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U.S. DEPARTMENT OF COMMERCE/National Bureau of Standards

Requirements for an Effective National Ionizing Radiation Measurements Program

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Requirements for an Effective National Ionizing Radiation Measurements Program

A Report to the Congress by the National Bureau of Standards

Prepared in cooperation with
The Conference of Radiation Control Program Directors, Inc.

Center for Radiation Research
National Measurement Laboratory
National Bureau of Standards
Washington, DC 20234

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Abstract

This report was prepared for the Senate Committee on Commerce, Science, and Transportation in response to its recommendation that the National Bureau of Standards review, in cooperation with the Conference of Radiation Control Program Directors, the need for intermediate calibration laboratories for ionizing and nonionizing radiation. Conclusions relevant to the measurement of nonionizing radiation are presented in a separate report. This report is a description of the elements of an effective support system for ionizing radiation measurements, an evaluation of current needs in this area, a description of necessary measurement accuracies for specific applications, and a discussion of possible options to improve the support system. The focus is on institutional and technical actions needed to assure the accuracy of ionizing radiation measurements for the protection of workers and the general public.

Key words: Beta rays; Federal and State laboratories; gamma rays; instrument calibrations; intermediate calibration laboratories; ionizing radiation measurements; measurement accuracies; neutrons; radiation dosimetry; radiation protection; radiation standards; x rays.

Contents

Executive Summary

This report was prepared for the Senate Committee on Commerce, Science, and Transportation in response to its recommendation that the National Bureau of Standards review, in cooperation with the Conference of Radiation Control Program Directors, the need for intermediate calibration laboratories for *ionizing*[1] and nonionizing radiation. Conclusions relevant to the measurement of nonionizing radiation are presented in a separate report.

Included in this report is a description of the elements of an effective support system for ionizing radiation measurements, an evaluation of current needs in this area, a description of necessary measurement *accuracies* for specific applications, and a discussion of possible options to improve the support system. The focus is on institutional and technical actions needed to assure the accuracy of ionizing radiation measurements for the protection of workers and the general public.

Problem

Reliable measurements have been demonstrated for only a fraction of the ever-increasing uses of ionizing radiation and for human exposures to this radiation. The increase in applications of ionizing radiation has resulted in numerous regulations intended to protect the public from potential radiation hazards. Compliance with these regulations is generally determined by measurement of radiation levels resulting from a particular radiation source. Thus it is essential that the measurements be adequate if compliance is to be determined and public safety assured.

Currently, 19 Federal agencies have some radiation health and safety authority, and over 100 enabling acts for radiation protection regulations have been passed by the States. Effective, equitable enforcement of regulations requires measurements that are reliable, uniform, and sufficiently accurate. Uniformity of measurement results is of primary importance for conformity between the regulator and regulatee. Adequate accuracy and uniformity can be achieved when measurements are made in terms of the national physical measurement standards maintained by NBS, and are therefore consistent with these standards. To achieve the necessary degree of consistency, actions and programs such as *calibrations* and *measurement quality assurance* tests may be employed. These provide the route by which field measurements can be traced to the national standards.

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[1]Italicized words are defined in the glossary which follows.

Measurement Needs vs. Present Capabilities

The report summarizes the required accuracy and the currently available accuracy for various types of radiation. Accuracy requirements resulting from field measurements of radiation vary with the type and intensity of the radiation. In general, the greater the intensity the better the accuracy needed:

- °Radiation therapy, where large doses are required for killing cancerous cells, requires a dose measurement accuracy of about 3 percent. Diagnostic x rays, on the other hand, require measurement accuracies of 10 percent because the dose is smaller.

- °Occupational safety measurements for ionizing radiations frequently require accuracies of about 20 percent for area surveys and about 30 percent for personnel dosimeters.

- °Accuracy requirements for environmental field measurements are typically in the range of 10 to 20 percent, relaxing to a factor-of-two for very low level measurements, such as normal background radioactivity in natural materials.

The report also identifies several areas where improvements in measurement capabilities are needed to meet the requirements set forth by regulations or good practice. Accuracy requirements become more rigorous as one moves through the various levels of the *measurement support system*, starting with field measurements, then to the intermediate level calibrations, and finally to the *national standards* maintained by NBS. Adequate accuracy at the higher levels is a prerequisite for satisfying accuracy needs at the lower levels. In the medical applications three areas of need stand out:

- °The accuracy of cobalt-60 radiation therapy *dosimetry* is in a nearly satisfactory state at all levels, but the accuracy of radiation therapy dosimetry for high energy x rays and electrons is not satisfactory either at NBS or at intermediate level laboratories.

- °The accuracy of neutron dosimetry, a new method for radiation therapy, is also unsatisfactory.

- °Accuracy available at hospitals and clinics for medical diagnostic x rays has not been documented, although capabilities at the Federal-sector intermediate laboratory level and NBS levels are adequate.

In occupational radiation protection, there is no generally available mechanism for demonstrating the accuracy of field measurements such as *area surveys*. In *personnel monitoring*, required accuracies are not available at the field level, the intermediate level, or in some cases at NBS.

Environmental radioactivity measurement accuracies achieved vary widely. Intermediate level services, in the form of radioactivity standards, are available from the EPA, but do not provide complete coverage of the field. NBS standards and calibration accuracies for environmental radioactivity appear to be generally satisfactory, and *standard reference materials* enable the users to calibrate their instruments or procedures in terms of the national standards.

Measurement Support System

To ensure consistent and accurate measurements at the user level, there are many necessary technical elements of the measurement support system. These include measurement standards, calibrations, field instrumentation, data analysis and recording, measurement quality assurance (MQA), documented procedures, research and development, and education and training. To ensure that the system works properly, each element must receive proper attention and must function adequately.

In addition to the technical elements, there are necessary institutional elements of the measurement support system: international standards laboratories, national standards laboratories, intermediate level laboratories, *field level entities*, voluntary standards organizations, and professional societies. An effective system is dependent upon the achievement of adequate institutional arrangements in conjunction with the necessary technical capabilities.

The current measurement support system has many strong points. National measurement standards for many radiation quantities exist. Calibrations are provided by NBS for many instruments used by intermediate standards laboratories and others. The framework is in place to support and to develop voluntary standards needed for good measurement practice. Several Federal regulatory agencies and professional societies have established intermediate standards laboratories.

Nonetheless, a number of important deficiencies exist. National standards need to be developed or improved in the areas of (1) dosimetry for high-energy x rays and electrons, and fast neutrons; (2) monitoring occupational exposure to neutrons and beta rays; and (3) measurement of low-level radiation in the general environment. Instrument calibrations and measurement quality assurance services are not available to all who need them. Only a few *measurement traceable* intermediate standards laboratories exist at this time. A pressing need is seen for intermediate standards laboratories to provide services to state and local regulatory agencies. Instruments available for use at the field level are sometimes inadequate, particularly for measurement of beta and neutron radiation. Other deficiencies include the lack of adequate education and training and an obvious lack of coordination of measurement-related efforts among the various Federal, state, and local regulatory agencies.

Options for Institutional Improvements

Several ways of restructuring institutional relationships to improve *measurement traceability* can be considered. A greatly expanded role for NBS in providing direct calibration services to the user is one option. While this would provide direct *traceability*, the disadvantage of physical distance from the user could cause serious time delay and transportation problems. NBS would be unable to handle the increased volume of services without a significant change in both its resources and the nature of its programs.

Another option would be to use existing DOE and DOD radiation laboratories. These are well equipped and regionally distributed. However, neither agency has as its mission the provision of measurement and calibration service on a general basis, nor is there traceability to a common set of national standards in all areas.

Some Federal regulatory agencies currently provide some calibration and measurement quality assurance services to users. These services might be expanded to give more complete coverage of the radiation measurement field. Again, the regulatory agencies do not have the provision of measurement and calibration services as their general mission and calibrating instruments for regulatees may present enforcement problems to the regulator.

Congress might support the establishment of federally-supported regional calibration facilities, either government or contractor operated. This would solve many of the problems described above as these laboratories would be chartered with the specific mission of providing measurement services. The Federal cost of this option would be higher than other possible choices. Duplication and competition with some currently existing private-sector services are potential problems. Additionally, federally-supported laboratories create a dependence by the states on the Federal government, when what is needed is a general improvement of state capability.

Fostering increased private-sector involvement in measurement services is another option. This might be done by having contractor-run facilities evolve into independent entities, by establishing "quasi-public" corporations, or by encouraging the private sector to expand current services. Examples of private-sector services now in place are calibrations by instrument manufacturers and measurement services provided by professional and industrial groups, e.g., the regional calibration laboratories accredited by the American Association of Physicists in Medicine and the MQA program sponsored by the College of American Pathologists.

The last possibility to be considered here is the establishment of state-run regional calibration laboratories. By sharing the expenses of operating such a facility, the states have the opportunity to lower the costs of obtaining needed services. The primary laboratory services would be calibrations, measurement quality assurance, and education and training. One disadvantage is that the state-subsidized laboratories might be competing with the private sector in some areas. This could restrict the users of the facilities to state and local governments. To explore this option, the National Bureau of Standards is establishing a pilot program with the State of Illinois for a regional calibration laboratory.

Analysis

A cooperative analysis by NBS and the CRCPD has resulted in the identification of actions that should be considered for improvement of the measurement support system. These actions are of two types - programmatic and institutional.

Programmatic actions can be considered for medical, occupational, and environmental radiation measurement:

°For personnel monitoring, the greatest need is for measurement quality assurance at the field level.

°Occupational radiation survey measurements could benefit from development of a wider range of national standards, criteria for interactions between the intermediate level and NBS, and development of continuing MQA programs.

°For radiation therapy, national standards should be developed for high-energy x rays and electrons, and for neutrons.

°Environmental radioactivity measurements could benefit from better-defined traceability for radioactivity standards and cross-check samples issued by intermediate laboratories.

°For very low levels of radiation, national standards should be developed and suitable calibrations provided.

°With regard to medical diagnosis, it would be desirable to have operational MQA programs between NBS and intermediate laboratories, followed by similar programs between the latter and those making measurements in the field.

Institutional actions needed for improvement of the measurement support system include the provision of more services at the intermediate level.

°Traceability mechanisms from Federal agencies to NBS could be improved through better interagency communications and cooperation.

°Improving traceability to the private sector is complicated by the diversity of actors in this area, e.g., instrument manufacturers, radiologists, private calibration services, etc. All levels of the measurement support system together with the voluntary standards writing organizations should develop measurement traceability criteria for calibration services provided by the private sector. Further development of calibration services, and particularly measurement quality assurance programs, is needed before the private-sector measurements can be considered satisfactory.

°In the state sector, the Federal government, in cooperation with the Conference of Radiation Control Program Directors, should foster the establishment of up to seven state regional laboratories to provide calibrations and measurement traceability to state radiation control programs. The number of these laboratories and the speed at which they could be established would be dependent on the amount of funding available.

Summary

The most effective measurement support system would provide those mechanisms required to ensure the continuing adequacy of radiation measurements that are intended to provide public safety and health. Some of the required mechanisms are in place and functioning, but many have not yet been developed. These weaknesses could be overcome with additional technical programs and institutional improvements at the intermediate laboratory level.

Glossary

Absorbed Dose (D)[2]: The amount of energy imparted by radiation to matter per unit mass. Its unit is the rad, which is equal to 1/100 joule per kilogram.

Accuracy: The degree of agreement of an individual measurement result or the average of several measurement results with an accepted reference ("true") value or level. As used in this report, numerical values of accuracy (2%, 5%, 10%, etc.) indicate the deviation of the measured value from the "true" value.

Air-Cavity Ionization Chamber: A contained volume of air usually surrounded by an air- or tissue-equivalent wall, and provided with electrodes that collect ions produced when ionizing radiation enters the volume. The number of ions produced, which are manifested in a small electrical current, is an indication of the radiation level.

Ambient Radiation: As used in this report, low-level x or gamma radiation that is emitted by radioactive materials in the environment or that results from manmade radiation sources. This type of radiation generally occurs in an area to which access is not restricted.

Area Survey: The measurement of radiation level within a specified area or within the vicinity of a radiation source.

Calibration (Instrument): A comparison of the response of a given instrument with the response of a standard instrument when both have been exposed to the same radiation source under the same conditions; or the determination of the response of a given instrument when exposed to the output of a standard source under well defined conditions. The standard instrument is calibrated against the national standard or against a secondary standard which has its calibration traceable to the national standard.

Dose Equivalent (H) : In general, the biological effectiveness of a given absorbed dose depends on the type of radiation and on the irradiation conditions. In current radiation protection procedures, an indication of the effect upon a given organ is inferred by weighting the absorbed dose in that organ by certain modifying factors. The product of these modifying factors and absorbed dose is called dose equivalent, H. The special unit of H is the rem. When D is expressed in rads, H is in rems.

Dosimetry: The practice of measuring or evaluating the absorbed dose, exposure, or similar radiation quantity.

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[2]Dose is often used loosely in the field to mean either absorbed dose or dose equivalent.

Environmental Radioactivity: Radioactivity that exists in the general environment as a result of natural occurrence of radioactive materials or as a consequence of radiation applications by mankind.

Field Level Entity: That element of the measurement support system that functions at the level where radiation is applied or used, and where routine measurements are necessary. This may involve an individual instrument or person, or may involve a laboratory with many measurement instruments and employees.

Instrument Traceability: The ability to demonstrate that a particular measuring instrument or artifact standard has been calibrated at acceptable time intervals either against the national standard or against a secondary standard which has been in turn calibrated against the national standard or a transfer standard.

Intermediate Level Laboratory: A laboratory equipped with transfer standards for providing calibrations for measurers in the field. Sometimes these laboratories provide instrument testing, measurement quality assurance, and other services.

Ionizing Radiation: Any type of particulate or electromagnetic radiation that, as a result of physical interaction, can cause atoms or molecules to lose (or gain) one or more electrons and, thereby, to become ionized. X rays, electrons, neutrons, gamma rays, beta rays, alpha particles, and pi mesons are examples of ionizing radiations.

Measurement Quality Assurance (MQA): Procedures which enable a measurer to demonstrate that the total measurement uncertainty relative to the national standard is within prescribed limits. One of these procedures may be a performance test.

Measurement Support System: The system of technical and institutional elements that serves as the mechanism for enabling field measurements to be sufficiently in agreement with the national standards.

Measurement System: The specific combination of instrumentation, operator, and procedure used to make a particular measurement of a radiation quantity.

Measurement Traceability: The ability to demonstrate on a continuing basis that the measurement results from a particular measurement system are in agreement with comparable measurement results obtained with the national standard within a specified uncertainty.

Millirem (mrem): See rem.

National Standard: Artifacts, such as well-characterized instruments or radiation sources, that embody international definitions of primary physical measurement standards for national use.

National Standards Laboratory: The laboratory which maintains the national measurement standards, such as the National Bureau of Standards in the United States.

Nuclide: A species of atom characterized by its mass number, atomic number, and nuclear energy state, provided the mean life in that state is long enough to be observable.

Occupational Radiation Survey: The measurement of radiation level within the vicinity of a radiation source for protection of workers from possible radiation hazards.

Personnel Monitoring: The measurement of the amount of radiation to which a person has been exposed by means of a small measurement instrument worn or carried by that person.

Person-Rems: The product of the average individual dose in a population times the number of individuals in that population.

Precision: The degree of reproducibility with which a measurement is performed.

Radionuclide: A radioactive nuclide.

Radiopharmaceutical: A radionuclide usually contained in a pharmaceutical preparation that is administered internally to the human body for the purpose of medical diagnosis or therapy.

Rem: The unit of dose equivalent. The dose equivalent in rems is numerically equal to the absorbed dose in rads multiplied by the quality factor and any other necessary modifying factors. (Originally derived from roentgen equivalent man.) A millirem (mrem) is 1/1000 of a rem. (See also person-rem.)

Standard Reference Material: A well-characterized reference material generally used for calibration of a measurement system, or for development or evaluation of a measurement method.

Traceability: The systematic process (or set of processes) whereby a quantity is measured in terms of an appropriate reference measurement standard which serves as a national standard. (See also instrument traceability, measurement traceability.)

Transfer Standard: A physical measurement standard which is calibrated by direct comparison with the national standard. A transfer standard is typically a high-quality measurement instrument or a radiation source.

Uncertainty: An estimate of the limits of the total amount of inaccuracy in a measurement or series of measurements. The total uncertainty consists of both random and systematic uncertainties.

Organizational Abbreviations

AAPM - American Association of Physicists in Medicine

ANSI - American National Standards Institute

BIPM - Bureau International des Poids et Mesures

BRH - Bureau of Radiological Health

CRCPD - Conference of Radiation Control Program Directors

DOD - Department of Defense

DOE - Department of Energy

EPA - Environmental Protection Agency

ISO - International Organization for Standardization

ICRP - International Commission on Radiological Protection

ICRU - International Commission on Radiation Units and Measurements

NBS - National Bureau of Standards

NCI - National Cancer Institute

NCRP - National Council on Radiation Protection and Measurements

NRC - Nuclear Regulatory Commission

OSHA - Occupational Safety and Health Administration

Requirements for an Effective National Ionizing Radiation Measurements Program

1. Statement of the Problem

Reliable measurements have been demonstrated for only a fraction of the ever-increasing uses of *ionizing radiation*[1] and for human exposures to this radiation.

Adequate *accuracy* is achieved when field measurements are in agreement with national physical measurement standards to within specified limits. To achieve and document this needed agreement, field measurements must be *traceable* to the national standards through *calibrations* and *measurement quality assurance* tests. The United States currently lacks the means to achieve these calibrations and measurement quality assurance goals in key areas of radiation measurement. In other areas for which there are already agreement mechanisms, these mechanisms may need further refinement.

1.1 Pervasiveness of Ionizing Radiation

1.1.1 Naturally-Occurring Sources

Mankind is continuously exposed to a number of natural sources of radiation. In fact, all life has evolved in the presence of radiation. These natural sources include: cosmic rays; electromagnetic and charged particle radiation from the sun; and radioactive materials found in the earth's biosphere. As indicated in Figure 1-1, natural sources make the largest contribution to the average whole-body radiation dose in the United States. The actual dose of ionizing radiation received by individuals varies with geographic location [NCRP - 1975], but averages over 100 *mrem*/y.

Exposure to natural sources is generally uncontrollable, but does not appear to be a biological hazard unless the *radionuclides* contained in the earth are redistributed or concentrated by human activity or technology. Actions that enhance naturally-occurring radiation include mining operations, well drilling and development, burning of fossil fuels, and the use of construction materials (e.g., granite, brick, concrete block) containing radionuclides [Gesell - 1975].

1.1.2 Man-made Sources

Radiation sources developed by man include devices such as x-ray machines and charged-particle accelerators, and

[1]Italicized words are defined in the glossary found following the Executive Summary.

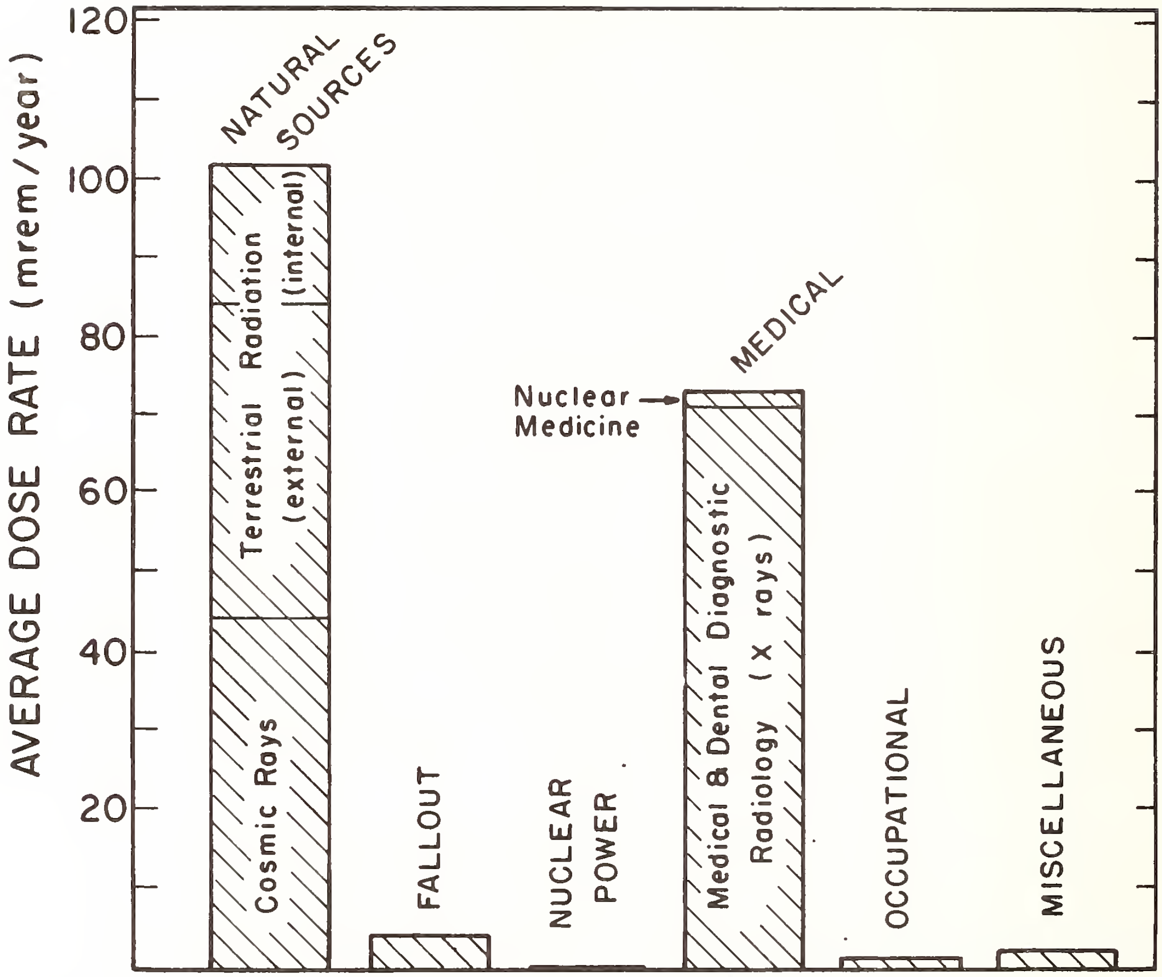

Fig. 1-1. Estimated average annual whole-body dose rates in the U.S. (1970) [BEIR-1, 1972].

artifically-produced radionuclides such as those generated in the operation of nuclear reactors, or those produced specifically for use in nuclear medicine or industrial applications. As shown in Figure 1-1, the total average annual dose to the public from all man-made radiation sources is approximately 80 mrem per person, which is less than the dose resulting from the natural sources. Diagnostic x rays and other medical procedures make up 90 percent of the population dose from man-made sources. In contrast to radiation dose received from undisturbed natural sources, the dose due to man-made sources can be effectively controlled.

1.2 National Concern with Radiation

1.2.1 Public Concerns with Risk

The nation's leaders and the general public are seriously concerned about possible health hazards resulting from exposure to ionizing radiation from man-made or naturally-occurring sources, and from radiation administered during medical procedures.

Probably the single event which caused greatest public concern about ionizing radiation was the accident at the Three Mile Island nuclear power plant in Pennsylvania. It has been estimated [TMI-1979] that the 2 million people who live within a 50-mile radius of the plant received an excess aggregate radiation dose of 3300 person-rems due to the accident. This is equivalent to the natural background radiation dose that the same population would be exposed to in a period of 10 days. Many of the instruments used to measure radiation levels were subsequently submitted to NBS for calibrations because the particular type of radiation predominant in off-site locations was characteristically different from the type used originally to calibrate the instruments. The calibration results showed that most of these instruments overestimated radiation present at Three Mile Island.

