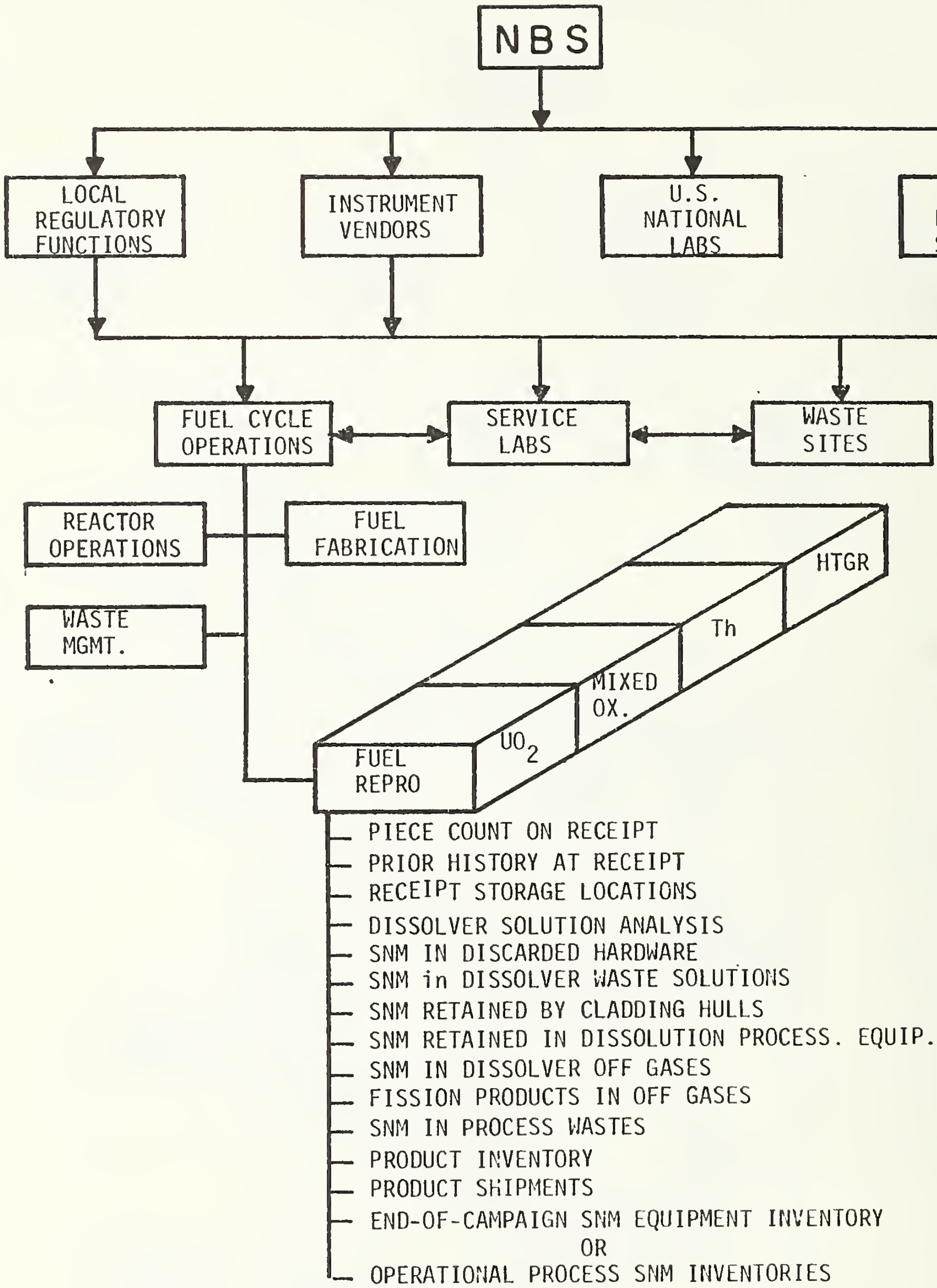


Figure D-4

Fuel Reprocessing Measurements Suggested by ANSI N15.13

APPENDIX E[1]

CONSENSUS STANDARDS IN THE NUCLEAR POWER INDUSTRY

A massive effort to develop operating and performance standards for the nuclear industry is in progress. Many people, representing all interest sectors, are involved.(1) The basic objective of the program is to develop consensus standards to guide the operation and performance of all aspects of the industry.

The way these standards should be developed and applied is illustrated by Figure E-1. In practice, it is apparent from current literature that the system does not always function in this manner. There are sometimes differences of opinions between the AEC and industry concerning the adequacy of proposed standards.