General concern about the effects of low level radiation encountered occupationally or in the general environment has also been increased by recent studies. Effects of low radiation levels have been reported for workers at the Hanford (Washington) facility of the Department of Energy [Mancuso-1977, Kneale-1978] and the Portsmouth naval shipyard [Najarian-1978]. Low-level radiation's effects have prompted a number of recent studies including a reanalysis of the Tri-state medical x-ray survey data [Bross-1977, 1979], investigation of military personnel exposed to atomic weapons tests, a study of the effects of fall-out on children downwind from such tests [Lyon-1979] and a re-examination of atomic bomb survivors in Hiroshima and Nagasaki [Rossi-1978]. Several of these studies indicate increased deleterious health effects at low doses, but questions have been raised about the adequacy of the measurements that were made and the adequacy of the methodology of analysis employed [Sanders-1978, Gertz-1978, Anderson-1978, Reissland-1978, Rothman-1979, Boice-1979, and Spiers-1979].

The Committee on Biological Effects of Ionizing Radiation (BEIR) of the National Academy of Sciences has reviewed its 1972 report [BEIR 1-1972] concerning the health effects of ionizing radiation. Despite the new studies mentioned above, this group concluded that risk estimates remain essentially the same as those presented in the 1972 report.

A report by the Presidentially-mandated Interagency Task Force on the Health Effects of Ionizing Radiation concluded that inherent methodological problems may prevent scientists from ever finding a definitive answer to the low-dose question [Libassi-1979]. This group listed *dosimetry* first among these problems:

> "It is often impossible to determine the dose received by an individual although researchers usually attempt to estimate it. As a result, it may be difficult to determine whether an observed response indicates a greater-than-expected effect of a low dose of radiation or a predictable effect of a higher-than-expected dose of radiation."

All of the above studies have one thing in common--they attempt to relate biological effects to radiation dose. For the results to be meaningful, it is necessary to know accurately the dose distribution to the population under study. It is now increasingly acknowledged that the ultimate accuracy in determination of a dose-effect relationship rests on accurate knowledge of the dose given to the population under study. This knowledge can only come about through more extensive and accurate radiation measurements.

1.2.2 Benefits of Radiation

The degree to which sources of radiation should be controlled is determined by an assessment of the benefits from their application, balanced against the resultant risk to public health and safety. This assessment is difficult because the risk cannot be precisely quantified, particularly when the level of radiation exposure is low [Libassi-1979]. If the risk is overestimated, potentially beneficial radiation applications may be foregone.

An important example of a national benefit of radiation applications is nuclear power, which currently provides over 10 percent of the total U.S. electric generating capacity [INFO-1979].

This percentage is expected to increase over the next few decades, thereby reducing our relative dependence on imported oil.

Substantial benefit is received from medical applications of radiation for diagnosis and therapy. Each year, more than 150 million Americans receive medical and dental x rays. It has been estimated [McIntyre-1979] that the number of nuclear medicine procedures, which employ radioactive materials, has risen from 7 million in 1975 to 14.5 million in 1979. A vast increase in diagnostic information has been made possible through the use of recently-developed computed-tomography x-ray systems (CT scanners).

Industrial radiation processing is used primarily for curing plastics and sterilizing medical products, resulting in improved qualities or lower costs. Since 1970, industrial radiation processing has grown six-fold to become a billion dollar industry (see Appendix C, which discusses this and other selected examples of the growth and economic value of radiation applications).

1.3 Regulation of Radiation

Regulations have been promulgated by Federal, state, and local agencies in response to public concern about potential hazards resulting from rapidly expanding applications of ionizing radiation. As indicated in Table 1-1, radiation control responsibilities in the nation are broadly distributed among many agencies at the Federal and state level. In some cases, the authority granted to a specific agency may be unclear and may appear to overlap the authority granted to a different agency. At the Federal level a relatively large number of agencies issue regulations for radiation control under authorities specified by an increasing number of acts [Dodge-1978].

Through various contracts and agreements, responsibility for enforcing many of the Federal regulations is delegated to state radiation control programs [AEA-1954]. This responsibility, combined with that of enforcing a growing number of regulations issued by states themselves, assigns to state programs a major national role for ensuring public health and safety.

The legislative authorities under which various Federal agencies issue specific regulations are shown in Table 1-2 [Dodge-1977, 78, 79]. Although 19 Federal agencies have been identified which have some radiation health and safety authority, only those agencies with major responsibility are included in the table.

Table 1-1. Major Responsibilities for Radiation Protection

CATEGORIES OF EXPOSURE OF THE PUBLIC

	MEDICAL	OCCUPATIONAL/INDUSTRIAL	NUCLEAR POWER/FUEL CYCLE	CONSUMER PRODUCTS	TRANSPORTATION	WASTE	ENVIRONMENT
STATES	Agreement States have authority over licenses covered under Atomic Energy Act (see NRC below). Most states have enabling legislation to control radiation from devices (x rays, etc.) and all radioactive material.	Agreement states have authority over licenses under Atomic Energy Act (see NRC below). Most states have authority to control exposure to radiation from all sources.	Agreement states have authority to regulate source, by-product and special nuclear material (up to critical mass) under Atomic Energy Act (see NRC below).	Agreement States regulate and license if contains source, by-product, or special nuclear material, in addition, many states have enabling legislation to regulate and control naturally-occurring and accelerator produced radioactive material.	Most states have authority to regulate intrastate transport of radioactive material.	Agreement states have authority to control low-level radioactive materials (see NRC below).	Most states have extensive authority to regulate radiation in the environment. Many conduct extensive ionizing and nonionizing radiation monitoring programs.
NUCLEAR REGULATORY COMMISSION (NRC)	Possession and use of radioactive material containing source, by-product or special nuclear material regulated and licensed by NRC or Agreement States.	Regulates and controls occupational exposure for all workers covered under Atomic Energy Act.	Regulates and licenses all phases and aspects relating to commercial nuclear facilities and to some DOE and other federal facilities.	Regulated by NRC or Agreement States if contains, source, by-product or special nuclear material.	Licenses regulated by NRC if involves source, by-product or special nuclear material.	Regulates commercially produced high-level wastes from nuclear fuel cycle, and all other waste containing source, by-product or special nuclear material.	Regulates effluents and emissions from all commericial nuclear facilities. Licenses under Atomic Energy Act regulated by NRC or Agreement States. Requires extensive monitoring.
FOOD AND DRUG ADMINISTRATION (FDA) BRH, etc. (in HHS-PHS)	Provides radiation protection guidance for diagnostic x rays. Regulates production, distribution, and use of radiopharmaceuticals. Establish device performance standards, and conduct QA programs.	Provides recommendation to states for workers in health professions.		Regulates radiation emission from electronic products (x ray, microwave, etc.) and medical devices containing radioactive materials.		Provides guidelines for disposal of radioactive materials used in medicine, and conducts (jointly with EPA) a program to collect and dispose of defective radium sources.	
ENVIRONMENTAL PROTECTION AGENCY (EPA)	Responsible for general federal guidance on radiation protection (inherited from Federal Radiation Council). Excludes radiation used in healing arts and occupational exposures to radiation under Public Health Service Act.		Promulgates generally applicable environmental standards for the nuclear fuel cycle.	Oversight authority inherited from Federal Radiation Council. Authority has not been used.	Oversight authority inherited from Federal Radiation Council. Authority not used.	Authority to regulate under Resource Conservation and Recovery Act. Responsible for radioactive wastes, mill tailings, and ocean disposal.	General responsibility and authority to regulate for environmental protection. Conducts, and sponsors extensive ionizing and nonionizing radiation monitoring programs.
DEPARTMENT OF ENERGY (DOE)		Responsible for radiation health and safety at all DOE owned and operated and DOE-contractor facilities.	Controls all DOE owned and operated and DOE contractor facilities including military nuclear weapon program and power generation (e.g. naval vessels).			Controls military high-level wastes from nuclear weapons program and power generators.	Responsible for radiological environmental protection at all DOE owned and operated and DOE-contractor facilities. Conducts extensive monitoring.
DEPARTMENT OF DEFENSE (DOD)	Broad in-house responsibility for control of radiation used in diagnostic and therapeutic medicine at military facilities.		Nuclear weapon program and power generation (naval vessels) under DOE control.			High-level military wastes controlled by DOE.	Responsible for radiological environmental protection at all military facilities. Nuclear weapons and power under control of DOE. Conducts extensive monitoring of both ionizing and nonionizing radiation.
DEPARTMENT OF TRANSPORTATION (DOT)					DOT regulates type of packages, labelling and shipment by all modes of carriage (air, rail, road, water). DOT and NRC jurisdictions overlap and have Memo of Understanding.		
OCCUPATIONAL SAFETY AND HEALTH ADMIN. (OSHA) (in Labor)		Authority to establish regulation for workers exposed to radiation and not covered under other authority (eg. NRC or FDA). Adopted ANSI Microwave Standard as mandatory. May not be enforceable.		Authority to regulate under OSHA Act. Authority not used.			
CONSUMER PRODUCT SAFETY COMMISSION (CPSC)				If risk is involved and material not applicable to control by NRC, CPSC can ban or require appropriate labelling, etc. Authority has not been used.			
U.S. POSTAL SERVICE (USPS)					Regulates shipment of radioactive materials through mails.		
MINE SAFETY AND HEALTH ADMINISTRATION (MSHA) (in Labor)		Regulates exposure of miners.					

Table 1-2. Responsibilities and Authorities of Regulatory Agencies.

Agency	Responsibilities	Legislative Authorities
1. Nuclear Regulatory Commission (NRC)	Regulation of nuclear facilities and radioactive materials; public and occupational safety; oversight of the use of radioisotopes in nuclear medicine and industry.	Atomic Energy Act of 1954 as amended. Energy Reorganization Act of 1974.
2. Department of Energy	Ionizing and non-ionizing radiation research related to hazards, biological effects safety standards; regulation of contractor facilities.	Energy Reorganization Act of 1974.
3. Environmental Protection Agency	Control and monitoring of ionizing and non-ionizing radiation in the environment; establishment of safety and exposure standards.	National Environmental Policy Act of 1969. Clean Air Act. Federal Water Pollution Control Act. Resource Conservation and Recovery Act of 1976. Safe Drinking Water Act. Marine Resources and Engineering Development Act of 1966. Toxic Substances Control Act. Solid Waste Disposal Act. Marine, Protection, Research and Sanctuaries Act of 1972. Uranium Mill Tailings Radiation Control Act of 1978.
4. Department of Health and Human Services (DHHS) National Institute for Occupational Safety & Health (NIOSH) Food and Drug Admin. (FDA)	Biological effects and medical applications. Occupational safety and health standards. Protection of public from radiation emitting electronic products, and establishment of exposure standards.	Radiation Control for Health and Safety Act of 1968. Medical Device Amendments of 1976.
5. Dept. of Labor (DOL) Occupational Safety and Health Admin. (OSHA)	Occupational safety and health of personnel, including those working around radiation sources.	Occupational Safety and Health Act of 1970.
6. Dept. of Transportation (DOT)	Safety aspects of the transportation of radioactive materials.	Transportation Safety Act of 1974.

In addition to Federal regulation, the states maintain their own regulatory authority which in many cases is more comprehensive. The number of state enabling acts for radiation protection regulations is over 100 [Moats-1978]. States can implement model regulations as provided in the Suggested State Regulations for Control of Radiation [SSRCR-1978], with or without modification, or they can develop the regulations independently. It is highly desirable from the standpoint of the regulatee that the measurement requirements of the various Federal, state, and local regulatory agencies be consistent with one another.

Essentially all regulations which have as their purpose the control of public exposure to radiation hazards are stated in terms of specific measured upper limits. Most Federal and state agencies also support the ALARA principle, which suggests that every reasonable effort should be made to maintain radiation exposures as low as reasonably achievable. In recognition of this, agencies which have regulatory responsibility for radiation safety are increasingly emphasizing the need for reliable measurements. Whereas requirements for measurements of radiation consistent with national standards were formerly almost the exclusive province of procurement contracts, such requirements are now also found in radiation regulations [CFR-1979].

Uniformity of measurement results is of primary importance for conformity between the regulator and regulatee. Regulators are increasingly concerned that their measurements may have to be defended in a court of law (see Appendix A). Therefore, the incentive to assure adequate measurement quality is becoming stronger.

2. Measurement Needs vs. Present Capabilities

Greater accuracy is needed in measuring certain types of medical, occupational, and environmental exposures to ionizing radiation. Field accuracy, measurement standards for selected types of radiation, and measurement quality assurance programs are not yet adequate in key areas.

2.1 Needs for Accuracy in Radiation Measurements

The need for accuracy in radiation measurements varies with the application or situation, and to some extent with the type of radiation. The accuracy of measurements in the field is established by calibrations or measurement quality assurance tests by intermediate-level or national standards laboratories (see Section 3 for a full discussion).

2.1.1 Medical

The need for the highest accuracy in the field of medical radiation is for radiation therapy. Here it is generally agreed that 5 percent accuracy in absorbed dose to the tumor is desirable [Herring-1971; Shukovsky-1970; Shalek-1976]. This requires accuracy in radiation dose measurement of about 3 percent. The additional uncertainty is due to other factors such as patient movement, uncertainty in knowledge of the position of the tumor, uncertainties in the depth dose curve due to body inhomogeneities, etc. which may affect the tumor dose. The stringent accuracy requirement is due to the rather small difference between the radiation dosage for tumor control and the radiation level which will unacceptably damage the normal tissues. Regulatory requirements for accuracy are somewhat lower, 5 percent for beam calibration of Cobalt-60 (^{60}Co) therapy units under NRC regulation, and 10 percent as recommended by the Conference of Radiation Control Program Directors.

Since diagnostic x rays constitute the greatest contribution to the lifetime dose of the general public from man-made radiation, it is important that sufficient accuracy be achieved. The CRCPD and the Bureau of Radiological Health have specificed that measurements with 10 percent accuracy are needed in the field.

Accuracy requirements for *radiopharmaceuticals* used for diagnostic procedures such as brain and liver scans, and for therapy, have been adopted by the concerned regulatory agencies, particularly the NRC. A diagnostic dose of a radiopharmaceutical differing from the prescribed dose by more than 50 percent, or a therapeutic dose differing by more that 10 percent, is defined as a misadministration and must be reported and recorded. Accuracy is needed because too high a dose will give unnecessary radiation to the patient, while too low a dose may not yield a satisfactory diagnostic image, requiring repeated exposures.

2.1.2 Occupational

Occupational safety measurements for ionizing radiations frequently require accuracies on the order of 10 to 20 percent, if the radiation level is near or above permissible dose limits. If the levels are low, accuracies of a factor-of-two are frequently permitted. In the case of personnel monitoring where workers wear film badges or other kinds of dosimeters, accuracies of the order of 30 to 50 percent are frequently accepted, largely because of the extreme difficulty in achieving higher accuracy in this situation where precise location of the radiation source is frequently not known, and the orientation of the worker's body may influence readings. Requirements are the same, whether the worker is involved in medical, nuclear power, or conventional industrial applications of radiation.

Whereas radiation work is generally done in some kind of restricted area, there are always areas near radiation facilities where the public is admitted without restriction. The permissible radiation levels in these unrestricted areas are typically about one-tenth of those in the radiation hazard areas. Accuracy requirements are correspondingly somewhat relaxed due to the low radiation hazard levels.

2.1.3 Environmental

Environmental radiation measurements are generally made in support of regulations to protect the general public from exposure to radiation. Accuracy requirements for field measurements at levels near the regulatory limits are typically in the range of 10 to 20 percent, relaxing to a factor-of-two for very low level measurements such as background levels of radioactivity in natural matrices, food and water, etc. Monitoring of external radiation is typically done in terms of exposure or *absorbed dose*, whereas for the other categories activity is generally determined. For the purposes of regulation of ingested radioactivity, activity of an identified radionuclide is the appropriate measurement. Activity can be used with internal dose models to estimate the dose to the affected organs in the body.

2.2 Comparison of Needs with Capabilities

In Appendix B, a table of information is presented detailing accuracy needs in state radiation control programs as developed by the Conference of Radiation Control Program Directors (pp. B-11 to B-23). This and other information is summarized in Table 2-1, 2-2, and 2-3. Typical accuracy requirements are indicated in these tables for medical radiation measurements, occupational radiation measurements, and environmental radiation measurements. In the following sections we shall discuss the tables and the implications of the information given on field measurements, on intermediate level and NBS calibrations, and on NBS standards.

2.2.1 Medical Radiation

Radiation Therapy. In Table 2-1 are indicated some typical accuracy requirements for four types of radiation used in therapy: cobalt-60 gamma rays, high-energy x rays, high-energy electrons, and fast neutrons. A measurement assurance test of cobalt-60 therapy units in hospitals carried out by the National Bureau of Standards and the Bureau of Radiological Health found 83 percent of respondents within 5 percent of the accepted value, but 5 percent of the respondents more than 10 percent away from this value [Soares-1978]. A study conducted by the Nuclear Regulatory Commission yielded comparable results [Dicey-1978]. As can be seen from the table, a requirement of 3 percent accuracy in the field requires an accuracy of about 2 percent at the intermediate level, and requires an accuracy for the NBS national standard of about 1 percent. Cobalt-60 radiation therapy dosimetry is in a nearly satisfactory state. NBS calibrations and standards, and the intermediate level calibrations, which are provided by three American Association of Physicists in Medicine Regional Calibration Laboratories and by the Radiological Physics Center in Houston, Texas under National Cancer Institute (NCI) sponsorship, provide acceptable accuracy for those who use their services [Golden-1972]. What is presently needed is one additional regional calibration laboratory on the west coast, and measurement quality assurance on a continuing basis to help hospitals which are not meeting the required accuracy [AAPM-1979].

Two large and rapidly growing methods of radiation therapy are high-energy x rays and electrons produced by linear accelerators and betatrons. The accuracy available in radiation therapy centers for high-energy x rays is not known. For

Table 2-1. TYPICAL ACCURACY REQUIREMENTS FOR MEDICAL RADIATION

Kind of Measurement	Radiation	Field: Accuracy Required	Field: Accuracy Available	Field: Source of Accuracy Requirement	Intermediate Level Calibration: Accuracy Required	Intermediate Level Calibration: Accuracy Available	NBS Calibration: Accuracy Required	NBS Calibration: Accuracy Available	NBS Standard: Accuracy Required	NBS Standard: Accuracy Available
Dosimetry for radiation therapy, external beam	^{60}Co γ	3%[a]	<5%, 83%[d] 5-10%, 12% >10%, 5%	Herring and Compton, 1971; Shukovsky, 1970; Shalek et al., 1976; NRC[e] CRCPD	2%	2-3%	1.5%	1-2%	1%	≤1%
	High energy x	3%	?		2%	4%[b]	1.5%	4%[b]	1%	4%[b]
	High energy e-	3%	<5%, 60%[d] >5%, 40%		2%	4%[b]	1.5%	4%[b]	1%	4%[b]
	n	3%	7-10%		Not needed at present		2%	Not available[c]	1.5%	Not available[c]
Medical x ray, diagnostic	x	10%	?	BRH CRCPD	5%	5%	3%	1-2%	2%	1%
Nuclear medicine diagnostic and therapeutic	β, γ	10%	<30% (hospital) <10% (manufacturers)	NRC[f] CRCPD	5%	Not available (needed for short-lived materials only)	2-5%	1.5%	2-3%	1.5%

[a] Good therapy practice requirement (3%) is sometimes tighter than regulatory requirement (5-10%).
[b] Best available is ^{60}Co calibration with use of absorbed dose conversion factors, C_E and C_λ.
[c] Small program just starting with NCI support.
[d] The meaning of this notation is, for example, that 83% of those tested demonstrated accuracy better than 5% (12% of those tested demonstrated accuracy between 5 and 10%, etc.).
[e] Required accuracy of calibration measurements for teletherapy units is stated in 10 CFR 35.21 (b) (1).
[f] Accuracy requirements are implied in 10 CFR 35.41 (d), (e), and (f).

high-energy electrons NBS has provided a ferrous sulfate dosimetry service for a number of years which has shown about two-fifths of the respondents to be outside of a 5 percent accuracy limit. Accuracies available at NBS and intermediate calibration levels are not satisfactory because direct calibrations with high energy x rays and electrons are not provided. Instead, cobalt-60 calibration is provided with the use of absorbed dose conversion factors for electrons and for high energy x rays. There is about a 4 percent uncertainty in these factors, which is the dominant uncertainty in the accuracy available at NBS [Nahum-1976].

A new method for radiation therapy using fast neutrons is being tested at about five centers in the United States. The accuracy available is about 7 to 10 percent, as shown by two international dosimetry comparisons, one sponsored by the International Commission on Radiation Units and Measurements (ICRU) and the other by the Commission of the European Communities. This accuracy is considered unsatisfactory [ICRU-1978; Broerse-1978]. Therapy centers in the United States are using similar dosimetry instruments and are on a closer relative scale than this [Smith-1976]. Due to the small number of centers no intermediate level calibration laboratory is needed. NBS calibrations are not available for neutron radiation therapy dosimetry. However, a small program was started at NBS in September 1979 with National Cancer Institute support to develop neutron dosimetry calibration capabilities.

Diagnostic X rays. As shown in Figure 1-1, medical diagnostic x rays constitute the major source of man-made ionizing radiation dose to the population. Calibration of the useful beam output is required to an accuracy of 10 percent. Accuracy available in hospitals has not been documented. The AAPM regional calibration laboratory system has recently agreed to permit calibration of diagnostic instruments. However, at present, calibrations for diagnostic x-ray measurements are provided chiefly by equipment manufacturers and the Bureau of Radiological Health (BRH). As an example during 1979 BRH performed approximately 250 calibrations on state-owned instruments and 380 on federally-owned instruments on active loan to the states [Ohlhaber-1979].

Nuclear Medicine. Radiopharmaceuticals are used in nuclear medicine primarily for diagnosis but occasionally for therapy. An accuracy requirement of 10 percent for therapy and 50 percent for diagnosis has been established by the NRC. Current measurement assurance testing of hospitals by NBS indicates that most report values which differ by less than 30 percent from the NBS value. Radiopharmaceutical manufacturers who jointly sponsor a measurement assurance program with NBS are now nearly always within 10 percent of the NBS value. This is a significant improvement over the situation before this program [Cavallo-1977]. Intermediate level or regional calibration laboratories are needed only for short-lived materials since NBS long-lived radioactivity standard reference materials can be used directly by the hospital or clinic. Regional calibration laboratories are not available, however, to provide calibrations of short-lived materials such as metastable technetium-99 (^{99m}Tc). When available for the given nuclide, NBS calibration and primary standardization accuracies are sufficient.

2.2.2 Occupational Radiation Protection

Restricted Area Survey. As is shown in Table 2-2, accuracy requirements for radiation surveys of restricted areas (utilized by radiation workers but not by the general public) are typically 20 percent. The accuracies available in the field are not known. Some intermediate level calibrations are available, but there is no regional calibration laboratory or secondary standards laboratory that is *measurement traceable* to NBS. Some manufacturers do offer calibration services and may claim *instrument traceability* to NBS. Furthermore, most field instruments are not submitted to such secondary standards laboratories on a regular basis. NBS calibration services and

Table 2-2. TYPICAL ACCURACY REQUIREMENTS FOR OCCUPATIONAL RADIATION PROTECTION

Kind of Measurement	Radiation	Field			Intermediate Level Calibration		NBS Calibration		NBS Standard	
		Accuracy Required	Accuracy Available	Source of Accuracy Requirement	Accuracy Required	Accuracy Available	Accuracy Required	Accuracy Available	Accuracy Required	Accuracy Available
Restricted area survey	x,γ	20%	?	NRC[f] and CRCPD	5%	Not available[d]	3%	3%	2%	2%
	β	20%	?	NRC and CRCPD	5%	Not available[d]	3%	Not available	2%	Not available
	n	20%	?	NRC	5%	Not available[d]	3%	Varies[a]	2%	Varies[a]
	α (airborne)	20%	?	CRCPD	5%	Not available[d]	3%		2%	
Personnel monitoring	x,γ	30-50%[b]	33%[e] within spec.	ANSI Draft National Standard	5-7%[c]	Not available[d]	3%	3%	2%	2%
	β	30-50%[b]	59%[e] within spec.	ICRU, NCRP, NRC[g]		Not available[d]	3%	Not available	2%	Not available
	n	30-50%[b]	36%[e] within spec.			Not available[d]	3%	Varies[a]	2%	Varies[a]
Unrestricted area survey	x	20%	?	CRCPD	10%	Not available[d]	5%	3%	3%	2%

[a]For neutron sources useful for checking normalization, of instrument readings accuracy available is 2% for calibrations, 1.2% for standard. Reactor beam monoenergetic neutron (2 keV, 25 keV, 144 keV) accuracies are both 10%. Van de Graaff monoenergetic beams are available 0.2-1.2 MeV with calibrations accuracy of 5%; standard, 2%. Monoenergetic neutron beams are needed to check energy response of instruments.
[b]At values small compared to the permissible limit, factor-of-2 accuracy is permitted.
[c]Based on ISO standard.
[d]No calibrations are available from measurement traceable intermediate level laboratories.
[e]The number shown is the percent of participants who performed within specifications during a pilot test of a draft American National Standard.
[f]NRC Regulatory Guide 8.21 states accuracy requirements for calibration of survey instruments.
[g]Accuracy requirements for pocket dosimeters are stated in 10 CFR 34.33 (c).

standards are acceptable for *x* and gamma radiation. They are not satisfactory for the case of monoenergetic neutron calibrations where a wider range of energies and higher accuracy are needed, for beta rays where a series of higher accuracy NBS standards is needed, nor for airborne alpha radiation where NBS has no suitable calibration facility. Measurement quality assurance is not available.

<u>Personnel Monitoring</u>. For the radiations shown, which are the most important, accuracy requirements range from 30 to 50 percent based on a draft American National Standard prepared by the Health Physics Society for the American National Standards Institute (ANSI), which is in turn based on ICRU, National Council on Radiation Protection and Measurement (NCRP) and International Commission on Radiological Protection (ICRP) recommendations. This requirement is relatively low because it is not presently possible to make significantly better measurements. Some reasons for uncertainties in the measure-

ment process are variability in dosimeter materials, poor procedures, inherent limitations in dosimeter design, and use of correction factors in lieu of a range of radiation sources for dosimeter calibration. A recent performance test of commercial personnel monitoring services in the United States indicated that about one-third of the suppliers are within specifications for x rays, gamma rays, and neutrons, and roughly 60 percent for beta particles (see Table 2-2). The required intermediate level calibration accuracy as recommended by the International Organization for Standardization (ISO) is 5 to 7 percent. This accuracy can reasonably be expected to be much better than the actual accuracy in the field since the important perturbing factors in the measurement situation are absent. Intermediate level calibration laboratories are not available. The standards situation is the same as for restricted area surveys.

Unrestricted Area Surveys. Accuracy requirements here are lower than for restricted area surveys because of the very low radiation levels in areas of public access. Accuracy available in the field is not known, nor are suitable intermediate calibration laboratories available. NBS standards and calibration accuracies are sufficient.

2.2.3 Environmental Radiation

Radioactivity. Typical accuracy requirements near regulatory limits are in the range of 10 to 20 percent. The requirements decrease to a factor-of-two accuracy at levels less than or equal to 10 percent of the maximum permissible activity level. Environmental measurements are difficult, frequently involving questions of chemistry and sampling. As a result the accuracies available as found by measurement assurance testing vary widely as shown in Table 2-3 from uncertainties such as 5 percent to a factor-of-ten. Intermediate-level services, in the form of radioactivity standards, are available from the Environmental Protection Agency (EPA), but do not provide complete coverage of the field. NBS standards and calibrations, when available for the particular radionuclide in question, are usually sufficiently accurate. Environmental radioactivity standard reference materials provide a means of giving calibrations directly to the user without going through the intermediate level. In practice, however, because of the large number of measurers, many standard reference materials are supplied by the intermediate level laboratories.

Measurements of radioactivity in natural matrices such as water, soil, and biological materials are important to establish natural background levels and as an aid to environmental radioactivity measurements. Since the radioactivity of these samples is normally well below the regulatory limits, a factor-

Table 2-3. TYPICAL ACCURACY REQUIREMENTS FOR ENVIRONMENTAL RADIATION MEASUREMENTS

Kind of Measurement	Radiation	Field			Intermediate Level Calibration		NBS Calibration		NBS Standard	
		Accuracy Required	Accuracy Available	Source of Accuracy Requirement	Accuracy Required	Accuracy Available	Accuracy Required	Accuracy Available	Accuracy Required	Accuracy Available
External radiation (dose)	γ	20%[a]	5% to factor of 10	NRC,[e] CRCPD	10%	5%[b]	3%	≤2%[b]	3%	≤2%[b]
Airborne (activity)	α, β, γ	10%[a]	5% to factor of 10	CRCPD	5%	5%	2%	≤2%[c]	2%	≤2%
Food and water (activity)	α, β, γ	10%[a]	5% to factor of 10	CRCPD	5%	5%[d]	2%	≤2%[d]	2%	≤2%[d]
Liquids (activity)	α, β, γ	15%[a]	5% to factor of 10	CRCPD	8%	5%	3%	≤2%	3%	≤2%
Surface contamination, solids (activity)	α, β, γ	10%[a]	5% to factor of 10	CRCPD	5%	5%[d]	2%	<2%[d]	2%	≤2%[d]

[a]Near regulatory limit. Requirements decrease to factor - of -2 well below limit.
[b]Calibrations and standards are available only for a limited energy sprectrum.
[c]Services are available for a limited number of gaseous radionuclides.
[d]Services are available for a limited number of radionuclides and matrices.
[e]Accuracy requirements for thermoluminescence dosimeters are stated in NRC Regulatory Guide 4.13.

of-two accuracy in the field is sufficient. However, the measurement problem is extremely difficult and outlying results are sometimes as far off as a factor of 50. A partial solution to this problem is to use standard reference materials traceable to NBS.

During the past few years, potential health hazards of radiation exposure due to the presence of the radioactive gas radon in the environment and in houses have received increasing attention. The measurement of radon and its decay products, which manifest themselves as airborne alpha and beta radiation, is relatively difficult. Commercial availability of newer types of instruments is limited, and calibrations provided by commercial suppliers have been found to be unsatisfactory [Breslin-1980]. NBS can provide only a well-characterized radium source which produces radon, and has no standards or facilities for calibration of the various types of instruments used to make relevant measurements.

External Radiation. Since the radiation levels measured to determine the dose from external radiation in the general environment are usually quite low (at or near normal background levels), the required accuracy is on the order of 20 percent. Although no comprehensive performance testing of field capability has been done, there is reason to believe that this level of accuracy cannot be achieved when certain types of common survey instruments are used. If pressurized ionization chambers are used, the desired accuracy can be achieved when this instrument is calibrated properly. A series of international intercomparisons of environmental thermoluminescence dosimeters showed a large variation in accuracy of participants' results. Although intermediate level calibrations are available, they are not always performed with a radiation source that is representative of the energy spectrum encountered in the field. The NBS standard and calibration capability also are not representative of environmental field conditions.

3. Measurement Support System

3.1 Necessary Elements of a Radiation Measurement Support System

3.1.1 Measurement Standards

Primary physical measurement standards are ones which, with certain defining relationships, fix the size of all units of measurement. *National standards* are artifacts that embody international definitions for national use. Often for more frequent use and service, other standards called national reference or national transfer standards are developed by the national standards laboratory. These are compared as frequently as necessary with the national standards. For ionizing radiation, national standards exist for the quantities of exposure, absorbed dose, radioactivity, source emission rate, and fluence rate. For example, a national standard for exposure is the free-air chamber while the corresponding national transfer standard is an *air-cavity ionization chamber*. The types of ionizing radiation of most interest for measurement in the medical, occupational, and environmental areas are x rays, γ rays, β particles, α particles, electrons, and neutrons. Establishment and maintenance of a national ionizing radiation standard usually involves an instrument used in conjunction with a well-characterized radiation source.

3.1.2 Calibrations

Transfer standards provide a measurement reference basis where it is needed and used. These standards are compared to the national standards or national reference standards. The process of comparison constitutes a calibration. When transfer standards are calibrated and returned to an intermediate laboratory, a factory or other local laboratory, they become the basis for calibration of local working standards or field instruments. Instruments calibrated against these transfer standards are said to be _instrument traceable_. Concepts fundamental to calibration of a standard and its use are _accuracy_, _precision_, and _uncertainty_ (see Appendix B, p. B-7). _Accuracy_ is the degree of agreement of an individual measurement or the average of several measurements with an accepted reference value or level, and _precision_ is the degree of mutual agreement among individual measurements under defined conditions. The _uncertainty_ of a measurement is usually taken as a combination of the random and systematic errors associated with the measurement.

3.1.3 Field Instruments

Working instruments for measurements by scientists, technicians, inspectors, or regulators at a local site of interest are called field instruments. These instruments are calibrated against transfer standards maintained by a local laboratory or sometimes at an intermediate standards laboratory. Field instruments can often be tested and adjusted by the application of a known, associated quantity. For example, some ionizing radiation measurement instruments may be tested by applying a known voltage to their associated electrical circuits and their readout adjusted accordingly. Desirable properties of field instruments are that they be simple to calibrate, maintain, and use, and also be portable and rugged.

3.1.4 Data Analysis and Recording

Essential to valid interpretation and, when necessary, comparison of measurement data is that all data be recorded properly and analyzed by acceptable statistical techniques. Accuracy and/or precision and uncertainty of measurements should be reported when appropriate. Records of the conditions under which measurements were made are also essential. This makes possible the proper identification of inconsistencies, errors, and significant changes in the data. On some levels, measurement data analysis and evaluation can lead to standard reference data. Such data are important in developing and maintaining measurement standards. In addition, these data, along with other associated measurement data on the interaction of ionizing radiation with matter, serve as the basis for mathematical models for calculating the effects of ionizing radiation. Direct measurement of certain physical quantities is impractical under some conditions and must be based on calculations involving other, related phenomena. These calculated values become the basis for interpreting the conditions and effects of a particular ionizing radiation environment.

3.1.5 Measurement Quality Assurance

Measurement quality assurance is a procedure that enables a measurer to demonstrate, for example by measuring an accurately-known quantity (unknown to the measurer), that the total measurement uncertainty relative to national standards is within prescribed limits. Measurement quality assurance is necessary on both a national and an international level. Periodic comparisons should be made between nations of their national standards, and between national and international primary standards. These comparisons assure that particular national standards satisfactorily define the internationally agreed upon units of measurement to a sufficient level of accuracy. Within a nation, continuing measurement quality assurance testing of intermediate standards laboratories and of field measurements can assure that measurements are sufficiently accurate for their intended purpose. Such measurements on the local level are said to be measurement traceable when they are demonstrated to be consistent with measurement results obtained with national standards. Measurement traceability is a rigorous test of the measurer's overall capability including performance of the instrument and personnel, and adequacy of procedures. For this reason it is much more desirable than instrument traceability which by itself does not assure correct measurements.

3.1.6 Documented Procedures

Accurate and traceable measurements often depend on the development of written standards or procedures that include: definitions; compilations of reference data; data recording and analysis; calibrations; recommended measurement practices; and test methods. Such written standards are prepared by voluntary consensus organizations, professional societies, instrument manufacturers, and governmental organizations. These documents should take into account the needs of those who will apply them in practice, and thus, ideally should be developed in cooperation with or open to comments by users before implementation or adoption.

3.1.7 Research and Development

In order to improve the accuracy of national and transfer measurement standards and improve the accuracy of the traceability path, a vigorous program of research and development must be supported. New knowledge, scientific data, and technical innovations in scientific instrumentation make possible continual improvements. An example of this is the semiconductor detector technology which revolutionized both radiation measurement and standardization. Research and development are usually performed at national standards laboratories, specialized scientific and technological institutions, universities, and private industry.

Activities usually cover areas larger than physical standards development and include test methods and all applications of measurement science and technology.

3.1.8 Education and Training

To develop the knowledge and skills needed to maintain competent measurement systems, education and training must occur on all levels. Errors found in measurement quality assurance testing can frequently be associated with inadequate education or training. Specialized courses are essential for disseminating the basic procedures needed for an in-house quality assurance program that guarantees adequate continuous performance between periodic tests. On some levels, education and training are needed on a long-term basis, while on other levels specialized seminars, workshops, and short-term training courses are sufficient. Intermediate or regional calibration laboratories often serve an educational or training function.

3.2 Institutional Structures for Measurement Support

The accuracy of field measurements of ionizing radiation is supported by reference to intermediate level laboratories. These intermediate level institutions in turn depend on national standards laboratories (such as the NBS in the United States) to keep their instruments and measurement standards comparable, as shown in Figure 3-1.

3.2.1 International Standards Laboratories

In 1875, an international treaty called the "Treaty of the Meter" was established to define and maintain basic measurement standards. At present, over 40 nations, including the United States, are signatories of this treaty [NBS-1977]. Measurement standards are maintained at the Bureau International des Poids et Mesures (BIPM) located at Sèvres, France. The BIPM serves as a center for comparison of national standards of measurement with international standards, and coordinates information exchange on measurement units and on progress in research and development on measurement science.

3.2.2 National Standards Laboratories

The National Bureau of Standards develops and maintains the national measurement standards for the United States. It also represents the U.S. in international deliberations and comparisons of measurement standards. Other comparable national laboratories are:

- National Research Council of Canada
- National Physical Laboratory (United Kingdom)
- Physikalisch-Technische Bundesanstalt (Federal Republic of Germany)

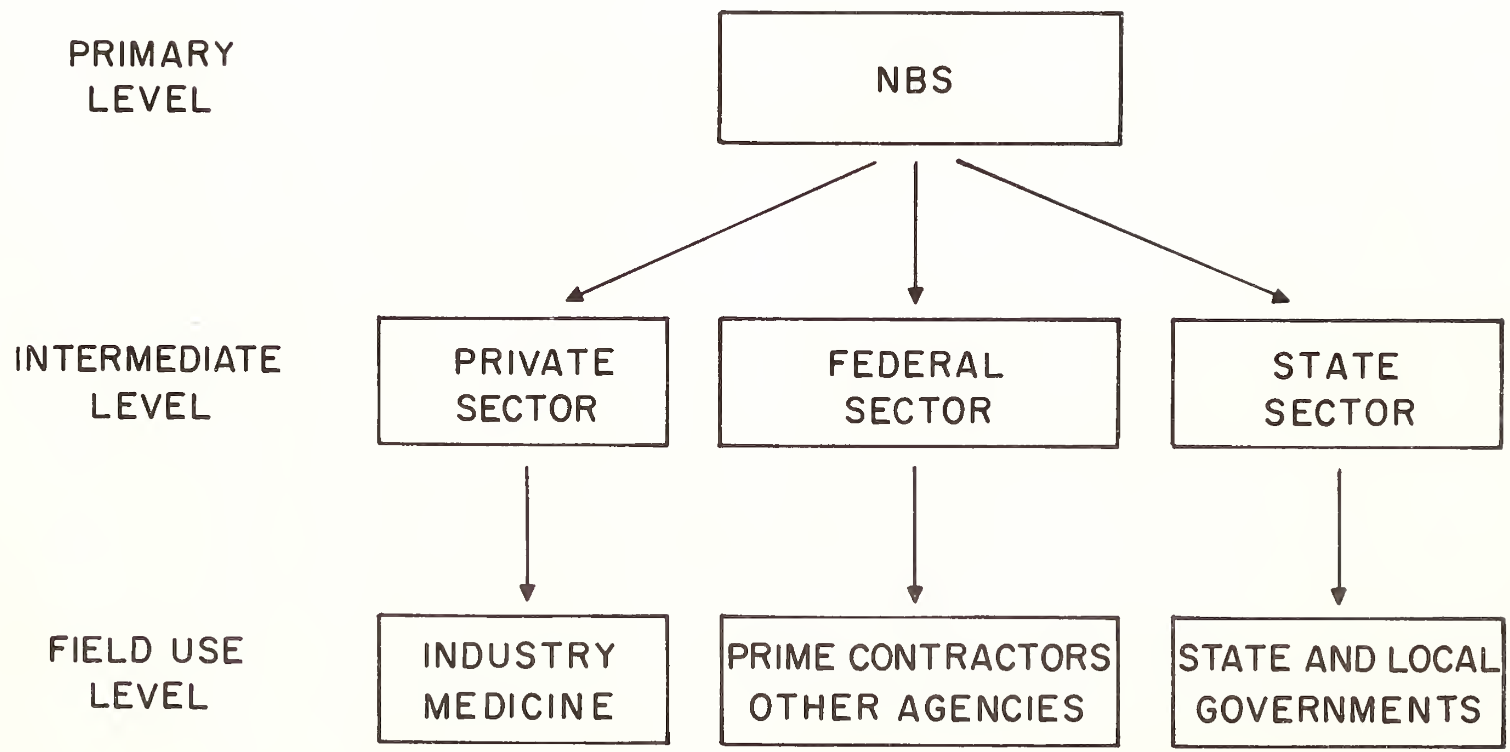

Fig. 3-1. Schematic showing the national measurement support system three-level concept.

The national standards laboratories serve as a reference for standards needs for governmental agencies, industries, and other relevant sectors of the national economy. In some nations, they have regulatory responsibilities. This is not the case for NBS in the United States.

3.2.3 Intermediate Level Laboratories

Intermediate standards laboratories are normally equipped with *transfer standards* and provide calibrations, and they sometimes provide measurement quality assurance and other services to measurers in the field. Intermediate standards laboratories are often convenient sources of education and training for field measurers, for example by observing the calibration or through short courses. These laboratories should be measurement traceable to NBS.

Advantages of inserting intermediate-level laboratories between the national standards laboratory and users in the field include: (1) ability to provide services to large numbers of users; (2) intermediate-level laboratories are often closer to users and can give faster service; (3) training of field measurement personnel is often more convenient; and (4) with regional intermediate-level laboratories, programs can be adapted to the needs of the region. However, the gains achieved by introducing intermediate-level institutions between the primary and field levels may be lost if more than one intermediate level is introduced, since this would allow uncertainties in the calibration chain to increase.

For therapy applications, three intermediate laboratories have been established under sponsorship of the American Association of Physicists in Medicine (AAPM). The Bureau of Radiological Health, Environmental Protection Agency, and Nuclear Regulatory Commission also maintain a limited number of intermediate standards laboratories for carrying out their respective regulatory responsibilities.

3.2.4 Field Level Entities

The measurement support system exists to serve the needs of those who make measurements at the field level. These are the ultimate measurement makers, who have the day-to-day responsibility for ensuring the safety and health of workers and the public. The nature of these entities varies considerably, ranging from laboratories that may have in-house capability for testing and calibrating instruments to an individual who possesses a single instrument. Included are manufacturers of radiation sources, users of such sources, manufacturers of radiation-measuring instruments, and those who enforce safety regulations.

Ideally, the adequacy of measurements at this level would be demonstrated periodically through participation in performance testing services provided by intermediate-level laboratories which, in turn, provide a measurement traceability link to the national standards laboratory. This is not the present situation, however, because the testing programs that would provide measurement traceability for field-level entities are not generally available. At this time, the predominant type of traceability at the field level is instrument traceability, which does not entail a demonstration of measurement adequacy. Calibrations that provide a high degree of instrument traceability may not be available to all who make measurement at the field level. Those calibrations that are available sometimes have questionable quality because too many intermediate levels are involved in making the link to the national standards.

3.2.5 Voluntary Standards Writing Organizations

A number of voluntary standards writing organizations exist both nationally and internationally. Ideally, a consensus standard is developed by inputs from representatives of all sectors interested or affected by the use of the standard. Written standards usually include: standard definitions, recommended practices, test methods, classifications of materials, and specifications for products. Voluntary standards are often incorporated in legal specifications for products and in Federal, state and local governmental regulations. Some international standards writing organizations important to ionizing radiation are:

- International Organization for Standardization (ISO)
- International Electrotechnical Commission (IEC)
- International Atomic Energy Agency (IAEA)
- International Commission on Radiological Protection (ICRP)
- International Commission on Radiation Units and Measurements (ICRU).

National standards writing or coordinating organizations include:

- The American National Standards Institute (ANSI)
- American Society for Testing and Materials (ASTM)
- National Council on Radiation Protection and Measurements (NCRP)

3.2.6 Professional Societies

As part of their organization, many professional scientific and technological societies maintain committees or task forces that concentrate on standards development. One of the important functions of some professional societies is to provide accreditation of laboratories for calibration and testing of measurement instruments and services. Examples of such organizations that have activities or concerns in development of voluntary standards in the areas of ionizing radiation are:

- Conference of Radiation Control Program Directors (CRCPD)
- Health Physics Society (HPS)
- Institute of Electrical and Electronics Engineers (IEEE)
- American Association of Physicists in Medicine (AAPM)
- Atomic Industrial Forum (AIF)
- College of American Pathologists (CAP)
- American Nuclear Society (ANS)

3.3 Status of the Present Measurement Support System

3.3.1 Strong Points

Both the elements of a radiation measurement support system discussed in Section 3.1 and the institutional structures discussed in Section 3.2 are basic to the measurement support system. Many of the essential elements of the measurement support system are in place in the United States; however, it is recognized that improvements are needed overall [see Appendix A]. A list of strong points of the system follows:

- National measurement standards for many quantities are established at NBS. Frequent comparisons have been made of these standards both bilaterally and multi-laterally with other nations that have well-established national standards laboratories and internationally with those ionizing radiation standards maintained by BIPM.

- NBS provides calibration, measurement quality assurance, and consultation services to various levels of the measurement support system. NBS also provides educational services such as symposia, workshops, and seminars.

- The framework is in place to support and to develop voluntary standards writing for all areas of ionizing radiation on both a national and international level. For example, on the national level, the NCRP has more than 40 published documents and 54 functioning committees for standards review and development.

- Federal regulatory agencies, namely BRH, EPA, and NRC, have established intermediate standards laboratories to be responsive to some of their regulatory responsibilities. For example, the EPA laboratory in Las Vegas and the Radiological and Environmental Sciences Laboratory of the Department of Energy (DOE) in Idaho Falls serve as intermediate-level standards laboratories for EPA and NRC, respectively [Ziegler-1978; Weiss-1974]. Some state and local governments have been supported by these Federal agencies to carry out the agencies' responsibilities in regulation of ionizing radiation. In the Federal sector, the Department of Defense (DOD) and DOE provide intermediate level calibration services for their own needs.

- Professional societies have been active in supporting establishment and fostering of intermediate standards laboratories and services. Those involved include:

American Association of Physicists in Medicine (AAPM)- has a program for providing accredited calibration services for instruments used in medical therapy. Three regional calibration laboratories have been accredited by this organization: M.D. Anderson Hospital (Houston Texas), Memorial Hospital (New York, N.Y.), and Victoreen Instrument Company (Cleveland, Ohio). Standard instruments and their measurements in these laboratories are traceable to NBS. A significant part of the service of these laboratories is also providing free consultations on measurement and calibration problems. In addition to these regional calibration laboratories, a Radiological Physics Center [Shalek-1976] has been set up at the M.D. Anderson Hospital. This Center is operated by the AAPM and funded by the National Institutes of Health through the Committee for Radiation Therapy Studies. The Center is conducting a measurement quality assurance program for the ionizing radiation dosimetry practices of approximately 200 participating hospitals.