Our survey of the literature suggests that equity interests have had limited participation in the standards promulgation process to date. When fuel recycle becomes more of a need or reality, however, increased participation from this sector will probably be obtained.

The potential operational NBS role in nuclear industry standards is suggested in Figure E-1 by the diamond labeled "measurement assurance". The basic role envisioned is to assist utilization of measurement methods, when appropriate, and to provide SRM's, etc., needed to assure reliable data (see Appendix F). NBS also can and does contribute to development of the consensus standards.

Scope and Status of Fuel Measurement Standards

Relatively few of the many standards under development focus on measurement and control of fuel materials. When those relevant are completed, however, they will provide at least first-order coverage of all areas of interest.

Standards currently under development may be classified and described as follows:

- Guides to practice, Nuclear Material Control Systems. Provide, for each operation in the fuel cycle, guides for measurements to be made and suggestions for organization and management to assure materials control. Developed by ANSI Committee N-15.

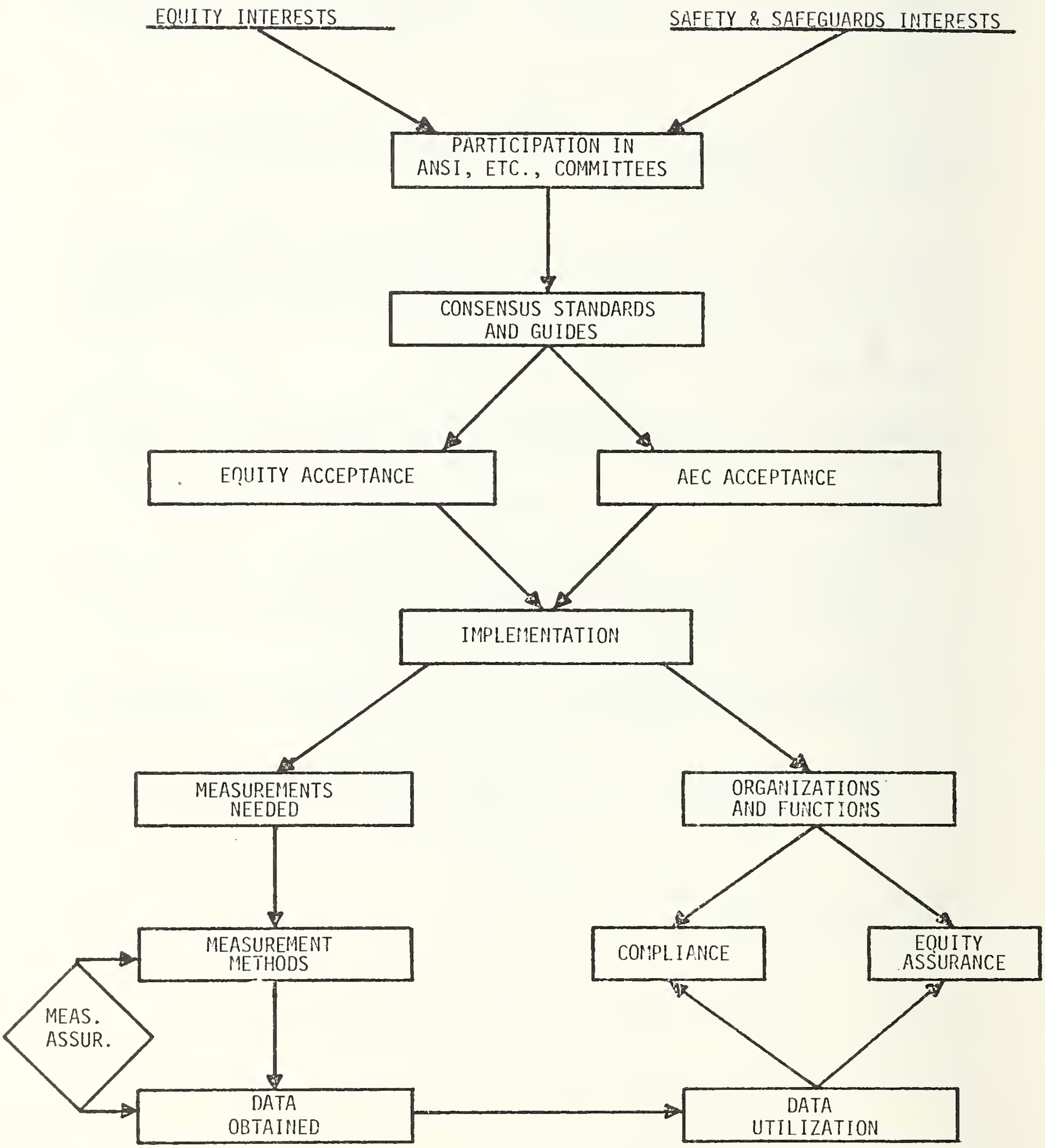
- Calibration standards. Provide calibration techniques for mass, volume, and other specific measurement techniques. Developed by ANSI Committee N-15.