Atomic Industrial Forum (AIF) - has a cooperative program with NBS in the area of radiopharmaceuticals. A research associate program has been established by AIF at NBS. This program provides a mechanism whereby NBS supervises a radioactivity measurement quality assurance program for the radiopharmaceutical industry [Collé-1976; Cavallo-1977]. At present, seven major commercial radiopharmaceutical manufacturers are participating. NBS also has currently an interagency agreement to provide similar services to the Food and Drug Administration.

College of American Pathologists (CAP) - also has a cooperative program with NBS in the area of radiopharmaceuticals. The Nuclear Medicine Subcommittee of CAP in cooperation with NBS provides a radiopharmaceutical measurement quality assurance program for subscribing hospitals, clinics, and nuclear pharmacies [Cavallo-1977]. Under CAP sponsorship, NBS distributes radioactive samples twice a year for identification and assay to approximately 50 to 100 participating laboratories.

3.3.2 Weak Points

Although many of the basic elements of the measurement support system for ionizing radiation are in place, a number of serious deficiencies exist:

- As pointed out in Section 2 of this report, national measurement standards maintained by NBS are not adequate in the areas of (1) dosimetry required for the use of high-energy x rays, high energy electrons, and fast neutrons in radiation therapy; (2) monitoring of occupational exposure to neutrons and beta rays; and (3) measurement of low-level radiation in the general environment. As a result NBS is unable to provide calibrations in these areas.

- Instrument calibrations and measurement quality assurance services are not available to all who need them at the field level. Only a few accredited intermediate-level laboratories exist at this time, and they cover limited areas of need. A pressing need appears to be for intermediate laboratories to provide a broad range of services to state and local regulatory agencies. These agencies have primary responsibility for detecting and monitoring radiation in the interest of public health and safety, and demands on them are increasing both in terms of quantity and quality of their measurements [Parrott-1976].

- Instruments available for use at the field level are in some cases inadequate for the intended purpose. This is particularly true for measurement of beta and neutron radiation. Needed improvements include: less dependence of instrument response on radiation energy; better response to short-pulse radiation; more adaptability to automated calibration; better reliability; capability to analyze the radiation energy spectrum; and reduced effects from extraneous environmental factors. Standardized performance specifications for field instruments are not generally available, nor is the capability to conduct definitive tests of instrument performance.

- Although a number of regulations require instrument calibrations, there is no accompanying guidance with regard to what constitutes an acceptable calibration and no recommended procedures for achieving it. In addition, there are in general no documented criteria for adequate performance of intermediate calibration laboratories. Ideally, such criteria would specify procedures for the achievement and maintenance of demonstrated traceability to national measurement standards. Voluntary consensus standards writing organizations are a logical source of such procedures and criteria.

- Another serious deficiency in the measurement support system is the lack of adequate education and training (see appendix A). This is another example where the magnitude of the need - many thousands of technical personnel-cannot be met at the national standards laboratory level but could very well be handled by intermediate standards laboratories which could best supply most of the training urgently needed at the field level. Inclusion of radiation measurement science in university curricula might contribute to the solution of this problem.

- Measurement quality assurance services are not available to the extent desirable at the field level (see Tables 2-1, 2-2, and 2-3). Only limited, sporadic programs exist which serve a small fraction of those who make routine radiation measurements. The procedures, instruments, and reference materials required for more extensive MQA programs, and the institutional mechanisms needed to conduct them, have not been developed. A crucial element for successful MQA efforts is follow-up consultation to improve performance, and yet such support is almost totally unavailable.

- There is an obvious lack of coordination of measurement-related efforts among the various Federal, state, and local regulatory agencies. This gives rise to many inconsistencies and results in inefficient application of limited resources. Improved coordination is necessary for uniform national implementation of procedures and criteria that will enable a more adequate measurement support system.

3.4 Priorities for Improvement of Ionizing Radiation Measurements

Clearly not every deficiency can be attacked at once. Table 3-1 is an attempt by the NBS and the CRCPD to place priorities on the actions which could be taken to improve each

Table 3-1. PRIORITIES FOR IMPROVEMENT OF IONIZING RADIATION MEASUREMENTS

	NBS		Intermediate Level			Improve		
	National Standards	Calibrations	Foster Industrial I.L. Labs	Establish State RCL's	Federal Lab Traceability	Field Instrumentation	MQA	Education & Training
Rad'n Therapy ^{60}Co			2	2			1	
Rad'n Therapy Hi-En X	1	1	2	3			1	
Rad'n Therapy Hi-En e-		1	3	3			1	1
Rad'n Therapy n	1	1				2		
X-Ray Diagnosis			2	1	2		1	2
Nuclear Medicine			2	3	2	3	2	1
Occupational Survey x, γ			1	1	2		1	1
Occupational Survey β	1	1	1	1	2	2	1	1
Occupational Survey n	1	1	2	2	2	1	1	1
Occupational Survey α (air)		2				1		1
Personnel Monitoring x, γ					1		1	1
Personnel Monitoring β	2	2			1		1	1
Personnel Monitoring n	2	2			1	1	1	1
Unrestricted Area Survey x			2	2	2		2	3
External Radiation γ, (dose)	1	1	2	1	2		2	1
Airborne α, β, γ (activity)		1			1	1	2	1
Food, water, liquids α, β, γ (activity)					1		2	1
Surface Contamination solids α, β, γ (activity)					1		2	1

Note: Priorities are listed in numerical order, 1 being highest. Items left blank indicate no need for improvement or need of relatively low priority.

class of ionizing radiation measurement. There is a four-step scale of priorities: 1, 2, 3, and blank. Priorities 1, 2, and 3 have the usual meaning, and a blank indicates either no need for action or that priority for action is low compared to other actions.

Table 3-1 was prepared by considering the necessary actions for each radiation measurement class:

- Medical
  - Radiation therapy (x ray, γ ray, electron, neutron)
  - Medical diagnosis (x ray, nuclear medicine)
- Occupational
  - *Occupational radiation surveys* (x ray, γ ray, β-particle, α-particle, neutron)
  - *Personnel monitoring* (x ray, γ ray, β-particle, neutron)
- Environmental
  - *Environmental radioactivity* (airborne, food, water, liquids, solids)
  - *Ambient radiation* (unrestricted area survey, external radiation)

Actions which could be taken to improve radiation measurements in each of these areas include improving field instruments, carrying out measurement quality assurance, and providing additional education and training. Actions at the intermediate calibration level could include fostering industrial intermediate-level laboratories, establishment of state regional calibration laboratories, and improving traceability for intermediate-level Federal laboratories (see Section 4). At NBS possible actions include development or improvement of calibration services and standards.

In the next two sections various proposals for improvement of the radiation measurement support system will be considered to fulfill the needs indicated in Table 3-1.

4. Possibilities for Improving Measurement Traceability Through The Intermediate Level

The measurement deficiencies discussed in the previous section may be remedied in part through an improved institutional structure of the measurement support system. In this section several possibilities for improving the structure of the measurement support system are discussed. These approaches are not mutually exclusive.

4.1 Enlarge NBS In-House Calibration Services

The NBS has responsibility to be the source and custodian of the national standards of physical measurement, and thereby provide the country with a scientific basis for accurate measurements. To this end, NBS maintains a number of national radiation standards, provides various calibration and testing services, and conducts a research program to support these efforts and to ensure that its measurement methods are at the state-of-the-art and meet the needs of current technology. NBS also plays a key role as an impartial coordinator of the consensus approach to the solution of radiation measurement problems. Additional details may be found in a report on NBS interactions with the entire ionizing radiation community [Caswell-1977].

Although NBS has the national responsibility to develop and maintain the basic standards of measurement, and to provide means and methods for making measurements consistent with them, it nevertheless has limited resources and cannot provide detailed services directly to the thousands who routinely make radiation measurements without a significant change in both its resources and in the nature of its programs. Specifically, within its present resources, NBS could not provide these services without serious impairment of its efforts in measurement research and basic standards development.

The principal advantage of expanding the NBS calibration services is that the traceability link would be as direct as possible, i.e., all calibrations would be made by direct reference to national standards. However, it is important to recognize that for many ionizing radiation measurements maintenance of traceability currently depends on the stability of a given instrument which has been calibrated by reference to a national standard. The stability of these instruments is affected by their handling, their environment, and time. Measurement quality assurance is needed to maintain the accuracy of radiation measurements. The NBS program is based on improving the accuracy of measurements of the national standards, improving the stability of the components of a traceability path to reduce the need for repeated calibrations, and improving measurement technology such that inherently more accurate and/or more sensitive measurements can be made in the field. It is in these areas that NBS can make the greatest contribution toward more accurate radiation measurements.

A disadvantage of this possibility is that to the field measurer who needs calibration, the convenience of a more accessible laboratory would often be preferable to an NBS calibration. A local laboratory can provide faster service (less transit time) and more direct access for consultation. A laboratory servicing fewer customers could also provide more personal services to the user.

4.2 Use Existing DOE and DOD Laboratories

Another approach that would make use of existing facilities and expertise is to expand the role of DOE and/or DOD laboratories to provide calibration services. For example, a number of the DOE facilities, notably some of the national laboratories operated under contract for DOE, have extensive expertise, developed over many years, in radiation measurements. These laboratories are well-equipped for ionizing radiation measurements. Except in providing measurement services for DOE's own programs, these facilities and personnel have not been utilized for routine calibration services. This may be partly attributed to the prohibition by OMB on having these public-subsidized laboratories compete with private calibration enterprises.

The advantages of using these existing facilities as calibration laboratories are: (1) the facilities already exist, (2) the laboratories are well located geographically (the DOE labs, for example, are in New York, Illinois, Tennessee, New Mexico, Washington, and California and these could be supplemented with DOD laboratories), and (3) neither DOE nor DOD are primarily regulatory agencies, minimizing conflicts of interest with regulatees. This latter advantage is reduced by the fact that both DOE and DOD are viewed by a segment of the public as promoters of radiation applications, specifically nuclear power and nuclear weapons.

The principal disadvantage is that neither DOE nor DOD consider providing measurement and calibration services to other organizations and users as part of their principal mission. It might be that these agencies would have to divert resources away from their primary mission to serve this function; in fact, it is not clear that such diversion is within the legislated authority of these agencies. Furthermore, not all of the laboratories currently have expertise in all of the radiation measurement areas of interest, nor is there traceability to a common set of national standards in all areas. NBS and the national laboratories do plan to strengthen their interaction regardless of whether the laboratories are used as generally-available intermediate calibration facilities. They do serve as intermediate-level laboratories in a limited portion of the Federal sector.

4.3 Regulatory Agencies Provide Intermediate Level.

A number of Federal agencies have specific interests in assuring the accuracy of radiation measurements that are traceable to national standards [Schneider-1976]. They have recognized the importance of having accurate measurements that can provide protection of workers and the public from radiation hazards, and that can be used to enforce the extensive and growing number of regulations and guidelines. As a result, they are already providing limited measurement support services in some areas. As was mentioned earlier, the EPA runs a quality assurance program out of the National Environmental Research Center in Las Vegas, the NRC conducts a confirmatory measurements program from the Radiological and Environmental

Sciences Laboratory of the Department of Energy in Idaho Falls, and the BRH provides the states with calibrated instruments, personnel training and other services.

There are advantages in having regulatory agencies provide measurement support services and in having them serve as intermediate laboratories. First, since the measurement interests of an agency are quite specific, they are able to focus their resources on those calibration services and those measurement assurance activities which are of importance to specific regulations. For example, the NRC reference laboratory is concerned with radioactivity standards and measurement intercomparisons for only those radionuclides that are present in the nuclear fuel cycle, while NBS maintains a much broader measurement capability to provide the physical basis of measurements that go beyond specific regulatory needs. Secondly, since regulators maintain traceability to NBS, it may be logical to utilize these agencies as the intermediate link between NBS and the many different radiation users. Lastly, a number of agencies maintain laboratories which have extensive expertise developed over many years in radiation measurement. These facilities and personnel are a national resource which could be utilized to a greater extent.

However, it is unlikely that all existing needs for measurement support services could be satisfied by utilizing the regulatory agencies as the intermediate laboratories. Even agencies like EPA or the Occupational Safety and Health Administration (OSHA) which have a clear role in these areas may not support the calibration of instruments and provide other services necessary for the implementation of their regulatory posture, and they may seek support in this regard from NBS and from the industry. Furthermore, the states and other users would need to go to different agencies for each type of calibration, with each agency maintaining traceability to NBS. The laboratories are not regionally distributed, requiring either travel or shipping over long distances. Because instrument calibration is not a primary function of regulatory agencies, long-term continuity of calibration services may not be assured. Finally, the practice of regulators calibrating instruments for regulatees may present enforcement problems to the regulators (one can imagine a situation where a utility cited for releasing too much radioactivity claims that an NRC-calibrated instrument was the source of difficulty).

4.4 Establish Federally-Supported Regional Calibration Laboratories

An option that would not use any currently existing institutions is to establish federally-supported regional calibration facilities. This facility could be either a government owned and government operated (GOGO) facility or government owned and contractor operated (GOCO). In the former case, NBS is a logical agency, although not the only possibility. In the GOCO case, the NBS role could be as contract monitor.

Both the capital investment and operational funds would probably need to be subsidized by the Federal government with part or all of the cost recovered through fees for services. The customer would be anyone who needs the services and who pays a reasonable fee. Several regional laboratories could be created, the number depending upon demand. Services could include calibrations, measurement assurance, consultation, education and training, instrument lending pool, and instrument performance tests. Traceability mechanisms would be specified by NBS, applicable to all laboratories.

Based on opinions offered during this review, (see also Appendix A) this possibility (either GOGO or GOCO) would be acceptable to the majority of the radiation measurement community. It avoids essentially all questions about conflict of interest or political sensitivity because the laboratories would be operated by a non-regulatory organization. Long-term commitment by the Federal government to radiation measurements and services would ensure stability. Duplication of new facilities would be avoided in the Federal, state, and private sectors although conflicts with pre-existing private sector facilities would have to be resolved.

The disadvantages include relatively high capital costs and continuing operational costs, both covered with Federal funds. (Some of the high capital costs might be reduced by locating the laboratories at appropriate current or surplus Federal facilities). Also, it could represent government competition with private sector laboratories, including many which are now providing some of the needed services. Additionally it creates a dependence by the states on the Federal government, when what is needed is a general improvement of state capability.

The GOGO case, with NBS acting as the operator, has the same disadvantage as enlarging NBS in-house services (see Section 4.1). In this case NBS would have expanded its mission to providing direct calibration services to all users.

4.5 Foster Private-Sector Intermediate Calibration Laboratories

One interesting possibility for the above-mentioned GOCO facilities is that they might eventually become self-supporting or very nearly so. If that were to occur, the Congress might want them to become independent of governmental control (except for traceability to NBS). This could occur through allowing the contractors to "buy out" the government's interest or through the establishment of "quasi-public" corporations. Successful examples of the latter are the TVA, Comsat, and the Corporation for Public Broadcasting. Alternately, the GOCO step could be skipped and an effort made immediately to establish private-sector control of the calibration laboratories.

The advantages of such private-sector control are that the Federal research agencies could continue to concentrate on their principal missions and the regulatory agencies would be relieved of making calibrations for their regulatees. The principal disadvantage is that of economic uncertainty. The question of whether a "full service" private-sector laboratory could make a profit must be carefully examined. Rates high enough to ensure profitability could prevent state and local governments from obtaining all of the necessary services. A private-sector laboratory might be forced to abandon some important services that were losing money to concentrate on more profitable services. If a private laboratory declared bankruptcy, the government might have to step in to maintain services and insure continuity. If calibrations or measurement quality assurance were generally required by regulations, this would greatly improve economic viability of private-sector intermediate-level laboratories.

There does exist at the present time some private-sector involvement in intermediate calibrations through commercial calibration service companies, instrument manufacturers, and professional groups. Instrument manufacturers occupy a unique position in the radiation measurement community since all measurements of radiation must be made with instruments. As a result, when a user suspects that there is a problem with an instrument, the manufacturer is usually considered first for repair and recalibration of the instrument. Most manufacturers offer repair and recalibration services for their own instruments, and some manufacturers will calibrate instruments from other manufacturers. However the consensus of instrument manufacturers is that most instruments will not be returned unless there is obviously something wrong with them. One manufacturer estimated that less than 10 percent of the instruments are ever returned for repair and recalibration, and less than 1 percent are returned for recalibration alone.

In the absence of legal requirements for traceability, many instrument manufacturers do not interact directly with NBS to insure that the calibration services they offer are closely tied to the national standards. This is clearly an area where improvement is needed. Although instrument manufacturers provide an important role at present with their calibrations, there are disadvantages to the user. First, the instruments must often be shipped long distances with the attending possibility that handling on the return route has disturbed the calibration. Second, calibrations of different instruments must go to different manufacturers. And lastly, not all calibration services are available.

Professional and industrial groups now provide another mode of private-sector involvement in the intermediate calibration services. Three programs serving the medical radiation community (see Section 3.3.1) have been provided through professional and industrial groups. These programs have been highly successful technically and the extension of them into other areas of radiation measurements must be considered as a possible solution. The principal drawback is that users again must go to different institutions for different types of services. NBS is also required to interact with many different groups (which it has done quite successfully though this may not be the most efficient use of its resources.) Also, present institutions would have to greatly expand their services or other professional groups would have to become involved in this process.

4.6 Establish State-Run Regional Calibration Laboratories

State radiation control programs have the major responsibility for assuring public health and safety in the radiation area. This requires the ability to make accurate measurements and, in the case of their enforcement powers, to be able to demonstrate that accuracy. Traceability to national standards is the key to demonstrating accuracy. States can obtain this traceability through direct interaction with NBS, from private industry, or through a system of regional calibration laboratories. The states feel it may be undesirable, however, for states to have their instruments calibrated by private industry, since the states license these industries and must use the same instruments to determine their compliance with state regulations.

Creating regional calibration laboratories run by state governments is attractive for several reasons. By sharing the expenses of operating such a facility, the states have the opportunity to lower the costs of obtaining needed services. Through cooperation in the design of the facility, the states can assure that the most necessary services are provided while obtaining infrequent services through a more cost-effective route. These laboratories can be used by the states as "centers of excellence" for radiation measurements, e.g., the laboratories can be used for training state employees in new measurement techniques either through exchange programs, course offerings, or seminars. To obtain maximum participation in such a program, several laboratories would be needed, geographically sited so that each state was near a laboratory. Traceability mechanisms would be developed by a consensus procedure involving the states, the voluntary standards writing organizations and NBS. Another advantage of the state regional calibration laboratory approach is that those agencies having major responsibility for radiation control would be closely coupled with the required measurement capability.

A state regional calibration laboratory, or in fact the radiation measurements laboratory in a given state, could be located in a state radiation control department, or in a state metrology department, or in some other independent agency such as a university.

One disadvantage is that these state laboratories might be unable to supply calibrations to the private sector since these laboratories would be subsidized by public funds and hence should not compete with private enterprise calibration laboratories. Additionally, laboratories located in state radiation control departments may not with to calibrate instruments for industries they regulate, since they feel it may present enforcement problems. In instances where no private-sector service is available, the state-run laboratories could provide needed services.

At this time the National Bureau of Standards, in cooperation with the State of Illinois, is establishing a pilot program for a state-run regional calibration laboratory. NBS is supplying the capital equipment on a loan basis as an incentive to establishing this type of laboratory. The State of Illinois is supplying the space for the facility and the personnel to run the laboratory.

5. Analysis

The national achievement of demonstrably reliable radiation measurements for health and safety requires both specific technical actions and changes in institutional arrangements and structures to ensure adequacy and reliability for ionizing radiation measurements. Most importantly, there is a need for strengthening the intermediate level coupling national standards and field users of radiation measurement.

5.1 Needed Programmatic Actions

For purposes of analysis the classes of radiation measurement discussed will be those listed in Section 3.4 of this report.

From a programmatic perspective, it is useful to consider two types of action:

A. Those programs required for interactions between NBS and the intermediate laboratory level

B. Those programs required for interactions between intermediate laboratories and the field level.

The most effective approach is first to develop those programs that will result in improved interactions between NBS and the intermediate level, followed by developing programs required to link intermediate laboratories to the field level.

It is important to recognize that, in the interest of accuracy and uniformity for all measurements made in the United States, both types of actions should be dependent only upon the particular radiation quantity of interest, and not on whether the Federal, state, or private sector is involved. For example, the actions should be identical for intermediate laboratories in all these sectors for the particular quantity or measurement class involved. It is also important to recognize that the ultimate objective of all programmatic actions is to achieve measurement quality assurance at the field level. This requires continuing demonstration of satisfactory measurement performance, in terms of acceptable limits of deviation from national measurement standards. However, before such programs can be implemented by intermediate laboratories it is first necessary to assure that their performance is sufficiently consistent with national standards. Those actions required to achieve an acceptable degree of consistency will be emphasized in the following discussion of each radiation measurement group.

5.1.1 Personnel Monitoring

The need for quality assurance at the field level has been recognized for 25 years, but no satisfactory national program has yet been developed. Since 1973 NBS has cooperated with the states, various Federal agencies, and the Health Physics Society in an attempt to establish a performance testing program for the organizations that provide personnel monitoring services. With NBS leadership, criteria have been developed that will form the basis of a future routine performance testing program [ANSI-1978]. As indicated in Section 2.2 of this report, a recent pilot test that utilized these criteria showed that present performance of personnel monitoring services must be improved.

As the future national program is envisioned by the Interagency Policy Committee on Personnel Dosimetry Performance Testing, there will be a testing laboratory (or laboratories) at the intermediate level which will continually test the performance of personnel monitoring services. The NBS role will be to ensure that this intermediate-level laboratory uses procedures that maintain consistency with national measurement standards. In this quality assurance role, NBS will periodically calibrate the radiation sources and instruments used by the testing laboratory, and will monitor overall technical performance.

To improve its interactions with the intermediate-level testing laboratory NBS should develop a wider range of national standards, particularly for beta and neutron radiation, and related calibration services. Routine quality assurance interactions between NBS and the testing laboratory should be developed and documented. Training and guidance must be provided to the operators of the testing laboratory.

5.1.2. Occupational Radiation Survey

With the personnel monitoring performance testing program serving as a model, discussions have been held between NBS and interested state and Federal agencies that will eventually lead to a similar program for measurements made with portable survey instruments. In this case, the intermediate laboratory is that which manufactures, tests, and/or calibrates such instruments. Present interactions between NBS and this intermediate level are limited and poorly defined.

A number of actions must be taken to achieve a satisfactory relationship. National standards should be developed and maintained by NBS over a wider range of radiation types, energies, and intensities. Photon radiation fields should be made available which are characterized in terms of their spectra and the exposure rate at the point of interest. Beam-type and immersion-type standardized beta radiation fields should be established and maintained over a range of energies, as well as monoenergetic electron fields. A standardized moderated fission field of neutrons should be added. Using these standard radiation fields, a wider range of primary calibrations should be provided.

Criteria should be developed for interactions between NBS and intermediate laboratories that will provide measurement traceability to national standards. Continuing measurement quality assurance programs should be implemented. As required, the technical artifacts and instruments suitable for use in such interactive programs should be developed or adopted. Education and training should be made available to operators of intermediate-level laboratories.

5.1.3 Radiation Therapy

In this particular area, there is a strong need to extend the range of NBS standards and services in response to changing medical practice. Increased use of high-energy x rays and electrons in cancer therapy has created a national need for standards and calibrations for these types of radiation.

Experimental use of neutron radiation for cancer therapy has resulted in similar needs for NBS standards and services. Under sponsorship by the National Cancer Institute, work is beginning in this area.

Measurement quality assurance is essential because the acceptable error is relatively small for radiation therapy. For this reason, MQA programs should be developed and implemented between NBS and the intermediate laboratories for all radiation quantities of interest.

5.1.4 Environmental Radioactivity

In terms of operational measurement quality assurance programs between NBS and intermediate laboratories, this area is relatively well under control. Interactive mechanisms and criteria are specified in interagency agreements with the participating Federal laboratories. Improvements should be considered that would allow better-defined traceability for radioactivity standards and cross-check samples issued by the EPA intermediate laboratory in Las Vegas.

Because follow-up consultation and training are not available, some who participate in MQA programs at the field level continue to perform unsatisfactorily [Jarvis-1976]. This is an effective demonstration that MQA programs must be accompanied by training if they are to be successful in improving performance. The measurement of radon and its radioactive decay products is a problem that must receive increased attention. A suitable exposure chamber should be built by NBS to serve as a national reference point for calibration of instruments that measure the various quantities of concern (radon concentration, radon daughter concentrations, working levels, and emanation rates).

5.1.5 Ambient Radiation

This group of measurements is presently concerned with low-level photon radiation that may occur naturally, may be technologically enhanced, or may be produced by man. In either case, the levels are sufficiently low to qualify as an unrestricted area. Because the levels are barely above natural background, special measurement problems are encountered. For devices that measure dose from gamma radiation (such as thermo-luminescence dosimeters) a national standard should be developed, and suitable calibrations should be provided. When this has been achieved, MQA programs should be implemented with intermediate laboratories and appropriate training should be provided.

5.1.6 Medical Diagnosis

Whether the radiation used for diagnostic purposes is emitted by an x-ray machine or a radioactive material administered internally, the NBS standards and calibrations are considered to be adequate for national needs. For nuclear medicine (radioactive materials), the existing MQA program with manufacturers appears to be adequate but does not involve all of them. The existing MQA program with hospitals reaches only a small fraction of the institutions where radiopharmaceuticals are administered to patients.

As mentioned earlier in this report, substantial public exposure to radiation results from diagnostic x rays. For this reason, it would be desirable to have operational MQA programs that monitor measurement performance at the field level. As a first step, NBS is beginning the development of criteria and physical mechanisms required to establish MQA programs between NBS and the AAPM intermediate laboratories. When a working relationship has been established at this level, similar programs will be developed for extending MQA from the intermediate level to those making measurements in the field.

5.2 Needed Institutional Structures and Functions

A clear need for improvement of the measurement support system is in providing services at the intermediate level. Although intermediate services now exist, there are obvious gaps and weaknesses which should be remedied (see Tables 2-1, 2-2, and 2-3). Possible improvements can be examined from the point of view of different levels of Federal involvement:

5.2.1 Current Situation

Some things can be and are being done with present resources. These involve no new additional Federal expenditures.

Traceability mechanisms from Federal agencies to NBS can be improved through better interagency communications and cooperation, and steps in this direction have already begun. As is indicated in Figure 5-1 the traceability in the Federal sector is primarily instrument traceability. Additional funding would be required to develop measurement traceability programs.

NBS in cooperation with state and local governments is developing traceability mechanisms through state regional calibration laboratories. One of these laboratories is already being set up in Illinois and another is being planned. If these state pilot programs are successful, host states for the other necessary laboratories may be forthcoming. Raising the necessary capital for equipping these laboratories remains an impediment to establishing additional laboratories.

As indicated in Figure 5-1 some (limited) measurement traceability reaches state radiation control departments through, for example, the EPA Las Vegas laboratory as an intermediary.

Some instrument traceability exists in the industrial (non-medical) private sector through intermediate level laboratories which are privately operated. A survey is currently being carried out by CRCPD to determine the number of these laboratories and their functions. The laboratories do not couple strongly nor do measurement assurance programs exist.

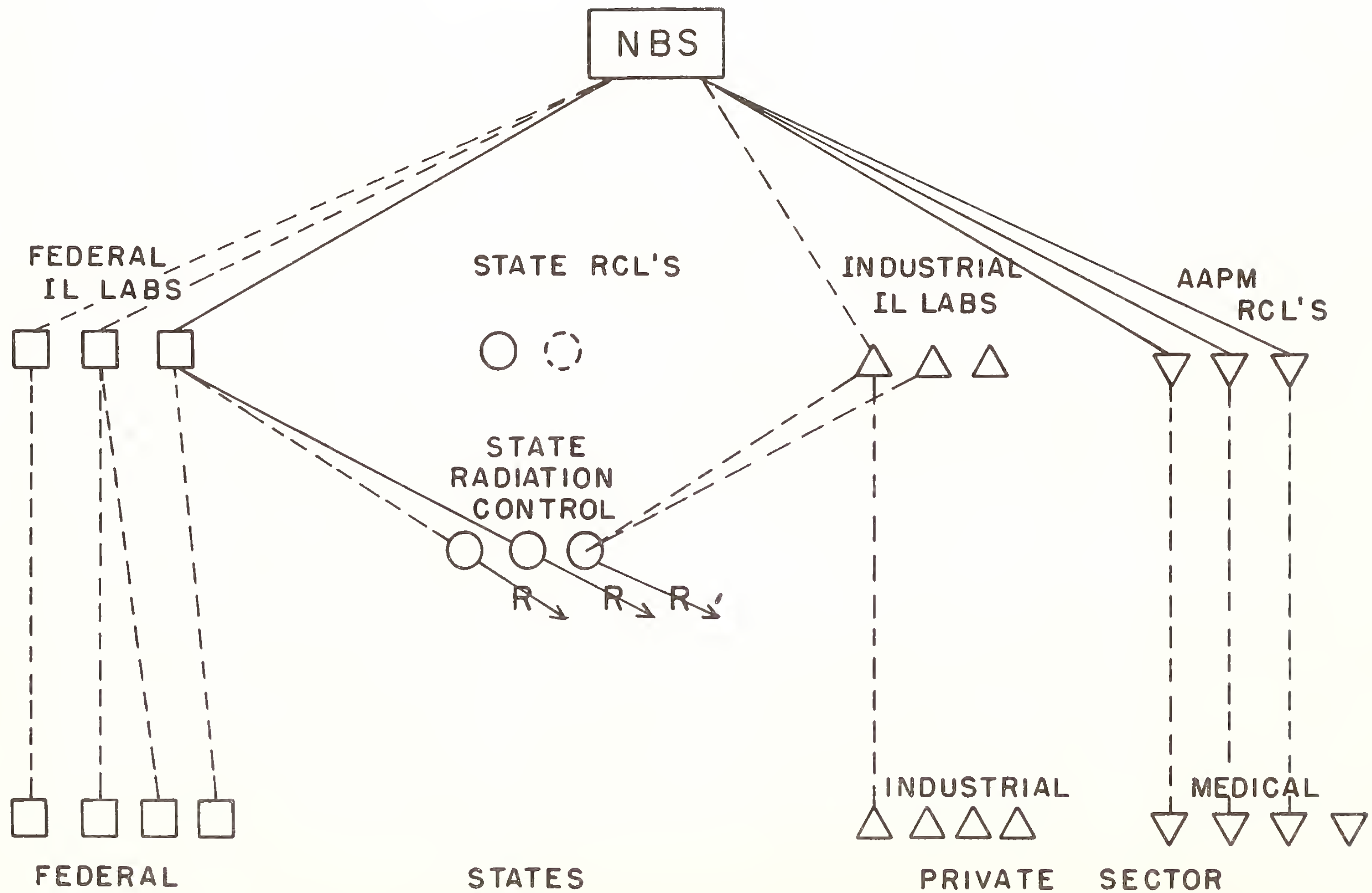

Fig. 5-1. Simplified schematic showing the current measurement support system for ionizing radiation. —— measurement traceable; - - - instrument traceable; R-arrow symbol indicates regulatory control.

Improving traceability to the private sector is complicated by the diversity of actors in this area, e.g. instrument manufacturers, radiologists, private calibration services, and so forth. In the case of medical radiology, several regional calibration laboratories have been set up by the American Association of Physicists in Medicine, a professional organization. These laboratories are measurement traceable to NBS and provide instrument traceability to hospitals and clinics. A study by AAPM indicates at least one additional regional calibration laboratory is needed [AAPM-1979].

The National Bureau of Standards together with the voluntary standards writing organizations and professional societies should develop measurement traceability criteria for services performed in the private sector. Further development of calibration services, and particularly measurement quality assurance programs, is needed before private sector measurements can be considered satisfactory. Progress will remain at a relatively slow pace unless financial support is increased.

5.2.2. Recommendation: Strengthen Intermediate Level Institutions

An improved measurement support system, represented schematically in Figure 5-2, would take advantage of existing intermediate level laboratories in the Federal, state and private sectors. New intermediate level laboratories would be established where appropriate, and a greater emphasis put on measurement traceability at all levels. This would ensure that the best form of traceability is made available to field users of radiation measurement in all sectors. In addition to making maximum use of existing laboratories, the advantage of the approach outlined in Figure 5-2 is that each sector has intermediate laboratories suitable to its own needs, and to whom the sector's field measurers of ionizing radiation can relate effectively.

In the case of the Federal sector, intermediate level laboratories exist in the Department of Defense, Department of Energy, Environmental Protection Agency, Bureau of Radiological Health, and for the Nuclear Regulatory Commission. Measurement quality assurance programs would be needed, both for testing the traceability of the Federal intermediate level laboratories to NBS, and of Federal measurers to their intermediate level laboratories. It is not likely that these laboratories in specialized agencies would broaden their missions to serve all sectors.

In the state sector, the Federal government in cooperation with the Conference of Radiation Control Program Directors should foster the establishment of up to seven state regional calibration laboratories which could provide calibrations and measurement traceability to state and local radiation control

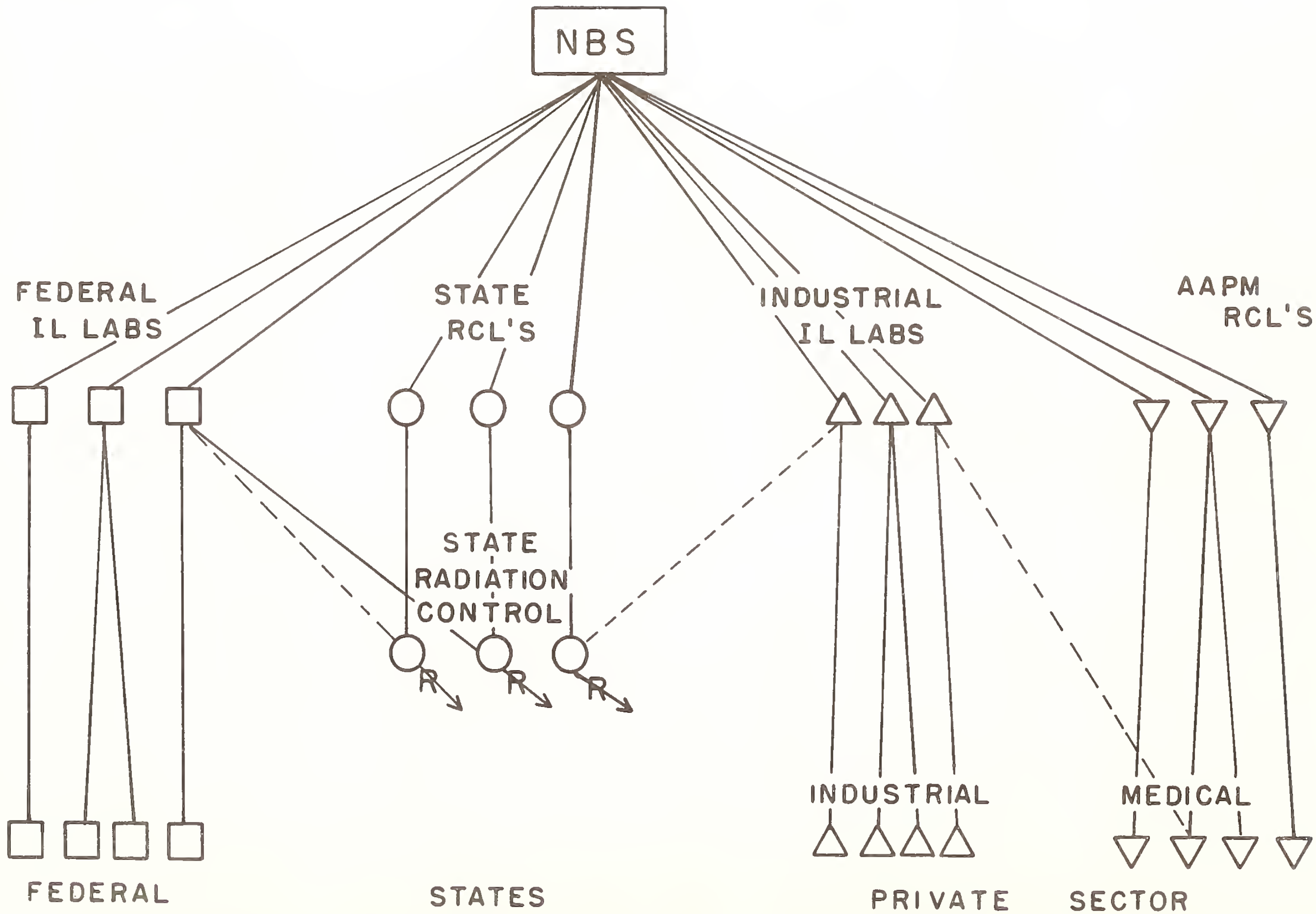

Fig. 5-2. Simplified schematic showing the measurement support system for ionizing radiation as a result of proposed strengthening of intermediate level laboratories. —— measurement traceable; - - - instrument traceable.

departments. The state regional calibration laboratory might be located in the Department of Health, as are the radiation control departments normally, or in an existing state metrology laboratory or in other institutions such as non-profit companies or universities. State radiation control departments could in principle operate state regional calibration laboratories and provide calibrations to licensees within the state or region. However, many of them feel that this represents a conflict of interest and would prefer that licensees receive their calibration from industrial intermediate level laboratories.

As mentioned in Section 4.6, NBS is cooperating with the State of Illinois in the establishment of a pilot regional calibration laboratory. It is expected to become operational in 1981, with original capability to provide calibrations of instruments used to measure x rays applied in medical and industrial radiography. The capability to provide calibrations for gamma radiation, using cesium-137 as the source, will be added in the very near future. As the laboratory develops, it is planned to add other calibration services, and to subsequently provide measurement quality assurance services. It is hoped that the Illinois laboratory will be able to subsequently provide training to other state personnel in the area of radiation measurement and calibration. Another service this laboratory may eventually provide is testing of instruments to determine whether state performance specifications have been met by the supplier.

The Illinois laboratory will serve that state's needs for measurement support services in implementation of its regulatory program, and will make its services available to other state and local governments on a fee basis. Most state radiation control programs in that region of the country have expressed their intent to use the available services. It is expected that the State of Illinois will recover a substantial fraction of the cost of laboratory operation from user fees. Procedures used in this laboratory, including specific interactions with NBS, will be documented and will serve as the basis of operational criteria for laboratories of this type. These criteria may subsequently be used for accreditation of this, and similar, state laboratories by the Conference of Radiation Control Program Directors.

In this cooperative endeavor, the State of Illinois has provided suitable laboratory space and the operational staff required for continuing provision of services to users at the field level. The National Bureau of Standards has provided, on a loan basis, the instrumentation and radiation sources required in an intermediate standards laboratory of this type. NBS also assisted in design of the laboratory and provided training for the operator. On a periodic basis, the instruments used as in-house standards by this laboratory will be recalibrated by NBS and the laboratory's services will be monitored to assure that adequate quality is maintained.

When a range of services is available, documented procedures are followed, and adequate quality is maintained, all the pertinent necessary elements of the measurement support system described in Section 3 of this report will be satisfied, and the Illinois laboratory will then serve as an example to be followed by other states interested in establishing similar facilities. Two additional states, South Carolina and Washington, have already expressed their desire to develop laboratories based on the Illinois model.

In the private sector there exist a number of private laboratories which may be instrument companies, calibration service companies, or in some cases not-for-profit institutions. Work needs to be done with the voluntary standards community and professional societies to establish criteria for the industrial intermediate level laboratories, and to establish measurement traceability to NBS through the industrial intermediate level laboratories for measurers in the industrial sector. As previously noted, in the case of the medical regional calibration laboratories, the American Association of Physicists in Medicine believes that one more laboratory is required. The calibrations for diagnostic purposes are only beginning, calibration for radiation therapy having been the primary service provided in the past.

To accomplish all that is represented under this option increased funding will be required. Equipment will be needed for state regional calibration laboratories. The states and a fee system will probably provide the operating funds for these laboratories. Measurement traceability criteria will be required for the laboratories in the industrial sector. A very large set of measurement quality assurance programs will be needed in all sectors to establish measurement traceability.

The benefits of following this overall approach which is keyed to strengthening intermediate level institutions include: (1) the measurement traceability of field measurements throughout the nation in each sector--Federal, state, and private; (2) strong support for regulatory measurements done by state and Federal regulators; (3) creation or improvement of a measurement support system suitable for each sector with a minimum of new institutions, the chief new institutions being the state regional calibration laboratories.

It should be recognized, however, that a satisfactory overall approach to the measurement support system for radiation health and safety also requires development of needed national standards where they do not exist, and improvement of field measurement methods in cases where current methods are not adequate.

As indicated in Tables 2-1, 2-2, and 2-3, the accuracy of field measurements is frequently inadequate or unknown. The ultimate criterion for judging an improved measurement support system is the achievement of demonstrated adequate accuracy for field measurements. NBS at present carries out a number of measurement quality assurance programs to determine or ensure field measurement capability. Where accuracy available in the field is indicated in Tables 2-1, 2-2, and 2-3, this has been determined by measurement quality assurance testing of field measurements (measurement of an unknown radiation source or radiation field), usually by NBS programs.

The approach suggested in Figure 5-2, which includes measurement quality assurance testing through the radiation measurement system, allows one to establish the accuracy currently being achieved in the field. A very important feature is that the system of Figure 5-2 is self-monitoring, providing its own indications of the success or lack of success of the measurement support system through the results of the MQA tests. For example, if the measurement quality assurance tests at the field level show steadily improving accuracy, then we know the measurement situation is improving. If all MQA test results were within the accuracy requirements as determined by regulatory agencies or codes of good practice, then one could conclude that the measurement support system is indeed in a satisfactory state. If, however, field measurement performance is often or usually worse than accuracy requirements, need for more drastic action would be indicated.

The National Bureau of Standards could take a lead role in bringing about a demonstrably adequate measurement support system by developing MQA programs reaching to the intermediate level laboratories (see Figure 5-2). It could assist the states, Federal agencies, and industry in the development of intermediate level laboratories in each sector, and bringing them to a high level of competence. NBS could provide technical backup and resolution of special problems for field measurers, and provide new standards and calibrations for radiation measurements where required but not now available.

5.3 Proposed Plan for Implementation

In this section an approach is suggested that would promote the achievement of consistency of radiation measurement with national measurement standards through a joint effort of laboratories in the Federal, state, and private sectors. This approach builds upon the current base program at NBS which will continue to provide essential standards and primary calibrations for low energy x rays, cobalt-60 gamma rays, radioactivity, and pure neutron fields. The current base program also provides a modest level of measurement quality assurance and the limited exploration of the intermediate level laboratory concept. The plan outlined below would provide a timely, comprehensive response to the most important unmet national requirements identified in this report. Additional funding would be required to augment the base program to meet these high priority national needs.

This plan would be implemented in two phases. In the first phase new intermediate level laboratories (e.g. state laboratories) and improved coupling of NBS with new and existing intermediate laboratories would be established to provide a more effective mechanism for measurement support and traceability between field users and national standards. This coupling would be effected through standards support, measurement assurance, training, equipment loans and consultation. The second phase would emphasize the implementation of measurement services to the field users by these intermediate laboratories plus the long-term development of advanced measurement technology by NBS to support new types of radiation measurement. The laboratory services would include calibrations, methods evaluation, measurement quality assurance and training.

First year

Begin development of operational criteria for intermediate laboratories in the state and industrial sectors.

Design prototype calibration laboratories to serve as a model for the states and industry.

Begin procurement of calibration and standards equipment for state laboratories.

Host states begin construction of intermediate laboratories.

Provide elementary training for state and industrial personnel.

Begin development of national standards for high-energy x rays, fast neutrons, beta fields, additional monoenergetic neutrons, and photon fields.

Begin development of MQA technology and procedures to be implemented by NBS, state, Federal, and industrial laboratories.

Second year

Begin development of operational criteria for MQA programs provided by intermediate laboratories to field-level users in all sectors.

Begin providing MQA services to state, Federal, and industrial intermediate laboratories.

States begin x-ray and gamma-ray calibrations.

State laboratories begin providing consultation to field personnel, for instrument requirements and performance, calibration methods, and measurement procedures.

Begin development of transfer standards.

Begin study of automated calibration systems.

Begin study of special measurement problems and development of field instruments.

<u>Third year</u>

State laboratories begin beta-ray and alpha-ray calibrations.

State and industrial laboratories begin MQA services for x and gamma rays.

State and industrial laboratories begin providing consultation and MQA procedures.

Begin providing refresher training by NBS for state and industrial personnel.

States begin testing service for newly-procured instruments.

<u>Fourth year</u>

Development of operational criteria for intermediate laboratories completed.

Procurement of equipment for state laboratories completed.

State and industrial laboratories begin MQA services for beta and alpha rays.

State laboratories begin providing elementary and refresher training; NBS limits training to intermediate laboratory operating staff.

Complete development of national standards begun during first year. Provide calibration services against these standards.

<u>Fifth year</u>

Host states complete construction of intermediate laboratories.

Development of transfer standards completed.

Study of special measurement problems completed.

The following activities continue into future years:

Revision of operational and MQA criteria for use in all intermediate laboratories.

Calibration and MQA services by state, Federal, and private intermediate laboratories.

Consultation services by NBS and intermediate laboratories.

Training of field personnel by intermediate laboratories.

Training of intermediate laboratory operating staff by NBS.

Calibration and MQA services by NBS for state, Federal, and private intermediate laboratories.

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APPENDIX A

FINAL REPORT

TASK FORCE ON RADIATION MEASUREMENTS
CONFERENCE OF RADIATION CONTROL PROGRAM DIRECTORS

The States and Federal agencies are responsible for the protection of the public health from the hazards associated with the use of radiation. In order to meet this responsibility it is necessary to make radiation measurements which are accurate and defensible. Instances wherein such measurements were made with inappropriate instrumentation, of inappropriate types of radiation, with uncalibrated or poorly calibrated instruments, and with inappropriate techniques are rampant and too numerous to list.

This report has been prepared by the Task Force on Radiation Measurements of the Conference of Radiation Control Program Directors in accordance with U.S. Department of Commerce - National Bureau of Standards Contract No. 6-35737.

This report in its present form is divided into four sections: (1) Summary of Recommendations, (2) Background of Task Force Activities and Personnel during the contract period, (3) A more detailed discussion of the recommendations and suggestions for additional Task Force activities and (4) Attachments.

SUMMARY OF RECOMMENDATIONS

1. There was unanimous agreement of the need for more direct National Bureau of Standards assistance to the States in the areas of physical standards and measurement systems for radioactive materials and ionizing radiation. In particular NBS should develop a mobile calibration laboratory to assist the States in both quality assurance and training.

2. NBS should provide more standard reference sources directly to the states at little or no cost. Specific items which are needed will be determined and recommended in a future report.