- Analytical methods. Provide standard procedures for analytical measurements on U- and Pu-bearing materials.

[1] Of Bartlett (1974).

Figure E-1

Promulgation and Implementation of Nuclear Standards



The standards being prepared in each of these categories are at widely different stages of completion and approval.[2] In general, those on analytical methods have been approved and are in press; those on calibration techniques are in the early stages of the preparation/approval chain, and the draft of one[3] of the material control system guides (ANSI N15.13; for fuel reprocessing plants) has been submitted for N-committee approval and concurrent ANSI review. The other guides are in the early stages of development; extensive activity is scheduled through 1974.

The guides to practice are of most interest for their potential impact on fuel cycle operations. If ANSI N15.13 is typical, these guides will not address questions of measurement method, accuracy, data utilization, etc. Such questions presumably will be considered in the standards on calibrations and analytical methods. Even then, however, the link between measurements, methods, data, and data utilization for compliance and equity assurance (see Figure E-1) is not complete. A critical need is to identify data needs and accuracies that flow down from compliance and equity assurance requirements and to compare them with results that will be obtained from implementation of the consensus standards.

Use of the consensus standards is supplemented by the AEC's Division 5 Regulatory Guides. The guides related to measurement operations reference the appropriate consensus standards. In some cases, they indicate modifications to the standards considered essential for satisfactory compliance with regulations.

The consensus standards and the regulatory guides together will eventually provide a complete catalog of guidance for measurement operations in the nuclear industry. At present, however, both are incomplete. The rate of development of the standards and guides is essentially manpower limited, i.e., resources applied are not sufficient for a high volume of throughput in the preparation, review, and approval process. Meanwhile, measurement technology and regulatory requirements are changing. If current conditions persist, several years will elapse before all standards are in place, and many may be obsolete at the time of completion. The process of developing consensus standards will remain dynamic for many years.

REFERENCES

1. ORNL-NSIC-108, "Personnel involved in the Development of Nuclear Standards in the United States, 1972," prepared by the Status and Recommendations Committee, American National Standards Institute Nuclear Technical Advisory Board.

2. Nuclear Projects Status Report, NTAB-SR-3, dated August 5, 1973. Issued by the American National Standards Institute.

3. Nuclear Material Control Systems for Fuel Reprocessing Facilities (A Guide to Practice), comment draft. American National Standard N15.13-__.

APPENDIX F [1]

STUDY FOLLOWON: THE JOINT NBS/AEC TASK FORCE

This study has determined that a comprehensive, nationally-based measurement assurance system is needed for nuclear fuel material measurements; the next step is to design an appropriate system.

Expertise, responsibilities, and experience within the AEC and NBS make it appropriate that these organizations combine resources in order to produce fruitful results most effectively. We therefore recommend a joint AEC/NBS effort on the system design and development plan outlined below.

It should be noted that similar needs for measurement assurance exist in the nuclear industry activities of effluent monitoring, dosimetry, radiation medicine, and quality assurance. Since these activities have many measurement methods and problems in common with nuclear fuel material measurements, a comprehensive design and development program that embraces all these measurement-oriented functions should be considered. Such an approach could effect economies in the long run but would expand the resources applied to near term design activities. The alternative would be to implement a pilot effort with nuclear fuel materials measurement assurance as the focus. The choice between these alternatives should be a topic of dialog between the AEC and NBS.

Development Program Objectives and Anticipated Outputs

The objectives for the proposed program, which should be performed by a joint NBS/AEC task force, are to (1) develop a design for a nationally-based nuclear fuel materials measurement assurance system, and (2) define the procedures and resources required for implementation of that system.

Anticipated outputs from the project include (1) a design description of the measurement assurance system, and (2) a detailed plan of action for implementation, including description of participants, activities, schedules, milestones, and budget requirements.

Project Tasks

Three major project tasks can be anticipated, details of which should be developed by NBS/AEC interaction prior to initiation of the program:

1. Definition of measurement assurance service needs. This task is aimed at determining the functional requirements for the measurement assurance system. Users of the services should participate in the assessment effort.

2. Selection of the measurement assurance system structure. Activities in this task will be directed at defining and evaluating alternatives for the structure of the measurement assurance system.

3. Detailed design of the measurement assurance system. This task will identify facilities, staff, equipment, organization, activities, costs, and cost recovery methods for the measurement assurance system selected by Task 2. It will also develop a blueprint for implementation.