3. NBS should review and approve all Federal guidelines, standards, and regulations which require radiation measurements prior to the promulgation of such guidelines, standards, and regulations to assure that such radiation measurements are both technically feasible and practically attainable. The Task Force should continue to review this problem during the next contract period.

4. NBS should coordinate the development of model sampling procedures, chemical separation procedures, and analytical measurement methods for a variety of environmental radiocontaminants which could be used by all State, Federal, and private laboratories to assure consistency in the quality of the measurements.

5. NBS in cooperation with EPA should be designated as the Federal agency responsible for coordinating efforts among the Federal and State agencies to immediately develop a uniform data reporting system so that present environmental data which is being generated throughout the country can be utilized and evaluated in terms of possible population exposures.

6. NBS should design a model calibration facility and recommend procedures for calibration of field ionizing radiation survey instruments and monitoring systems.

7. There is a need for additional training for all State personnel involved in ionizing radiation measurements. Training programs should be sponsored and supported by all Federal agencies involved in ionizing radiation measurements. It is recommended that The Conference of Radiation Control Program Directors establish a Task Force on Training which would, as part of their efforts, coordinate the training activities sponsored by Federal agencies.

8. NBS should begin to work with specific states to resolve specific measurement problems which could be applicable to the remaining states. Such areas may include the design and operation of a state calibration facility, calibration of specific instruments for specific types of measurement problems, etc.

9. The present Environmental Protection Agency environmental radioactivity laboratory intercomparison studies program provides a cross-check on individual laboratories. That program has been very successful in identifying specific problems. However, there is presently no follow-up program to provide assistance to those laboratories which the cross-check program identifies as having such problems. The Task Force recommends that the Environmental Protection Agency, the Nuclear Regulatory Commission, the Energy Research and Development Administration, and the National Bureau of Standards cooperate in resolving this issue.

10. The Task Force was unable, because of restrictions in time, to adequately address all of the problems of radiation measurement. For that reason, it restricted its area of concern to ionizing radiation measurement systems only. In the field of ionizing radiation measurement, the Task Force was only able to scratch the surface of the problems. It is believed that a more in-depth analysis would be appropriate and may alter the above recommendations. Therefore, as a final recommendation, the National Bureau of Standards should continue to sponsor the Task Force on Radiation Measurements in a manner suitable to both the National Bureau of Standards and the Conference of Radiation Control Program Directors.

BACKGROUND OF TASK FORCE ACTIVITIES

The Task Force on Radiation Measurements was organized in 1975 by the Conference of Radiation Control Program Directors to work with the National Bureau of Standards in an attempt to provide input into Bureau activities relating to state radiation measurement problems and priorities. The Task Force consisted of six state radiation control personnel as follows: Thomas M. Gerusky, Pennsylvania, Chairman; Marshall W. Parrott, D.Sc., Oregon; Donald E. Van Farowe, Michigan; Ellen Haars, Ph.D., Iowa; Richard Bleumle, South Carolina; and Paul Eastvold, Illinois. Four Federal resource personnel were assigned as follows: Roger Schneider, FDA; Raymond Johnson, EPA; Bernard Weiss, NRC; and Sherman Fivozinsky, Ph.D., NBS.

An organizational meeting was held on October 22-23, 1975 at the National Bureau of Standards. Ellen Haars was elected Vice-Chairman and Paul Eastvold was elected secretary. Thomas Ohlhaber replaced Roger Schneider as the FDA resource person. During that meeting, a questionnaire was designed to determine the needs and desires of the states concerning laboratory and field radiation measurement systems for both ionizing and non-ionizing radiation.

On February 11, 1976 a contract between the Department of Commerce and the Conference of Radiation Control Program Directors was signed by the parties requiring the Conference through the Task Force on Radiation Measurements to "study radiation measurement needs and practices in the various state agencies . . ." The Task Force was also required to file a progress report, a draft final report, and a final report on the results of the study for NBS. The report was to include "the problem areas discovered, the kinds of technical and procedural activities which would serve to solve the problems, and the proposed role of NBS in aiding implementation of these activities."

On April 6, 7, and 8, 1976, the Task Force met in Las Vegas at EPA's Office of Radiation Programs facility to analyze the results of the questionnaire, to visit with EPA quality assurance personnel, and to tour the EPA radiation measurements facility. A report summarizing the questionnaire results was forwarded to NBS on April 13, 1976. (See Attachment A)

The Task Force also met during the annual meeting of the Conference of Radiation Control Program Directors in Springfield, Illinois in May to plan future activities of the Task Force.

A sub-group of the Task Force (Marshall Parrott and Robert Craig, Oklahoma, a new member) were requested to visit a state radiation control laboratory to discuss measurement needs directly with the state radiation control program personnel. They visited the California State Health Department laboratories on July 1 and 2, 1976.

A progress report on Task Force activities was submitted to NBS on August 10, 1976.

The Task Force was reconstituted by the Executive Board of the Conference of Radiation Control Program Directors due to changes in state personnel and resignations. Presently the following personnel constitute the Task Force on Radiation Measurements: Thomas M. Gerusky, Pennsylvania, Chairman; Marshall Parrott, Oregon; Robert Craig, Oklahoma; Larry McDonnell, Wisconsin; Paul Eastvold, Illinois; and Richard Bleumle, South Carolina. Federal resource personnel include Elmer Eisenhower, NBS; Bernard Weiss, NRC; Thomas Ohlhaber, BRH-FDA; and Raymond Johnson, EPA.

On October 27-29, 1976, the Task Force met in Des Plaines, Illinois to determine the content of the draft final report and to discuss future goals of the Task Force.

On February 23 and 24, 1977, the Task Force met in Phoenix to review the comments on the draft report and made significant changes as are incorporated in this final report.

DETAILED DISCUSSION OF PROBLEMS AND RECOMMENDATIONS

It became very evident during the first few hours of Task Force discussions that the problems involved in the measurements of ionizing radiation sources were of such a magnitude that the primary effort of the Task Force would be to attempt to prioritize those ionizing radiation measurements problems and then to recommend specific actions which could be taken to solve those problems. The attitude of the Task Force was not that there are no serious problems with non-ionizing radiation measurements, but that the needs of and demands placed upon state radiation control programs were mainly in the area of ionizing radiation. Non-ionizing radiation measurements are expected to become a more serious problem as more states become involved in this area of radiation protection.

The Task Force decision was backed up by the state questionnaire survey. One survey reporter stated: "Let's solve our present problems before we solve our future problems." That statement epitomized the feelings of the Task Force members.

The Task Force then wrestled with the problem of "quality assurance" versus "quality control" or instrument calibration. It was decided that the whole radiation measurement system was in desperate need of a properly designed and executed quality assurance program, both for low-level environmental radioactivity or radiation measurements and higher level field survey radiation measurements (such as x-ray output and scatter, neutron measurements etc.).

ENVIRONMENTAL RADIATION MEASUREMENTS

Problems involved with environmental ionizing radiation or radioactivity measurement systems dominated the Task Force discussions, mainly because of both the magnitude of the problems and the scope of involvement by Federal, state and private company programs in this vital area. Both routine and emergency measurement systems were discussed, but the Task Force concentrated on routine measurements. Other Federal and Conference Task Forces are reviewing emergency monitoring requirements.

The states needs in environmental measurements can be summarized as follows:

a. A quality assurance program to include:

   1. Sampling procedures (collection)
   2. Sample preparation
   3. Sample measurement
   4. Data reporting

b. Additional low level laboratory standards

There is a serious need to adequately define the term "quality assurance" as related to environmental radioactivity analysis. A recent paper by J. Selvidge entitled "Precision of Radiation Monitoring Measurements," Health Physics, Vol. 30, June, 1976, pp. 479-484, discusses the problem in general and specifically cites the example of the monitoring of ^{239}Pu concentrations in air from working areas and stacks.

Selvidge states "For measurements of levels of radioactivity to be most useful to decision makers, some indication of the precision of the figures obtained should be reported . . . To determine the cumulative error associated with such a measurement, the different sources of error must be identified, the magnitude of their contributions to the error estimated, and the propagation of the error throughout the procedure computed."

He addresses the types of error as follows: "The types of error important in radiation monitoring can be classified into four general categories:

1. Errors arising from the mechanics of the collecting and counting procedure;

2. Statistical variation in the phenomenon being observed;

3. Limitations on the number of significant figures obtainable for quantities appearing in the computations; and

4. Indeterminate errors."

Selvidge's conclusions and the conclusion of the Task Force are almost identical although arrived at separately. Selvidge outlined a method "for identifying sources and magnitudes of factors contributing to monitoring errors and their propagation through the calculation of the concentration [which] enables the analyst to determine <u>how</u> accurate a measurement of radioactivity is." He also states that error can be reduced by devising specific plans once the sources of the errors are known.

The Task Force for its purposes has defined "quality assurance" as both a determination of the error and a program to control that error within reasonable limits.

Within environmental radiation sampling there is a need for:

1. Universally accepted definitions of sampling procedures for specified samples (air, water, soil, etc.);

2. A method of reporting sampling procedures;

3. A method to determine if the sample collected is a representative sample; and

4. A standard procedure for determining sampling errors.

In the sample preparation procedure there is a need for:

1. Standardized procedures (does the checmical or mechanical procedure change the sample in such a way that one is not analyzing what one thinks he is analyzing?)

2. Procedures for determing error (What procedures produce uncertainties in the measurement system? For example, how much of a specific radioisotope is lost on glass walls, released to the atmosphere, etc. by the specific preparation? The quality assurance program should locate and assure that the variability in the sample preparation technique remains within acceptable limits.)

In the sample analysis area:

Equipment should be calibrated for the type of sample being analyzed including geometry and for specific isotopes in the sample.

In data reporting area:

There is a need for a standardized data reporting system for all agencies and other companies or individuals publishing environmental monitoring results. (Claude Sill, Chief, Analytical Chemistry Branch, Health Services Laboratory, ERDA, recently prepared an internal document which discusses in detail the problems with the way various laboratories report their analytical results. He also proposes a standardized procedure for the Health Services Laboratory. NBS, the other Federal agencies, and the states should review this procedure for its appropriateness. (See Attachment B)

There is a definite need for methods of calibration and suitable standards traceable to NBS for field environmental radiation measurements. Natural background levels of radiation are variable throughout the U.S. One example of the problem of low-level environmental radiation is the determination of exposure from natural uranium deposits. Calibration sources (e.g. a slab of uranium ore) are necessary to calibrate scintillation counters, thermoluminescent dosimeters, and pressurized ion chambers so that radiation exposure levels can be accurately determined.

During the discussions concerning environmental monitoring the Task Force agreed that the present EPA environmental radioactivity laboratory intercomparison studies program was indeed successful and that EPA should be lauded for this activity. The program should be expanded and a follow-up program should be started to assist those state programs where deficiencies exist.

The Task Force also agreed on the need for a continuing program of Federal agency cooperation and that NBS should play a greater role in this effort, especially since the remaining agencies are mainly regulatory in nature. In all cases, environmental radioactivity measurement systems should be traceable to an NBS system.

It is also recognized that NBS should maintain its independence from direct involvement in the regulatory process.

FIELD SURVEY MEASUREMENTS

Field survey measurements made by state radiation control programs may be subject to future court actions since many of these measurements are directly involved in the regulatory process. There is some question concerning the accuracy requirements of these instruments.

In any case, there is a need for survey equipment evaluation, survey equipment calibration standards and calibration procedures.

Presently, NBS does provide both equipment calibration services and reference sources. Both of these areas should be expanded and equipment evaluation should be included in any expanded program.

Of major concern to the states is the cost of the calibration of their survey equipment. Present costs are too prohibitive. It is recommended that the Federal and state agencies involved in field survey equipment calibration be given immediate monetary relief.

A major step toward relieving the states from the routine calibration cost burden is by NBS providing a mobile calibration facility or facilities which could assist the states in their calibration procedures. Most states polled felt that the optimum solution for calibration would be to have their own facilities with routine back-up by NBS. Unfortunately budgetary constraints again restrict most states from proceeding toward that goal. The NBS mobile calibration facility would solve the problem for the near future.

Some states expressed a desire and apparently had funds to establish their own calibration facility. The Task Force recommends that NBS develop a model calibration facility and work with those states desiring assistance in designing and use of state facilities. In this way, NBS would benefit by learning the problems inherent in the design and use of state calibration facilities and solving those problems.

Specifically, the Task Force recognized problems in the field survey measurement system and cites the following examples:

1. The wide spread of x and gamma energies (from 20 keV to ∿2 MeV for most operations) and spectra which are seen in the field;

2. The lack of neutron survey equipment and calibration standards;

3. The calibration of thermoluminescent dosimeters for both low and high level radiation sources;

4. The need for additional alpha and beta calibration standards; and

5. The need for survey equipment evaluation and model design specifications for survey equipment.

GENERAL COMMENTS

The Task Force also reviewed the lack of training courses and facilities for state program personnel, specifically as it relates to the areas of radiation measurement and quality assurance, the only areas of direct concern of the Task Force. It is realized that the problem is greater than this, hence the recommendation made concerning training activities.

The group also believes it necessary to continue the activities of the Task Force and strongly supports a greater role for the National Bureau of Standards in the activities of the Conference of Radiation Control Program Directors. The state radiation control programs can indeed benefit greatly from more direct contact with and support from the National Bureau of Standards. We do not feel it presumptuous to state that the National Bureau of Standards may also benefit from this relationship.

Areas in which further Task Force activities are desired are:

1. Determination of states instrumentation requirements;
2. Determination of the need for and kinds of accuracy required in radiation measurements;
3. Continued assistance to NBS and other Federal agencies in carrying out the recommendations previously made;
4. Non-ionizing radiation instrumentation and measurement needs;
5. Ultra-sound measurement needs; and
6. Maintenance of this new liaison between the states and NBS.

ATTACHMENT A

REPORT - TASK FORCE ON RADIATION MEASUREMENTS CONFERENCE OF RADIATION CONTROL PROGRAM DIRECTORS

On April 6, 7, 8, 1976, the Task Force on Radiation Measurements of the Conference of Radiation Control Program Directors met at the EPA Office of Radiation Programs Facility in Nevada to analyze the results of a joint Conference-NBS questionnaire on radiation measurement needs of the state and local radiation control agencies.

At the time of the meeting, twenty-eight state or local agencies responded. They were Arkansas Department of Health, California Department of Health, Florida Department of Health and Rehabilitation Services, Illinois Department of Public Health, Indiana State Board of Health, Iowa Department of Environmental Quality, Kansas Department of Health and Environment, Kentucky Department for Human Resources, Louisiana Department of Conservation, Maine Department of Human Services, Maryland Department of Health and Mental Hygiene, Massachusetts Department of Public Health, Michigan Department of Public Health, Minnesota Department of Health, Mississippi State Board of Health, Nebraska Department of Health, New Hampshire State Department of Health and Welfare, New Mexico Environmental Improvement Agency, New York State Department of Environmental Conservation, Oregon State Health Division, Pennsylvania Department of Environmental Resources, Philadelphia Department of Public Health, Rhode Island Department of Health, South Carolina Department of Health and Environmental Control, Tennessee Department of Public Health, Texas Department of Health Resources, Washington Department of Social and Health Services, and Wisconsin Department of Health and Social Services.

Twenty-two of the agencies responding have radioactive materials licensing and regulatory programs, twenty-three carry out environmental surveillance programs and twenty-seven have x-ray regulatory and inspection programs.

Fifteen of the respondents were USNRC Agreement States, eleven had USNRC contracts for monitoring reactor effluents, eleven had FDA-BRH contracts for monitoring electronic product radiation, and seven had OSHA contracts.

In response to the question concerning the types of NBS assistance needed, the following types were ranked in decreasing importance:

1. (MOST IMPORTANT) To provide transfer standards to establish and maintain traceability to NBS primary standards;

2. To prepare standard procedures for calibration of field instruments and; to prepare standard procedures for making accurate measurements; (tied)

3. To conduct periodic tests of measurement performance, and to provide assistance if needed for improvement;

4. To calibrate states' transfer standards periodically against NBS primary standards;

5. To conduct training sessions for state program personnel;

6. To provide technical assistance in evaluating measurement instruments;

7. To design a complete model state laboratory for radiation instrument calibrations; and

8. To design a recommended calibration range for survey instruments.

The agencies were most interested in NBS transfer standards for calibrated radioactive sources, with high interest in ionization chambers, moderate interest in high quality survey instruments and low interest in activation foils for measurement of neutron fields.

In response to a question concerning adequacy of field survey instrument measurements, the majority of respondants (19) believed that gamma field survey measurements were adequate, with a split on the adequacy of alpha, beta and x-ray measurements. Most states (18) felt that neutron field survey measurements needed improvement.

Twenty-six of the states (an overwhelming majority) believed that better uniformity of measurements among the states was needed. Fifteen of the states felt that this included all measurements, eight listed environmental monitoring as being most important for uniformity with three states mentioning field survey measurements.

Twenty-two of the states felt that better agreement between Federal and State measurements was needed with eight states mentioning environmental, and one mentioning field survey measurements. Suprisingly, five states felt that better agreement was not needed.

Only thirteen states responded to the question that better agreement of measurements among the federal regulators was needed with eight believing that better agreement was necessary and five disagreeing. The "no-response" by so many states may indicate that they did not know.

In responding to the question concerning a trend regarding needs for new types of radiation measurements, a great variety and number of responses were received. Non-ionizing radiation measurements headed the list, but states mentioned needs for more environmental monitoring, emergency radiation dose instrumentation, low-energy x rays, alpha, beta and gamma spectrometry, thermoluminescent dosimetry, standardization of survey procedures for x-ray equipment, nuclear reactor environmental monitoring, and high energy particle accelerators, and radon measurements in the field. Two states responded that we should solve our present problems with instrumentation and measurements before we worry about future problems.

In response to the question concerning the trend regarding demand for improved accuracy, the responses were also varied. However, the outstanding statement was that a definition of acceptable accuracy of radiation measurements was needed. Others included: low-level environmental monitoring for alpha, beta, gamma, and in particular Iodine-131 and Strontium 90; accident radiation measurement instrumentation; personnel monitoring devices; accuracy in measurements of x-ray exposures of the public; thermoluminescent dosimetry; and non-ionizing radiation instrumentation and calibration. Another important statement was that the states will need to "defend" their measurements in court cases. (A discussion among task force representatives re-enforced this statement in that one state was then in court defending its measurements).

In response to the question "Measurement assurance programs are designed to periodically monitor the measurement performance of a laboratory, and to assist it in improving performance if that necessity is indicated. Would your office be interested in participating in such a program, with NBS as a monitor?", the majority (26) responded yes.

Respondents who answered yes to the above question were asked to rank their priorities for the type of radiation measured in a measurement assurance program. The response in order of decreasing priority is as follows:

1. gamma environmental
2. beta environmental
3. alpha environmental
4. X radiation
5. gamma survey
6. beta survey
7. alpha survey
8. neutron radiation

In response to the question, "If you believe that a model state radiation calibration facility is needed, what calibration capability would you like to see included?", the response was as follows:

X-ray calibration range - 21
γ-ray calibration range - 22
TLD calibrator - 22
Reference radiation sources (rad mat) - 22
Radiopharmaceutical dose calibrator - 13
Non-ionizing radiation calibration equipment - 17

The states responded to the next question, "Are you confident that the measurements presently made by your program could be successfully defended for legal purposes if challenged in court?", the response was as follows:

2	12	14	0
few could	some could	most could	all could

It is an interesting response and will be pursued further in future meetings of the task force.

In response to the question, "Would additional ties to NBS make you more confident in defending your measurements?", the overwhelming response (26-2) was yes.

The recommended priority of measurements for which the states would like to have recommended procedures is as follows:

1. Environmental sample counting
2. X and γ radiation surveys
3. TLD monitors
4. Beta particle field measurements
5. Radiopharmaceutical dose calibrator

The recommended priority on procedures for calibrations is as follows:

1. Calibration of survey instruments
2. Calibration of counting systems
3. Calibration of TLD systems

This seems like an inconsistency with the above question, but the ranking of priorities for 1 and 2 was very close and does not really show a serious inconsistency.

The recommended priorities in the various mechanisms that NBS could use to disseminate national radiation measurements standards is as follows:

1. Calibration of states' transfer standards in a mobile NBS calibration facility which would visit each state periodically.

2. Calibration of states' transfer standards at an NBS regional calibration facility serving a number of states.

3. Calibration of states' transfer standards at NBS site.

Twenty-five of the respondents indicated that microwave radiation was a non-ionizing measurement made in their programs, five indicated lasers, and three indicated ultraviolet.

Thirteen respondents stated that they had legislative authority over lasers, thirteen over microwaves, and eleven over ultraviolet radiation.

In attempting to rate the services NBS should provide regarding non-ionizing radiation, the response was above average in all categories with ranking as follows:

1. Guidance on instrument selection
2. Training in use of measurement systems

3. Periodic test of electromagnetic radiation measurement system
4. Calibration of microwave instrumentation
5. Calibration of laser instrumentation
6. Calibration of ultraviolet instrumentation

Most states believed that in-house capability was the most desirable method for maintaining the calibration of survey instruments, with use of external service a low second, and return to the manufacturer a losing third.

The states responded in a variety of ways over their major concern (problems) regarding laboratory (environmental) measurements and calibration of systems used for this purpose. Apparently, all of the respondent's had differing opinions on this subject. Because of the overwhelming response and the number of problems encountered, it is obvious that serious problems exist in all state environmental radiation laboratories. It would have been interesting to determine if the federal laboratories had similar responses.

In response to the question, "How could NBS provide services that would help your program find an acceptable solution to the above problem(s)?", the answers were just as varied, but included reference standards, on-site assistance and training, new standard methods, etc.

NBS stated in the questionnaire that six states would be involved in a joint development phase of a mutually acceptable program and asked the states if they had an interest in being one of those six states. Fourteen had a very high interest, eleven had a high interest and three had a moderate interest. The instrumentation portion of the questionnaire is very difficult to summarize. The states possess a great variety of both laboratory and field survey instruments. A more detailed analysis will be attempted at a later date when all questionnaires are received.

However, there are some areas of response which can be rather quickly analyzed. In response to a question related to estimated accuracy for field surveys and another question related to the satisfaction with the accuracy, it appears that those respondents who believe they have ±20% accuracy or below are satisfied with that accuracy. Whether or not the estimated accuracy is correct is debatable. In any case, sixteen respondents stated that they are satisfied with their accuracy for inspections and surveys. Eleven respondents are not satisfied.

In the laboratory situation, four states responded yes to the question, "Is any energy determination made in a α-particle counting?", and twenty-three responded negatively.

ATTACHMENT B

REPORTING OF ANALYTICAL RESULTS

Analytical Chemistry Branch
Health Services Laboratory
U. S. Energy Research
and Development Administration

There is considerable confusion in the way various laboratories report their analytical results, particularly those from radiochemical measurements. Some laboratories report the standard deviation resulting from measurement of the random processes only; others report the random uncertainty after multiplication by two or three to obtain higher confidence limits. In many cases, only the statistical uncertainty of the final sample measurement is included, while other equally important random uncertainties incurred earlier in the determination are completely ignored. Some laboratories report various combinations of random plus systematic uncertainties, sometimes with no clear explanation as to what was done.

In addition to the confusion, there are other objectionable practices that are widespread. Analytical results should be reported in such a way as to convey as much information as clearly as possible. However, physical measurements should not be permitted to appear more precise and/or accurate than they really are to prevent unwarranted conclusions from being drawn from the data. For example, many laboratories report standard deviations to three or more significant figures with no more justification than "that's what the computer gives." A standard deviation is a value by which the associated measurement can be expected to vary once out of every three times. To infer that the results are sufficiently precise to permit interpretation of the standard deviation to three or four significant figures is certainly optimistic, even if the value of the standard deviation used were correct. More often, the value used is not even correct for several reasons: other important random errors have not been propagated to the final result; the population distribution is either not known or is known to be skewed; and other nonrandom (systematic) uncertainties are present and have not been included.