Schedule and Milestones

The anticipated schedule and major milestones for this program are shown in Figure G-1.

[1] Of Bartlett (1974).

Resources Required for Project

We estimate that this project can be accomplished with a minimum of three man-years of highly-skilled effort annually for the two-year period. The project director and one other staff member should have a working knowledge of forecasting and assessment methodologies; all should be familiar with measurement technology and its use in the nuclear industry.

Our preliminary estimate of the costs of the project are:

	Costs $k (each of two years)
Salaries & O.H.	$210
Travel	10
Supplies	10
Services (consultants, etc.)	20
	$250

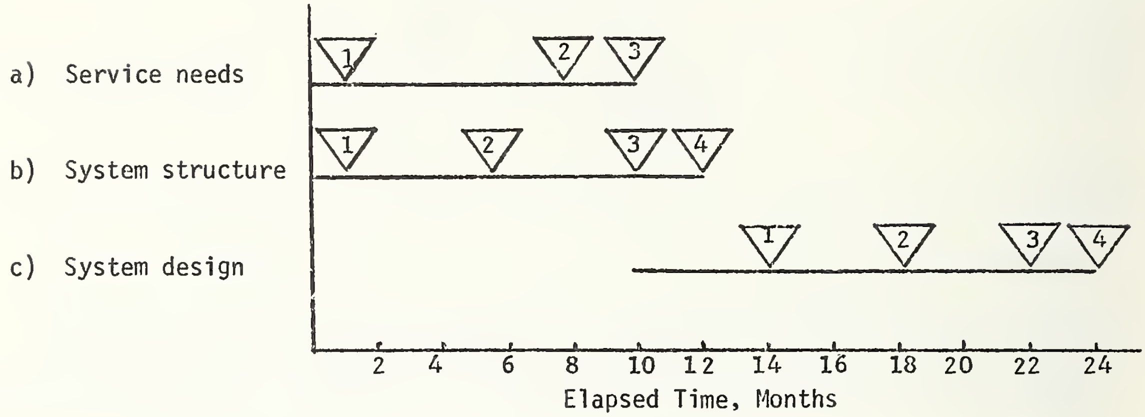
Implementation of Project

This project should be implemented as an outgrowth of dialog between the AEC and NBS. This dialog should be aimed at forming and funding the project task force. Discussions should cover scope of the project (i.e., focus on nuclear fuels measurement assurance or inclusion of other areas), allocation of resources to the project, role of other agencies, project methodology, and project followon.

The AEC/NBS interaction should be initiated at the policy level. These policy discussions should establish consensus and mutual understanding of the importance and role of measurement assurance. They should also establish the basis for subsequent interaction to formulate and implement the project.

FIGURE G-1

SCHEDULE AND MILESTONES FOR THE MEASUREMENT ASSURANCE DEVELOPMENT PROGRAM



<u>Major Milestones</u>

a. 1. Assessment method selected, use initiated

2. Assessment activities completed

3. Description of service needs completed

b. 1. Alternatives defined

2. Preliminary cut made

3. In-depth analysis of survivors completed

4. Description of preferred structure completed

c. 1. System scope, organization, operating modes defined

2. Facilities, equipment, staff, budget operations defined

3. Implementation procedures, costs, schedules defined

4. Blueprint for implementation completed

APPENDIX E. RADIATION PROCESSES OF COMMERCIAL INTEREST

PROCESS	PRODUCT	RADIATION SOURCE	PROGNOSIS[1]
Medical sterilization	Medical supplies (animal products, vitamins, enzymes, cosmetics, pharmaceuticals)	gamma rays electrons ultraviolet	A, B
Food sterilization, food shelf-life extension	Preserved food stuffs	gamma rays, electrons	B, C
Pest disinfestation	Insect population control, disinfested grain, crops, and food stores	gamma rays	B, C
Seed and bulb stimulation, mutation breeding, soil blight elmination	More productive crops and new types of flowers	gamma rays	B, C
Sewage and waste treatment and recycling	Cleaner environment	gamma rays electrons	D
Synthesis of detergents	Biodegradable detergents	gamma rays, electrons	B, C
Chain reaction synthesis of reagents	Ethyl bromide and other halogenated organics	gamma rays electrons	A, B
Polymerization	Polyethylene, conductive plastics, adhesives, rubber-plastics, battery separators	gamma rays electrons	B, C
Graft polymerization	Plastic peroxides, ion-exchange membranes, various plastic copolymers, textiles (permanent press), paper, plastic	electrons gamma rays ultraviolet	A, B
Polymer cross-linking	Better insulators, cables and wire heat-shrinkable plastics, toys, plastic foams	electrons gamma rays ultraviolet	A, B
Polymer and hydrocarbon degradation	Plastic foams, modified plastics, molecular weight control, floculating agent for ore processing	electrons	A, B