Another bad practice encountered frequently is the failure to ensure decimal agreement between the result and its associated uncertainty. For example, results such as 1.2 ± 0.002 or 1.234 ± 0.2 are internally inconsistent and should be clarified. Either the result is more precise than is given, as indicated by its standard deviation, and more significant figures should be retained; or the result is much less precise than indicated, and the number of significant figures should be decreased to agree with the precision indicated by the standard deviation. Lack of correspondence in the decimal places of numbers being added or subtracted frequently is responsible for implied precision and accuracy that cannot possibly be achieved. For example, suppose the annual release of radioactivity from several facilities was

21,200,000 curies from one, 5,260 curies from another, and 1.62 curies from a third. To say that the total activity released from the site was 21,205,261.62 curies certainly implies a precision in the measurement that is both incorrect and unintended.

Analytical results obtained from this Branch will reflect the following criteria.

Every result will be expressed as a finite number with a plus-or-minus uncertainty attached. The term "not detected" will not be used because it indicates only that the substance in question was in fact not detected by whatever means employed but gives no quantitative information as to the sensitivity with which it was not detected. The human eye is a much more sensitive indicator of the size of a lump of coal than the macro scales in the coal yard. The term "detection limit" will be used only to describe quantitatively the sensitivity of the analytical procedures available and not to express the quantitative results of actual analyses. The same objections and prohibition are also true with respect to the use of other similarly quantitatively nondescriptive terms such as nil, none, trace, negligible, etc. Except in the absolute sense of the last molecule, even the term "zero" is meaningless and requires quantitative description by use of appropriate numerical values, e.g., 0.00 is certainly different in its implication than 0.

The plus-or-minus value attached to the result is the total statistical uncertainty resulting from measurement of all random processes involved, properly carried through to the final result using the fundamental law of propagation of errors, at the 68% confidence level (i.e., one standard deviation). The standard deviation will be rounded off to one significant figure, or to not more than two significant figures when the numbers involved are less than 15. For example, the number 12 has twice as many significant figures as the number 9, but an absolute uncertainty of one part in the last place produces a relative uncertainty that is not significantly different for either number. The result itself will then be rounded off so that the last significant figure retained will occur in the same decimal place as that in which the standard deviation occurs. THESE NUMBERS MUST THEN BE INTERPRETED BY THE USER WITH DUE CONSIDERATION FOR THE CONFIDENCE LIMITS DESIRED!

An estimate of all nonrandom or systematic uncertainties incurred anywhere in the measurement process, if significant compared to the random uncertainties, will be placed in parentheses after the standard deviation. This estimate is highly subjective and generally difficult or impossible to achieve with any substantial accuracy. However, the impressions of the analyst can be as important in assessing the accuracy and acceptability of the final result as the numerical data. Because the numerical data are more objective and susceptible of exact statistical interpretation, the systematic uncertainties will be kept separate so that the precision with which the measurement was carried out can be kept clearly defined.

Reporting of Analytical Results

In the past, it has been the practice of this Branch to report analytical results at or near the detection limit somewhat indiscriminately in either of two ways. A "less than" value such as $< 6 \times 10^{-9}$ µCi/ml, corresponding to the detection limit at the 95% confidence level for the conditions used, and the net disintegration rate actually obtained together with the standard deviation of its determination, such as $2 \pm 3 \times 10^{-9}$ µCi/ml, have both been used. Although both numbers mean almost but not quite the same thing statistically, it was thought that the practical conclusions to be obtained and the intent would be clear from the way the data were presented. However, some confusion, loss of data, and additional problems have resulted. Particularly, when large numbers of radiochemical results are to be combined, such as in obtaining yearly averages, mean trends, etc., the question arises as to how to handle results reported in terms of "less than," detection limits, or negative numbers.

In all radiochemical measurements near the detection limit, the net value is obtained from the difference between a gross count and a background count, which are nearly identical in size for the same counting time and which reflect the measurement of statistically random processes. The problem is further complicated by the fact that a net reagent blank, also near zero, must also be determined in the same way as the net sample measurement and subtracted therefrom. Consequently, if the sample contains "no" activity, there is exactly the same probability of obtaining small positive net values that are in fact "zero" as in obtaining equally small negative net values that are "zero" because of the identical statistical probability of either number being numerically larger than the other. The inclination to accept a small positive value as being real simply because it is positive, but to reject an equally small negative value because it is negative is a purely human reaction, totally unsupported by mathematical statistics when random events are being measured. Although it is completely clear and logical that there can be no such thing as a negative concentration, it is equally clear that elimination of small negative numbers representing measurements of random processes will surely give rise to a slightly positive bias in the means of a large number of measurements.

Henceforth, it will be the policy of this Branch to report the net disintegration rate (expressed as a concentration) and standard deviation actually obtained, whether or not the sign is negative. When the absolute value of the net rate can be rounded off to one significant figure occurring in a decimal place to the right of the one in which the standard deviation occurs, the value is rounded to zero. For example, 0.086 ± 0.2 is rounded upwards to 0.09 and then to 0.10 and reported as 0.1 ± 0.2; 0.04 ± 0.2 is rounded downward and reported as 0.0 ± 0.2. Net negative numbers should then be rounded upwards to zero by the customer before publication or other release after the averages have been determined, or on each individual result if no further mathematical treatment is intended. It may be predicted with some confidence that net negative numbers larger than two or three times the standard deviation of the net will not be encountered. Much larger values would give increasing confidence that the negative values were real. Because of the physical impossibility of such a result, presence of a systematic error in the measurement is indicated that will be identified and eliminated.

Claude W. Sill, Chief
Analytical Chemistry Branch

APPENDIX B

IONIZING RADIATION MEASUREMENT CRITERIA FOR REGULATORY PURPOSES

CONFERENCE OF RADIATION CONTROL PROGRAM DIRECTORS, INC.
TASK FORCE ON RADIATION MEASUREMENTS

PREPARED FOR THE NATIONAL BUREAU OF STANDARDS UNDER THE TERMS OF NBS CONTRACT NUMBER 7-35787

IONIZING RADIATION MEASUREMENT CRITERIA FOR REGULATORY PURPOSES

TABLE OF CONTENTS

ABSTRACT

A number of approaches could have been made for providing the reader with the information contained in this publication. In the interest of brevity, it was deemed necessary to develop definitions and tabularize the material that could be most easily utilized by those persons enforcing certain regulatory requirements and guides as well as those persons who are affected by the requirements and guides. To that end, this report:

1. Defines "accuracy" which is necessary for radiation control purposes

2. Lists pertinent regulatory criteria and limits

3. Lists the radiation sources that require measurements

4. Lists the expected ranges for those measurements

5. Lists the accuracy requirements

6. Lists the instrument considerations necessary to make those measurements accurately

7. Discusses some of the problems and pitfalls in radiation control measurements.

INTRODUCTION

Because of the desire of the Conference of Radiation Control Program Directors to promote uniform radiation measurements nationwide, as well as the concern of the Conference regarding the lack of knowledge or training of personnel and the lack of proper instrumentation for making such measurements, the Task Force on Radiation Measurements was established. The Task Force was given responsibility to investigate current radiation measurement needs of state radiation control agencies throughout the United States, and on the basis of analysis of these needs, to suggest mechanisms by which radiation measurements might be improved such that they might be uniform nationwide. This, then, is the basis and goal of this report. The tables summarize the results of this investigation.

State regulatory agencies, with limited manpower, resources, and never enough training, are required to "spread themselves thin" by making measurements on a wide variety of radiation sources and yet, at the same time, are expected to be "expert" on each source.

The tables included in the body of this report have been developed to aid in relieving at least a portion of this problem. They point out the typical types of radiation measurements to be made and the reasons for making them by citing the applicable regulatory criteria and/or guides. It is important to note that when reviewing the regulatory criteria the ALARA (as low as reasonably achievable) concept should always be kept in mind. The range of radiation levels to be expected when making such measurements and the accuracy with which they should be made are also given in the tables. In addition, some of the items which must be taken into account when selecting and using instruments are listed in the column entitled "Instrument Considerations." Because of the limited time usually available to state personnel and the necessity to find fast answers to problems, there are deliberate redundancies in this report to assure that those persons scanning only small portions of this document obtain the desired information.

It is important to note that the information contained in these tables is not "all inclusive" and is not, by any means, the answer to all problems. These tables are a first attempt to comprehensively summarize the information and place it into a format which can be easily utilized.

Information contained in the tables represents the current consensus, not only of the members of the Task Force, but also of comments received from state radiation control programs, Federal agencies, industry, health physicists, and instrument manufacturers.

Use of the tables, as well as a continuing program for updating and upgrading the tables by regulatory personnel and other health physics professionals and the industry, is an important first step in promoting uniform radiation measurements nationwide. Hopefully, we will all be making measurements on the same basis.

In reviewing the tables, particular note should be taken of the rather wide range of accuracy requirements. For some applications more than one accuracy requirement is given, e.g., screening vs. verification measurements. In line with Lauriston S. Taylor's article "A Saga of Radiation Safety" in the May 1976 issue of NBS Dimensions, it must be kept in mind that radiation measurements should be made, not to assure regulatory compliance for compliance's sake, but to protect people. It is vital that we be reasonable and rational in our requirements because different accuracies may be appropriate for different applications. For example, an accuracy of $\pm 50\%$ may be appropriate for a small fraction of the occupational radiation exposure limit, while $\pm 10\%$ to $\pm 20\%$ may be appropriate for measurements at or above the limit.

Quoting from Taylor's article, the following principles are vital to the promotion of uniform radiation measurements:

"1. Assure the existence of basic standards of the necessary accuracy.

2. Assure the existence of transfer standards of the necessary accuracy.

3. Develop adequate and reliable field instruments.

4. Develop adequate means for calibrating field instruments.

5. Assure that at all times any instrument reading anywhere can be traced to its basic calibration source.

6. In measurements anywhere, do not lose your sense of humor."

NOTE: Not all references listed at the end of this report are specifically referred to in the text or tables. It would be necessary to increase substantially the size of the tables to include the references for each chemical procedure available, for example. The intent was to list references, however, for explicit purposes and procedures which should be available to all state personnel.

DEFINITIONS OF TERMS

THE MEANING OF ACCURACY

There are several terms which must be understood in order to discuss the problems encountered in radiation measurements. This understanding is especially important in the context of this report because many people use the terms interchangeably to describe concepts which are fundamentally different. The terms are "accuracy," "bias," "reproducibility," and "precision." Webster defines them as follows:

<u>Accuracy</u>	"Degree of conformity of a measure to a standard or true value."
<u>Bias</u>	"Systematic error introduced into sampling or testing by encouraging one outcome or answer above others."
<u>Reproducibility</u>	"The ability to 'cause' (the value of a measurement) to exist again."
<u>Precision</u>	"The degree of reproducibility with which an operation is performed or a measurement stated."

In the National Bureau of Standards Handbook 80 [7]* entitled "A Manual of Radioactivity Procedures," these terms and their relationship to one another are further explained.

Reproducibility and precision are very closely related and are usually expressed as the amount of variation to be expected between two or more measurements of the same quantity. Precision can be determined or (more properly) estimated from the results of a series of measurements. The standard deviation of the set of resultant values is usually taken as a measure of the precision.

"Accuracy" and "bias" are many times used interchangeably, but in the context of this report must be considered to be very different. Bias can be determined quantitatively as the amount by which a measurement (if only one is available) or the average of a series of precise measurements differs from the "true" value. Bias is many times called 'systematic error' and can be expressed quantitatively as the amount by which the average of a series of precise measurements differs from the true value. Accuracy is difficult to determine quantitatively since its essential components (bias and precision) cannot be combined in any simple fashion to produce a single measure which is meaningful. Instead, the accuracy required of a measurement system must be judged in terms of a predetermined degree of uncertainty which is acceptable for the type of measurement under consideration. The accuracy of the measurement can then be judged acceptable if the uncertainty associated with the result(s) lies within the acceptable range. Only in this case would the difference between the measured and true value not exceed the degree of acceptable uncertainty.

*NBS Handbook 80 has been superseded by NCRP Report 58 [1]

An essential part of this problem is that the result of a measurement is affected by all aspects of the measurement system, which includes not only the instrumentation used to make the measurement but the procedures used in operating the instruments, the care which the person making the measurement takes to follow the procedure, and the selection of the sample on which the measurement is to be made or the location at which the measurement is to be made. These aspects, and there are others, are sources of error which can affect both the bias and precision of the measurement.

Cali and Reed [22] have defined an accurate measurement system as "one that produces precise numerical values of the property or properties under test or analysis that are free of, or corrected for, all known systematic errors. Such values are also related to the 'true value' of the property(ies) under test or analysis."

In the following figures, the inner circle is the acceptable range of error of a measurement with the 'true value' being at the center. If the results of a series of measurements lie within this circle, then the accuracy of the measurement sytem is considered to be acceptable.

In Figures 1 and 2, the measurements have the same precision but are displaced (biased) from the center by different amounts. In Figures 1 and 3 the averages of the measurements have the same bias, but with different precision. In Figures 3 and 4, the measurements have the same precision, but the biases are different.

Figure 4 is the only one in which the accuracy is acceptable because both the bias and precision are such that the results of the measurements are within the acceptable range of uncertainty. In Figure 1 the accuracy is not acceptable because of both large bias and poor precision. In Figure 2 the accuracy is not acceptable because, while the bias may be acceptably low, the precision is so poor that it is not possible to make a decision as to the amount of bias which may be present and very few of the measurements fall within the acceptable range of uncertainty. Figure 3 has unacceptable accuracy because of the large bias, even though the precision is acceptable.

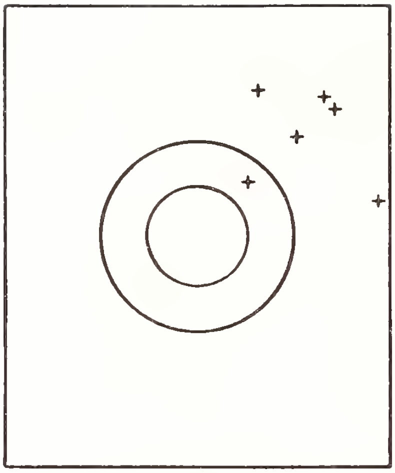

Fig. 1. Inaccurate, large bias, and poor precision.

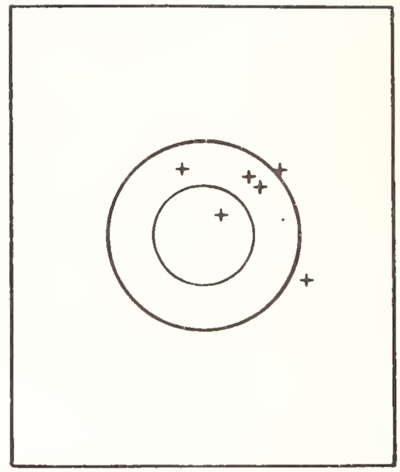

Fig. 2. Inaccurate, questionable bias, and poor precision.

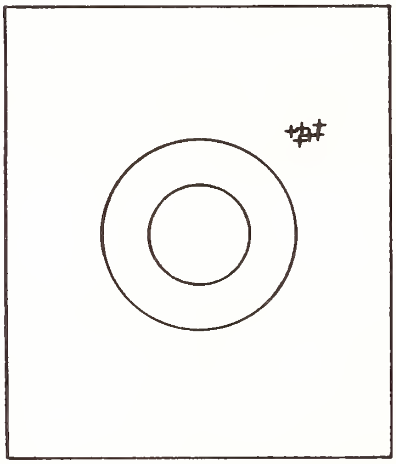

Fig. 3. Inaccurate, large bias, and acceptable precision.

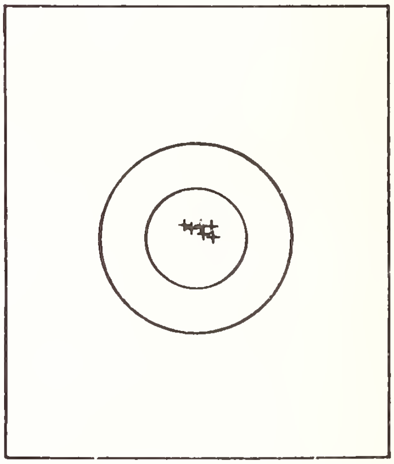

Fig. 4. Accurate, acceptable bias, and acceptable precision.

GENERAL DISCUSSION OF TABLES I-IV

In the following tables the column headed "Application" contains the type of radiation measurement which is to be made. The second column, labeled "Regulatory Criteria," lists those issuances which contain limits or criteria to which radiation measurements may be compared and, in some cases, the numerical value of those limits or criteria.

The column labeled "Range Expected" is the range of radiation characteristics which is expected to include most of the measurements made for a particular purpose. Values included here are based on a consensus of the Task Force members and others.

The column headed "Accuracy Requirements" contains values which express the consensus of measurement accuracy required to enable good decisions as to whether or not regulatory action should be taken. By way of explanation, it is considered that those measurement results which are near the regulatory limit require the best accuracy because it is at this point where a decision may be difficult. The following two examples illustrate that for measurement far from the regulatory limit even large errors will not affect decisions determining the need for regulatory action. First consider the case where the measured value is 5% of the limit. Even if there is a 100% error on the measurement, such that the true value is between 0% and 10% of the limit, there is no need for regulatory action. Second, consider the case where the magnitude of the error equals the limit. If the measured value is 300% of the limit, such that the true value is between 200% and 400% of the limit, there is a need for regulatory action. If the measurement and its error had included the regulatory limit, then there would have been some question as to the propriety of either decision and whichever decision was made would have been subject to valid criticism.

The fact that an error of 100% may be acceptable under certain circumstances does not mean that errors of this magnitude should be tolerated. The consensus is that measurement errors as great as 50% may be tolerable when the measurement is made for screening purposes. These would be subject to verification if the screening measurement were close to the regulatory limit. The measurements for verification purposes should not be subject to errors greater than 10% to 20%.

The last column of the tables, headed "Instrument Considerations," lists some of the types of instruments suitable for particular types of applications and some of the essential characteristics of the instrumentation. One of the essential characteristics not mentioned in the tables is that the instrument absolutely must be capable of detecting the type of radiation to be measured. This may seem to be obvious, but there are many documented instances in which the presence of alpha-emitting radioactive material has been sought with a Geiger-Mueller (G-M) detector with stainless steel walls. Other instances have been documented in which attempts were made to measure low energy x rays with uncalibrated G-M survey meters. It is essential that those people who are required to make radiation measurements be provided with instrumentation which is appropriate for the type of radiation to be measured and which has been properly calibrated with that type of radiation. They should also have been trained in the proper procedures for making measurements and in the choice of proper instrumentation. Interpretation of the results of those measurements (including the interpretation of the associated errors) is an essential part of the training.

In that light, the measurement of neutrons probably represents the greatest dilemma for the inspector. Sources which emit neutrons present a problem in measurement which is difficult but not insurmountable if the appropriate measuring equipment is available. Other sources are on the market which emit neutrons although not designed specifically for that purpose (industrial and medical accelerators). Due to the magnitude of the problem and the still unsolved methods of routine neutron measurement around those devices, they will not be included until some of these problems can be resolved.

Note added in proof: A glossary of abbreviations of terms and units used in the tables is included as Appendix III to this report.

HEALING ARTS X-RAY SURVEY MEASUREMENT CRITERIA

(Table I)

Measurements in the healing arts x-ray field are becoming more and more complex with the emergence of highly technical and specialized medical x-ray equipment. Promulgation of the Federal x-ray performance standard has added to the complexity of such measurements. This table outlines the different types of measurements which must be made on healing arts x-ray equipment as well as regulatory limits or criteria which must be used in the decision-making process. It is vital that instruments used to measure x rays be calibrated with x rays in the appropriate energy range.

Problems of instrument energy dependence can be partially solved by calibrating at a number of different energies and then plotting the response of the detector vs. energy. However, to use this information accurately, the energy spectrum of the equipment under test must be known. Since spectral measurements are not routinely performed in the field extreme care must be exercised in applying energy-dependent corrections.

Certain common attributes of instruments used for measurement of healing arts x rays have been omitted from the table. The instrument is assumed to be a rugged, portable survey meter with minimal temperature dependence, exposure rate dependence, directional dependence, background, and effects from other environmental causes, in addition to the other specific characteristics in the table. As a minimum, the instrument must be able to maintain a level of performance consistent with the accuracy requirement.

TABLE I
HEALING ARTS X-RAY
SURVEY MEASUREMENT CRITERIA

APPLICATION	REGULATORY CRITERIA	MEASUREMENT RANGE EXPECTED	MEASUREMENT ACCURACY REQUIREMENTS	INSTRUMENT CONSIDERATIONS
UNRESTRICTED AREA	State regs only. 2 mrem in one hour. 100 mrem in 7 consecutive days.	Few mR/hr to R/hr	Screening ±50% Verification ±20%	Survey meter, ion chambers. 20-120 kV capability. <1 sec. response time. Long-term integrate mode. Temperature insensitive.
OCCUPATIONAL EXPOSURE	1250 mrem/calendar qtr. 5 rem/year whole body. 75 rem/yr extremities. 30 rem/yr skin of whole body.	Personnel Monitoring: Background to several rem per year Radiation Area Monitoring: Few mR/hr to R/hr	Screening ±50% low end of exposure Verification ±10% above 25% of regulatory criteria	Pocket dosimeters, TLD, film badge. Survey meter, up to 150 kV range. (250 kV for therapy) TLD's of known energy response. Portable survey meter: integrating, rate and direction independent, wide exposure range.
OVEREXPOSURES	State regulations. Defined as anything over 1.25 rem/qtr.	Several rem to thousands of rem	±20% over 5 rem	Use same instrumentation as for occupational exposure. Stop watch to reproduce time involved. Film badge readout is critical. TLD not a permanent record [can't tell if fixed or moving relative to sources].
FLUOROSCOPIC OUTPUT (USEFUL BEAM)	State regs. Old equipment. <10R/min. New equipment with image intensifier <5R/min. BRH performance standard. Manual <5R/min. Hi Level Control <10R/min	<1R/min to 100R/min	±10%	Ionization chamber. Measured at skin entrance. Energy independent at 50 kV to 150 kV.

TABLE I
HEALING ARTS X-RAY
SURVEY MEASUREMENT CRITERIA

APPLICATION	REGULATORY CRITERIA	MEASUREMENT RANGE EXPECTED	MEASUREMENT ACCURACY REQUIREMENTS	INSTRUMENT CONSIDERATIONS
HALF-VALUE LAYER	State regulations for old equipment. BRH performance standard for new equip. (HVL shall not be less than values shown below.)	HVL range: 0.2 - 6 mm aluminum (type 1100) Radiation range: 10 mR to 0.5 R integrated. Rates 1 R/sec to several R/sec.	+40% to -0% ±20%	Small ion chambers (must be completely covered by beam). Exposure rate independent. 20 - 120 kV
LEAKAGE	BRH performance standard. 100 mR in an hour at 1 meter from tubehead; 2 mR in an hour at 5 cm from rest of unit.	Few mR/hr to R/hr	Screening ±50% Verification ±20%	Survey meter, ion chamber 20 kV-120 kV, <1 sec. response time; rate and/or integrate mode. Temperature insensitive. Ionization chamber with 100 cm^2 surface. No detector linear dimension greater than 20 cm.
DIAGNOSTIC BEAM OUTPUT (USEFUL BEAM)	State and BRH regs. Reproducibility, linearity. Federal guidance--NEXT, DENT and BENT programs.	Integrate 10 mR to several R Rates 1 R/sec to several R/sec	±10%	Ion chamber capable 20 kV to 150 kV, energy and rate independent. Tape measure (cm).
THERAPY BEAM OUTPUT (USEFUL BEAM)	Range of exposures for accepted medical practice. Reproducibility.	Up to 100 R/min (at skin entrance)	±10% Reproducibility and linearity ±1%	TLD. Ion chamber. Dose rate and energy independent. Integrating up to 100 R. Rate, 100 R/sec. 0-250 kV.