APPENDIX E. (continued)

PROCESS	PRODUCT	RADIATION SOURCE	PROGNOSIS
Rubber-vulcanization	Better rubber products, elastomers, rocket propellants, adhesives	electrons	B, C
Curing of coatings	Inks, automobile parts, paint layers, cookware, metal coil coatings	electrons	A, B
Polymer impregnation of materials	Building materials (wood, concrete, tiles, pipes, fibrous materials, sidings)	gamma rays electrons	B, C
Ion implantation	Electronic components, semi-conductors	ion beams	A, B
Microelectronic fabrication	Faster diodes, transistors, photoresists, printed circuits	electrons	C
Welding and machining	Metal parts and instruments	electrons	A, B
Non-destructive testing, surveillance	Various commodities	x and gamma rays	C
Radiation chemistry physics, and measurement research	Dosimeters	all	A, B
Fading of dyes	Fabrics	electrons	D
Curing of adhesives	Bonding systems	electrons	D
Curing of textile fibers	Flame-proof rugs, yarns, clothing and fabrics	electrons	D
Grafting biocompatible surfaces on plastics and rubber	Biocompatible materials for transplants	electrons	D

[1]"A" means already commercially successful in the U. S.
"B" means already commercially successful in other countries
"C" means will probably soon be successful in the U. S.
"D" means will be successful perhaps in the future

APPENDIX F. ENVIRONMENTAL RADIOACTIVITY MEASUREMENT SYSTEM INFORMATION

Table F-1. Examples of users of environmental radioactivity standards

1. Hospitals
   Mayo Foundation
   Emory Medical Center
   U.S.C. Medical Center

2. Nuclear power utilities
   (see Table F-2)

3. Nuclear reactor manufacturers
   Westinghouse
   Gulf General Atomic
   Babcock & Wilcox
   Combustion Engineering

4. Environmental service industry
   Radiation Management Corporation
   Nuclear Environmental Services
   NUS Corporation
   U. S. Testing Corporation
   Applied Physical Technology

5. Environmental research - universities and institutes
   Battelle Northwest
   Stanford
   Georgia Tech
   Penn State

6. Department of Defense
   Navy Submarines
   Army Power Reactors
   Armed Forces Radiobiology Research Inst.
   Ports and Harbors

7. National laboratories

   Argonne National Laboratory
   Oak Ridge National Laboratory
   Los Alamos Scientific Laboratory
   Brookhaven National Laboratory
   Lawrence Livermore Laboratory

Table F-2. Status of the use of NBS mixed radionuclide standards by U. S. nuclear power generating stations (> 100 MWe)

United States - NORTHEAST (19 Reactors)

Reactors using NBS standards as of December 1, 1974:

In operation		Scheduled for operation (1974-1975)	
Calvert Cliffs 1	(MD)	Calvert Cliffs 2	(MD)
Pilgrim 1	(MA)	Millstone 2	(CN)
Haddam Neck	(CN)	Peach Bottom 3	(PA)
Oyster Creek	(NJ)	Salem 1	(MA)
Maine Yankee	(ME)	Indian Point 3	(NY)
Millstone 1	(CN)	Beaver Valley 1	(PA)
Peach Bottom 2	(PA)		
Robert E. Ginna	(NY)		
Vermont Yankee	(VT)		
Indian Point 1	(NY)		
Indian Point 2	(NY)		
Nine Mile Point	(NY)		
Fitz Patrick	(NY)		

Table F-2 (Continued)

United States - SOUTH (15 Reactors)

Reactors using NBS standards as of December 1, 1974:

In operation		Scheduled for operation (1974-1975)	
Nuclear 1	(AR)	Oconee 3	(SC)
Oconee 1	(SC)	Brown's Ferry 3	(AL)
Oconee 2	(SC)	McGuire 1	(NC)
Hatch 1	(GA)	Virgil C. Summer	(SC)
Brown's Ferry 1	(AL)		
Brown's Ferry 2	(AL)		
Turkey Pt. 3	(FL)		
Turkey Pt. 4	(FL)		
Robinson 2	(SC)		
Surry 1	(VA)		
Surry 2	(VA)		

United States - MIDWEST (12 Reactors)

Reactors using NBS standards as of December 1, 1974:

In operation		Scheduled for operation (1974-1975)	
Dresden 1	(IL)	Prairie Isl. 2	(MN)
Dresden 2	(IL)		
Dresden 3	(IL)		
Zion 1	(IL)		
Zion 2	(IL)		
Quad-Cities 1	(IL)		
Quad-Cities 2	(IL)		
Donald C. Cook 1	(MI)		
Fort Calhoun 1	(NB)		
Kewaunee	(WI)		
Prairie Isl. 1	(MN)		

United States - WEST and NORTHWEST (4 Reactors)

Reactors using NBS standards as of December 1, 1974:

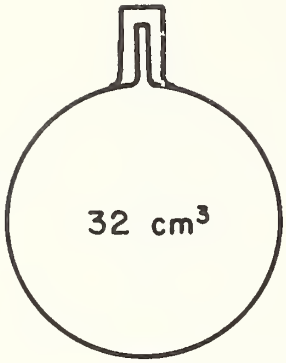
In operation		Scheduled for operation (1974-1975)	
Ft. St. Vrain	(CO)	Rancho Seco	(CA)
Hanford - N	(WA	Diablo Canyon 1	(CA)

Table F-3. Radionuclides for which the USEPA has requested NBS standardization

(Significant quantities of many of these will be produced in breeder reactor programs or will be evolved by coal-burning power plants)

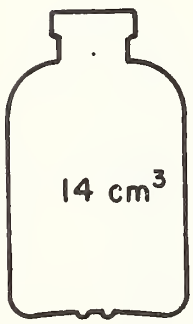
Solution Standards	^{238}Pu, ^{239}Pu, ^{241}Pu
	^{241}Am, ^{242}Am
	^{242}Cf, ^{244}Cf
	^{243}Cm, ^{244}Cm
	^{235}U, ^{238}U
	^{210}Pb
	^{210}Po
	^{230}Th, ^{232}Th
	^{228}Ra
Ore	Uranium

Table F-4. Distribution of NBS xenon-133 environmental gas standards SRM 4307



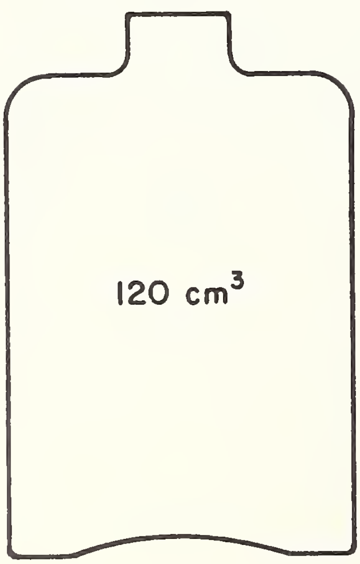
REGULATORS & PWR'S

USNRC, Health Services Laboratory
USEPA, NERC-LV
21 State Radiological Health Laboratories
Atomic Energy of Canada, Ltd. (AECL)
Oconee Nuclear Power Station



GENERAL ELECTRIC BWR'S

G. E., Vallecitos, CA
Commonwealth Edison
(Dresden 1, 2, 3)
(Zion 1, 2)
(Quad-Cities 1, 2)



GULF HTGR'S

Peach Bottom 1
Fort St. Vrain

APPENDIX G. PERSONNEL MONITORING SERVICES IN THE UNITED STATES

Commercial personnel monitoring services contacted. The following is a list of companies offering personnel monitoring services to users outside the company. Companies which are sales representatives or sales offices representing other companies are not listed. Only those organizations actually performing the monitoring service are listed. Services are available for x-rays, gamma-rays, beta-rays, and neutrons unless otherwise indicated. Alpha-ray monitoring is generally carried out by area monitoring rather than by personnel monitors.

	Services
Applied Health Physics, Inc. P. O. Box 197 Bethel Park, Pennsylvania Contact: Robert Gallagher, President 412-563-2242	Film badge, TLD, pocket chambers
Atomic Energy Industrial Laboratories 6421 South Main Houston, Texas Contact: Sherry Miller, Company Manager 713-526-5950	Film badge, TLD, finger badges
Atomic Radiation Laboratory P. O. Box 622, Shenandoah Station Miami, Florida Contact: Robert Schwartz, Owner 305-379-3295	Film badge (no neutrons)
Eberline Instrument Corporation Department of Nuclear Sciences P. O. Box 2108 Santa Fe, New Mexico Contact: W. S. Johnson (in charge of nuclear operations) 505-471-3232	Film badge (x and gamma rays) TLD (beta, neutrons)
International Chemical and Nuclear Corp. 26201 Miles Road Cleveland, Ohio 44128 216-662-0212	Film badge
R. S. Landauer, Jr. and Co. Glenwood Science Park Glenwood, Illinois 60425 Contact: R. S. Landauer, Jr. 312-755-7000	Film badge, TLD
Medi-Ray, Inc. 150 Marbledale Road Tuckahoe, New York 10707 Contact: James Summers 914-961-8484	TLD (x, gamma, beta only)
Nuclear Services Laboratory Knoxville, Tennessee Contact: D. K. Rector, General Manager 615-947-1400	Film badge

	Services
Nuclear Sources and Services, Inc. 5711 Ephendge Houston, Texas 77017 Contact: Robert Gallagher 713-641-0391	TLD
Radiation Detection Company Mountain View, California Contact: Gene Tochilin, President 408-735-8700	Film badge, TLD
Reynolds Electrical and Engineering Co. 2501 Wyandotte Las Vegas, Nevada Contact: Joseph Wells 702-986-9940	Film badges Serves Nevada Test Site and off-site operations
Searle Analytic, Inc. Des Plaines, Illinois Contact: William Todd, Manager, Film Badge Service 312-209-6600	Film badge, TLD (extremities only)
Teledyne-Isotopes Westwood, New Jersey Contact: Jack Dauch, in charge of personnel monitoring 201-664-7070	TLD
United States Testing Company Richland, Washington Contact: Norma Nunamaker, Supervisor Commercial Service 509-946-5157	Film badge, TLD (finger badges only)

Companies contacted providing personnel monitoring for themselves but not for the general public.

Dow Chemical Company Rocky Flats Plant Golden, Colorado Contacts: Clayton Lagerquist Roger Falk 303-494-3311, x2452	TLD Criticality monitor (S, In, Cu)
Newport News Ship Building and Dry Dock Co. Newport News, Virginia 23606 Contact: B. V. Cooke, Dosimetry Supervisor 804-247-2308	Film badge
Wallex, a Division of Halliburton Co. P. O. Box 2687 Houston, Texas 77001 Contact: George O'Bannion, Radiation Safety Officer 713-748-2000	TLD

Government laboratories contacted which operate their own personnel monitoring services.

	Services
Argonne National Laboratory Lemont, Illinois Contact: Walter Blyler, in charge of personnel monitoring 312-739-2847	Film badge
Battelle Northwest Richland, Washington Contact: C. M. Unruh	U. S. Testing Company provides monitoring service for entire Hanford plant, but Battelle Northwest does recording and quality control.
Brookhaven National Laboratory Upton, Long Island, New York Contact: Lee Phillips 516-345-4208	Film badge TLD (for extremities)
Health Services Laboratory AEC Idaho Operations Office Idaho Falls, Idaho Contact: John P. Cusimano 208-526-2279	Film badge Changing to TLD system
Lawrence Berkeley Laboratory University of California Berkeley, California Contact: Lloyd Stephens 415-843-5656	Film badge TLD supplementary
Lawrence Livermore Laboratory Livermore, California Contact: George Campbell 415-447-3368	TLD Albedo badge for neutrons being developed
Los Alamos Scientific Laboratory Los Alamos, New Mexico Contact: James Lawrence 505-667-4316	Film badge TLD (for extremities)
Oak Ridge National Laboratory Oak Ridge, Tennessee Contacts: James C. Hart John W. Poston 615-483-1336	Film badge Metaphosphate glass block S, Au, Au in Cd criticality dosimeter
Savannah River Laboratory, USAEC Aiken, South Carolina Contact: R. M. Hall Jack Hoy 803-642-7211	TLD, including albedo neutron dosimeter
Stanford Linear Accelerator Center Stanford, California Contact: Donald Busick 415-854-2345	TLD

Defense Department personnel monitoring services (all contacted)

	Services
U. S. Army Lexington-Blue Grass Army Depot Lexington, Kentucky 40507 Contact: A. Edward Abney 606-293-3646	Film badge
U. S. Army Sacramento Army Depot Sacramento, California 95813 Contact: Fred Toyama 916-449-2000, ask for 388-2427	Film badge
U. S. Air Force USAF Radiological Health Laboratory (AFLC) Wright-Patterson Air Force Base, Ohio 45433 518-255-5047	Film badge
U. S. Navy Radiation Safety Branch U. S. Naval Medical Center Bethesda, Maryland Contact: Capt. Howard Dowling 301-254-4295	Film badge Searching for better dosimeter (TLD) Ships and some navy yards operate as self-contained units.

Other organizations providing their own personnel monitoring services

Baptist Memorial Hospital
899 Madison Avenue
Memphis, Tennessee 38103
Contact: Carl Nurnberger, Ph.D.

Baylor University Medical Center
3500 Gaston Avenue
Dallas, Texas 75246

General Dynamics
Electric Boat Division
Groton, Connecticut

Harvard University
Radiological Services
University Health Services
75 Mount Auburn Street
Cambridge, Massachusetts 02138

Louisiana State University
Nuclear Science Center
Baton Rouge, Lousiana 70803

Michigan Division of Radiological Health
Michigan Department of Public Health
3500 North Logan Street
Lansing, Michigan

New Hampshire Department of Health and Welfare
Division of Public Health
61 South Spring Street
Concord, New Hampshire 03301

Puerto Rico Nuclear Center
College Station
Mayaguez, Puerto Rico 00708

University of California
Los Angeles, California

University of Utah
Salt Lake City, Utah

Vanderbilt University
Radiation Safety Office
Nashville, Tennessee 37203

APPENDIX H. STANDARDIZATION ACTIVITIES

Table H-1. Some NBS participation in standardization activities for ionizing radiations

Organization	NBS Participation
American National Standards Institute (ANSI)	
N12 Nuclear Terminology, Units, Symbols	Membership
N13 Radiation Protection	Membership
N15 Methods of Nuclear Material Control	Membership
N17 Research Reactors, Reactor Physics, and Radiation Shielding	Secretary
N42 Nuclear Instruments	Chairmanship
N43 Equipment for Non-Medical Radiation Applications	Chairmanship, secretariat, subcommittee membership
N44 Equipment and Materials for Medical Radiation Applications	Membership, subcommitee membership
Nuclear Standards Management Board	Membership
Nuclear Technical Advisory Group for ISO TC 85	Chairmanship, 2 memberships
U. S. National Committee for IEC TC 45	Technical advisor
American Nuclear Society (ANS)	
SC9 Nuclear Terminology, Symbols, and Units	2 Memberships
SC6 Radiation Shielding Standards, WG 1	1 Membership
American Society for Testing and Materials ASTM	
E10.07 Radiation Effects on Electronic Materials	Secretary, membership
D19.04 Methods of Radiochemical Analysis of Water	Membership
D20.20 Plastics, Radiation Methods	Membership
Bureau International des Poids et Mesures (BIPM) (International Bureau of Weights & Measures)	
Consultative Committee for Measurement Standards for Ionizing Radiations (CCEMRI)	Chairmanship, membership
Section I: X-Rays	Membership
Section II: Radioactivity	Membership
Section III: Neutrons	Chairmanship
International Commission on Radiation Units and Measurements (ICRU)	
Main Commission	Membership
International Neutron Dosimetry Intercomparison Committee	Chairmanship
Task Group on Methods of Assessment of Dose in Tracer Investigations	Membership
Stopping Power Committee	Chairmanship
Microdosimetry Committee	Membership

Organization	NBS Participation
International Electrotechnical Commission (IEC)	
TC 45 Nuclear Instrumentation	
WG 9 Radiation Detectors	Membership
TC 62 Electromedical Equipment (U. S. Advisory Group)	Membership
SC-62C, WG 3 Dosimeters	Membership
International Organization for Standardization (ISO)	
TC 85/SC 1 Terminology, Definitions, Units and Symbols	Membership
TC 85/SC 4 Radiation Sources	Membership
National Council on Radiation Protection and Measurements (NCRP)	
Main Council	2 Memberships
SC-4 Heavy Particles (Neutrons, Protons, and Heavier)	Membership
SC-7 Monitoring Methods and Instruments	Membership
SC-12 Electron Protection	Chairmanship
SC-18A Standards and Measurements of Radioactivity for Radiological Use--Standards Procedure Sections	Chairmanship
SC-22 Radiation Shielding for Particle Accelerators	Membership
SC-26 High Energy X-Ray Dosimetry	Membership
SC-33 Dose Calculations	Membership
SC-36 Tritium Measurement Techniques for Laboratory and Environmental Use	Membership
Department of Energy Nuclear Data Committee (DOE-NDC)	Membership

Note: Consultantships are not included in this list.

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16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

In this study the structure of the National Measurement System for Ionizing Radiation has been investigated for eight classes of radiation users: medical, nuclear power, industrial radiation processing, defense, environmental, science, chemical analysis, and miscellaneous radiation applications. In addition two fields of increasing importance to all radiation users were investigated: regulatory control of radiation and personnel monitoring. Needed major actions on the part of the National Bureau of Standards were identified particularly for nuclear power and its related environmental and safety impacts, medical applications of radiation, assistance to regulatory control of radiation and measurement assurance for personnel monitoring.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)*

Ionizing radiation; national measurement system; users of radiation; standards; dissemination; measurement assurance.

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