Design operating range (Kilovolts peak)	Measured potential (Kilovolts peak)	Half-value layer (Millimeters of aluminum)
Below 50	30	0.3
	40	0.4
	49	0.5
50 to 70	50	1.2
	60	1.3
	70	1.5
Above 70	71	2.1
	80	2.3
	90	2.5
	100	2.7
	110	3.0
	120	3.2
	130	3.5
	140	3.8
	150	4.1

NON-MEDICAL X-RAY SURVEY MEASUREMENT CRITERIA

(Table II)

This table includes a wide range of non-medical applications of x rays. The range of radiation energies and intensities is very wide, and instruments must be used which respond adequately for the particular application being considered.

As in medical x-ray measurements, it is important that instruments be calibrated over the appropriate range of energies typically encountered. This is necessary because most survey instruments show appreciable energy dependence over this broad range.

Since a wide range of environmental conditions will also be encountered, other effects on instruments must be considered. Shielding against the effects of radio-frequency radiation is important in airports, for example, when surveying baggage inspection units. The presence of radio-frequency and radar fields can result in erroneous indications from unshielded survey instruments.[17]

In using ion chamber type instruments, it is important that the entire active volume of the chamber be exposed to the x-ray field. If the entire chamber is not exposed, the meter indication will be low. Corrections can be applied if the beam size is known.

Instruments which are intended for use in high-energy radiation measurements should be calibrated with a suitable high-energy source of radiation. Build-up caps may have to be used to achieve adequate accuracy at higher energies. If measurements are made with the use of a build-up cap, it must also be in place during calibration.

Neutron contamination may be present when measuring radiation fields with energies above approximately 10 MeV. Instruments used primarily to measure photon radiation will not respond properly to neutron radiation, and the total radiation hazard will be underestimated as a result. Thus an instrument capable of measuring neutron radiation should be available.

High voltage generators, capacitor banks, transformers, and other electromagnetic equipment may generate x radiation during normal modes of operation or malfunctions. For instance, high-voltage transformers above 10 kV may produce x rays inadvertently, particularly if the transformer undergoes electrical breakdown. Capacitor banks can be a source of x radiation during breakdown of the dielectric at voltages above 10 kV. Capacitor discharges can produce x rays by a mechanism similar to that incorporated in capacitive discharge x-ray machines. Survey equipment used for these measurements must also be shielded against electromagnetic radiation in the radio-frequency range as well as being energy and rate independent.

TABLE II

NON-MEDICAL X-RAY SURVEY MEASUREMENT CRITERIA

APPLICATION	REGULATORY CRITERIA	MEASUREMENT RANGE EXPECTED	MEASUREMENT ACCURACY REQUIREMENTS	INSTRUMENT CONSIDERATIONS
CABINET	State regulations. BRH standard. 0.5 mR/hr at 5 cm. 100 mrem in 7 consecutive days to unrestricted areas.	0.1 mR/hr to 10 mR/hr	Initial survey $\pm 50\%$. Verification for regulatory requirements $\pm 20\%$.	Portable, rugged ion chamber 20 kV to 150 kV. Energy independent. Response time 1-2 sec, rate or integrate mode. R.F. shielded. 10 cm^2 surface with no detector linear dimension >5 cm.
ANALYTICAL	State regulations. Leakage and scatter 2 mrem in any one hour (some may be covered by cabinet standard)	mR/hr scatter to 10^3 R/sec direct beam	Initial survey $\pm 50\%$. Verification for regulatory requirements $\pm 20\%$.	Portable, rugged ion chamber 5 kV to 150 kV rate or integrate mode. Energy independent. Wide dose range. Capable of measuring pencil size beam.
VAN DE GRAAFF GENERATOR	State regulations. Scatter 2 mrem in any one hour	mR/hr to 100's of R/sec	Initial survey $\pm 50\%$. Verification for regulatory requirements $\pm 20\%$.	Portable, rugged ion chamber 0.1 to 12 MeV. Energy independent. Rate independent. Integrate mode.
RADIOGRAPHY	State regulations. 2 mrem in an hour in unrestricted area. Scatter, 0.5 mR/hr non-occupational.	0.1 mR/hr to several R/hr	Initial survey $\pm 50\%$. Verification for regulatory requirements $\pm 20\%$.	Portable, rugged ion chamber 20 kV to 500 kV. Rate and energy independent. Integrate mode.
GAUGES	State regulations. 2 mR in an hour in unrestricted area.	0.1 mR/hr to several R/hr	Initial survey $\pm 50\%$. Verification for regulatory requirements $\pm 20\%$.	Portable, rugged ion chamber 40 kV to 130 kV. Energy independent. Integrate mode.
ELECTRON MICROSCOPE	State regulations. 2 mR in an hour leakage. 0.5 mR/hr at 5 cm.	mR/hr	Initial survey $\pm 50\%$. Verification for regulatory requirements. $\pm 20\%$.	Ion chamber 20 kV to 150 kV. Energy independent. R.F. shielded or independent.

TABLE II

NON-MEDICAL X-RAY SURVEY MEASUREMENT CRITERIA

APPLICATION	REGULATORY CRITERIA	MEASUREMENT RANGE EXCEPTED	MEASUREMENT ACCURACY REQUIREMENTS	INSTRUMENT CONSIDERATIONS
T.V. SETS	State regulations. BRH standard. 0.5 mR/hr at 5 cm from any surface of the set.	0.1 mR/hr to 10 mR/hr	$\pm 20\%$	Portable, rugged ion chamber 5 kV to 50 kV. Energy independent. R.F. shielded or independent. 10 cm^2 surface. No detector linear dimension to exceed 5cm.
CATHODE RAY TUBES	State regulations. 2 mR in an hour. 0.5 mR/hr @ 5 cm from surface.	mR/hr	$\pm 20\%$	Ion chamber. Low kV x-rays. Energy independent. R.F. independent.
COLD CATHODE	State regulations. BRH standard. 10 mR/hr at 30 cm from the surface.	5 mR/hr to 50 mR/hr	$\pm 20\%$	Portable rugged ion chamber. 100 cm^2 surface area. No detector linear dimension to exceed 20 cm.
FLUOROSCOPY	State regulations. Scatter 2 mR/hr. Occupational exposures 1.25 rem/quarter or 5 rem/yr whole body. 75 rem/yr extremities.	mR/hr to several R/min	Initial Survey $\pm 50\%$ Verification for regulatory requirements $\pm 20\%$	Portable, rugged ion chamber 40 kV to 150 kV. Rate and energy independent. Wide exposure range.
ELECTRON BEAM	State regulations. Scatter, 2 mrem/hour. Occupational: 1.25 rem/quarter or 5 rem/yr whole body 75 rem/yr to extremities.	mR/hr to many R/hr	Initial Survey $\pm 50\%$ Verification for regulatory requirements $\pm 20\%$	Portable, rugged ion chamber 40 KeV to 120 KeV. Energy independent. Must measure x-ray fields produced, as well as the electrons.
BAGGAGE INSPECTION	State regulations. BRH standards. FAA rules 0.5 mR in an hour at 5 cm. [>1 mR/exposure to baggage requires notice to remove film.]	μR/hr to several mR/hr	$\pm 20\%$	Ion chamber 40 Kv to 100 kV. Energy independent. R.F. independent or shielded. 1 sec response time. Integrate mode (for pulsed x-rays)
INDUSTRIAL ACCELERATORS	State regulations. Scatter and unrestricted areas, 2 mrem in any one hour. Occupational: restricted areas, 1.25 rem/qtr or 5 rem/yr whole body. 75 rem/yr extremities	mR/hr to thousands of R/min	Initial Survey $\pm 50\%$ Verification for regulatory requirements $\pm 20\%$	High keV to MeV in neutrons, gamma, & electrons. Rate independent. Energy independent. Integrate mode. Wide exposure range.
LINEAR ACCELERATORS	State regulations. Includes shielding requirements and license for depleted uranium and induced isotopes. 2 mrem in any one hour in unrestricted area.	mR/hr to thousands of R/min	Initial Survey $\pm 50\%$	Ion chamber 0.1 to 20 MeV. Energy independent. Must measure neutrons in photon field. Wide exposure range.

X-ray Measurement Problems Encountered

It should be noted that even though calibration techniques may be available, they may not fill all needs for a specific measurement. An example of this is the measurement of scatter from a medical x-ray unit. The specified range of the instrument is from a few mR per hour to several R per hour. It may only be practical to calibrate the instrument with an exposure of approximately 1 R per hour. However, the requirement may necessitate measuring 2 mR per hour. On multiscale instruments, some other way must be used to determine if a measurement on a lower range (maybe 3 mR per hour full scale) is also accurate. It might be possible to do this check electrically but, by any method, something must be done to insure accuracy on the scale actually used for the measurement.

This problem is only the tip of the iceberg of measurement problems encountered. The accuracy requirements include the overall accuracy of the instrument, including effects due to energy dependence of detector, directional dependence of detector, exposure-rate dependence of detector, background noise or leakage of detector and readout, dynamic range of readout, scale non-linearities of readout, inability of readout to track linearly from scale to scale, and other serious environmental effects on both detector and readout. Problems of detector energy dependence can be partially solved by calibrating at a number of different energies and then plotting the response of the detector vs. energy. However, to use this information accurately, the energy spectrum of the equipment under test must also be known, and this is usually not the case. Many of the parameters mentioned above are provided by the manufacturer of the instrument. Unfortunately, not all manufacturers provide all the information, and those who do provide information are not uniform in how they specify the tests. Even more unfortunate, the limitations of the instruments are often overlooked when the measurement is performed.

The topic of environmental effects must be considered. Since most instruments used for x-ray measurements are vented air ionization chambers, it is obvious that corrections should be made for temperature and pressure variations in the environment. Not so obvious is the problem of the time lag involved before the air in the chamber achieves equilibrium with the ambient conditions after a change from one location to another, for example from a car trunk in summer to an air conditioned building. For some chambers, this lag could approach hours. Also, the change in relative humidity inside the chamber could cause increased leakage.

It must be noted that low levels of radio-frequency interference (levels which have been measured in hospital environments) can cause serious errors in most ionization chamber type instruments.[17] There is reason to believe that other environmental factors may cause equally serious effects.

The discussion above is not all-inclusive. The instruments in use are not ideal and, therefore, must be calibrated and corrected. Some of the required measurements outlined in the tables are very difficult, if not impossible, to make with present technology. However, with careful analysis and understanding of the measurement problem, many technically valid tests may be performed.

In some respects, equipment available for surveys around medical and dental x-ray machines comes closer to satisfying the needs of state programs than most of the instrumentation designed for use in other areas. Yet, routine x-ray safety evaluations by state inspectors are subject to errors from sources other than the measuring devices. Perhaps the major source of inaccuracy in the measurement system is the human element. The inspector's ignorance of, or inattention to, particulars of the measurement environment or limitations in the equipment may lead to incorrect or meaningless results. These factors can only be minimized by proper training and strict adherence to well-designed survey procedures.

Inspectors' techniques are often a significant factor resulting in a compilation of meaningless data. Since an inspector's performance may be evaluated on the basis of the number of machines checked, some individuals cut corners on the established survey procedures to increase productivity. This, coupled with their own vagueness concerning their equipment, has produced in at least some cases a scenario very similar to the following:

Arriving at a doctor's office, the inspector takes his survey equipment out of the trunk of his car where the temperature exceeds 120°F and enters the air-conditioned office. Moisture condenses inside the ionization chambers, and no time can be permitted for proper humidity and temperature equilibration. The doctor is also in a hurry and makes it clear that the inspection is costing him money, so no time is spent setting up the NEXT test stand; all output measurements are made with the chamber mounted in an inappropriate position. Half-value layer measurements are made with the aluminum filtration resting on top of the chamber, and the collimator of the unit is set at any convenient aperture. Scatter measurements are made at the same time and the exposure interval is less than a second. No correction for instrument response time is made. The instrument may be placed outside of the protective barrier with no consideration given to directional dependence. The survey is completed as quickly as possible. The film badge records are leafed through, and the inspector departs for the next facility after a brief interview with the doctor. Total time elapsed is a fraction of the time necessary for adequate inspection of a one-machine facility. The details on the inspection form may be filled in later.

The inspector in this case probably has no idea what effect these modified procedures have on his measurements, and his supervisor is not aware that the results of the inspection have been compromised because field performance evaluations are not routine.

RADIOACTIVE MATERIAL MEASUREMENT CRITERIA (RESTRICTED AREAS)

(Table III)

The measurement of radiation from radioactive material covers a wide variety of applications or purposes. As a result, there are numerous regulatory limits or criteria which apply to different situations, as well as a broad range of radiation levels which must be measured. It is essential that the person making the measurement be familiar with the instrument requirements for the particular measurement, e.g., type of radiation, energy of radiation, intensity, and rate dependency. Other considerations are noted in the table for each particular application.

Instruments used for these measurements should be operable over a wide range of environmental conditions such as temperature and humidity, relatively easy to operate and maintain, and capable of measuring the quantity of radiation or radioactivity encountered. Instruments used in field surveys should be portable, rugged, and appropriate for the intended purpose. Ancillary equipment needed to support the measurement, such as air sampling equipment, power supplies, etc., should also have many of the above attributes.

One must know the purpose for making the measurement, which then dictates the accuracy required. Calibration is essential to the measurement system, since a radiation measurement is no better than the calibration of the instrument used in making the measurement.

TABLE III

RADIOACTIVE MATERIAL MEASUREMENT CRITERIA (RESTRICTED AREAS)

APPLICATION	REGULATORY CRITERIA	MEASUREMENT EXPECTED RANGE	MEASUREMENT ACCURACY REQUIREMENTS	INSTRUMENT CONSIDERATIONS
EXTERNAL	NRC (10 CFR 20.101, 20.202). State regulations (S.S.R. Sec. D.101, Sec. D.202)	1 mR/hr to several R/hr.	Initial ±50%. Regulatory verification ±15%	Personnel dosimeters. G-M probes, ion chamber. NaI probes, 50 keV to 2 MeV. Energy and rate independent. Integrate mode for low level.
AIRBORNE	NRC (10 CFR 20.103 Appendix B, Table I). State regulations (S.S.R. Sec. D.103 Appendix A, Table I). FDA Guides for iodine	pCi/m^3. From bkg to 5000 x MPC	Initial (filter survey) ±50%. Regulatory verification ±10% for lab (Table IV).	Thin-end-window ion chamber survey meter. Proportional counter. α spectrometer, γ spectrometer. Liquid scintillation counters. Volume (1 cfm) air sampler with filters. Personnel air samplers. Calibrated air flow meter.
LIQUID EFFLUENT	NRC (10 CFR 20 Appendix B, Table I). State regulations (S.S.R. Sec. D.103 Appendix A, Table I).	May be several orders of magnitude higher than releases in Table IV (effluents to unrestricted areas)	See Table IV, Liquid Effluent	See Table IV Instrument Considerations for Liquid Effluents.
*BIOASSAYS**	NRC (10 CFR 20.108) (License conditions). State regulations (S.S.R. Sec. D.107) and license conditions and opinion of competent RSO	See footnote. Minimum detection limit: 10% of the body burden listed in ICRP #2	See footnote. ±10%	Nasal swabs. Whole-body counts. Thyroid scans. Urine, feces. NaI probe with scaler. Rectilinear scanner. Liquid scintillation counter. Gamma counter. Thin-end-window w/scaler equipment for counting biological samples; α, γ spectrometry.
MEDICAL DIAGNOSTIC	NRC (10 CFR 20, 30, 35). S.S.R. Sec. C.25 and C.26(a)(c). S.S.R. Sec. D.105 and 201	µCi to mCi and mR/hr to R/hr.	Dose assay ±5%. Surveys ±20%	Dose calibrators, gamma camera, rectilinear scanner, well counter. Instruments listed under External above plus thin-end-window and NaI µR probe.
MEDICAL THERAPEUTIC	NRC (10 CFR 20, 30, 35). S.S.R. Sec. C.25 and C.26(a)(c). S.S.R. Sec. D.105 and 201, Part G	mCi to Curies mR/hr to R/hr	±10%	Dose calibrators and instruments listed under External above plus G-M thin-end-window and NaI µR probes.

*Physical or chemical forms and/or conditions of use of radioactive materials may present an opportunity for uptake by the body through ingestion, inhalation, or absorption. Bioassays are required when it is necessary or desirable to determine the extent of an individual's exposure. The range will be dependent upon the isotopes the individual has been exposed to, as well as amounts. The accuracy required will depend on the isotope, i.e., tritium in urine may be high with small exposures while a very small amount (i.e., pCi/l of Am-241) must be accurate to ±10% because of the significance of small quantities of certain isotopes in urine. The counting equipment for biological samples must be able to accurately determine the presence of a pCi of material.

RADIOACTIVE MATERIAL MEASUREMENT CRITERIA (UNRESTRICTED AREAS)

(Table IV)

Table IV consists of common measurements that are made by state and Federal agencies for radioactivity in environmental samples. The regulatory criteria given for each application consist of Federal guidance or regulation and/or state regulation. Expected ranges are based on data from measurements currently made in the environment. Accuracy requirements are based on current desirable procedures and measuring equipment available, as well as projected needs. Instruments are listed by type for the various measurements. The list of instruments is not intended to be all-inclusive but is an example of the minimum equipment necessary to measure environmental radioactivity.

Radiation measurements in unrestricted areas include measurements of external radiation which impinges upon the body from outside sources and radioactivity in airborne particulates, gases, and liquids. These kinds of measurements are associated with environmental radioactivity monitoring programs carried on by states in the vicinity of potential sources of environmental radioactivity, including nuclear power plants and large hospital complexes. These measurements are also performed in other areas where environmental radioactivity is of concern. Milk, air, and water are commonly monitored by many state programs. In addition, the federal drinking water standards require screening of water supplies for gross alpha, gross beta, and identification and measurement of certain specific radionuclides in samples which exceed the screening levels.

Measurements for contamination, leak tests, lost sources, and emergency response require varied instrumentation. The table lists a few common instruments, required accuracy, and expected ranges. No attempt, however, was made by the Task Force to exhaustively study each application due to the multitude of measurements that might be required.

A list of radionuclides used for calibration by states is shown in Appendix I. If a sealed liquid source is received by a laboratory from NBS and is opened for analysis, it is no longer considered the "same, identical sample" prepared by NBS. As a consequence the result of the analysis of that sample is not traceable to NBS but may have some degree of credibility. If the results of the "round robin" or "blind" analysis of samples fall within the limits established by the sponsor of the samples, traceability may be achieved if the sponsor is NBS or a laboratory that has achieved traceability like EPA, Las Vegas.

TABLE IV

RADIOACTIVE MATERIAL MEASUREMENT CRITERIA*
(UNRESTRICTED AREAS)

APPLICATION	REGULATORY CRITERIA	MEASUREMENT EXPECTED RANGE	MEASUREMENT ACCURACY REQUIREMENTS	INSTRUMENT CONSIDERATIONS
EXTERNAL	DOT, EPA (variable, depending on sources of radiation, i.e., whole fuel cycle 25 mrem/yr). NRC (10 CFR 20.105). State regs. (S.S.R. Sec. D.105) <170 mrem/yr whole body for general population. 2 mrem/hr or 500 mrem/yr for an individual.	μR/hr to mR/hr	Initial survey ±50% Verification for regulatory requirements ±20%	TLD. Ion chamber. NaI μR meter. Useful for wide range of energies.
AIRBORNE	NRC (10 CFR 20.106- Appendix B, Table II). State regs. (S.S.R. Sec. D.106 Appendix A, Table II).	0.1 pCi/m^3 to 1000 pCi/m^3.	±100% at 10% of regulatory limit. ±10% near regulatory limit	Liquid scintillation counter. γ spectrometer. α spectrometer. Low background proportional counter. Low volume air samples (1 cfm) with filters and/or charcoal cartridge depending upon suspected material. Air flow meter.
LIQUID	NRC (10 CFR 20.106 Appendix B, Table II). State regs. (S.S.R. Sec. D.106 and Appendix A, Table II)	1 pCi/l to 3 μCi/l. Dependent upon isotope content of effluent	±100% on initial screening if well below permissible levels. ±15% if within 50% of maximum permissible levels. (Includes sampling and flow volume.)	Liquid scintillation counter. γ spectrometer. Low background proportional beta counter. α spectrometer. Sampling in accordance with Standard Methods.[9] Specific-element chemistry may be necessary

*See Appendix II

TABLE IV

APPLICATION	REGULATORY CRITERIA	MEASUREMENT EXPECTED RANGE	MEASUREMENT ACCURACY REQUIREMENTS	INSTRUMENT CONSIDERATIONS
FOOD and WATER	EPA drinking water standards. NRC (10 CFR 20). State regs. (S.S.R. Sec. D.). Evaluations must be made to assure the total intake will not exceed M.P.B.B. except for EPA standards.	1 pCi/l to 300 pCi/l. Dependent upon nuclides	Screening ±100% Specific nuclide ±10% near regulatory limit.	Radon emanation system. α spectrometer. γ spectrometer. Low background proportional counter. Liquid scintillation counter. Specific element chemistry may be necessary. 5 pCi I in milk may be bound up in preservative when chemically separated.
CONTAMINATION *SOLIDS*	Federal guidance to be developed. State guides.	0.1 pCi/gm to 10 pCi/gm. μR/hr to mR/hr.	±100% at 10% of limit. ±10% near limit.	Low background proportional counter. α spectrometer. Specific element chemistry may be necessary. Survey meters: thin-end-window G-M, NaI μR/hr. Radon emanation system.
SURFACE	State and NRC guides. DOT regulations. Evaluation of removable and fixed contamination must be made.	Few dpm to 100,000 dpm/100 cm^2. μR/hr to mR/hr.	±100% at 10% of limit. ±10% near limit.	Alpha survey CPM. Low background proportional counter. Survey meters. Filter paper wipes over a 100 cm^2 area.
LEAK/WIPE TESTING SEALED SOURCES	State regulations. NRC.	^{222}Rn emanation 0.0001 μCi/24 hr to 1 μCi/24 hr. Other radioactive material 0.0005 μCi to 1 μCi	±15%	Alpha counter. γ spectrometry. Beta counter.
LOST SOURCES	NRC and State regs. ("illegal transfer," "unsecured sources," "inadequate accounting," "theft," etc.)	μR/hr to R/hr.	Screening (for location only) ±100%	Portable survey meters; NaI probe with lead shielded sides. Reads in μR/hr. Alpha probe. Beta probe.
EMERGENCY RESPONSE	DCPA, NRC, and EPA guides. Some State guides and plans.	μR/hr to R/hr. pCi/m^3 of air.	±25% near evacuation guides. ±25% for establishing restricted area barriers	μR with NaI probe for determination of plume width, center line and evacuation measurements. All equipment listed in Airborne and Contamination above and Table III External will be necessary. Laboratory backup as in Food and Water above.

APPENDIX I

LIST OF RADIONUCLIDES USED FOR CALIBRATION OF COUNTING SYSTEMS
[FROM ALL-STATES QUESTIONNAIRE - 1976-1977]

(For availability see Ref. 21)
(Also see Footnote - Appendix II)

H-3	Ru-106	Pu-239
C-14	Cd-109	Am-241
Na-22	Ag-110	Pu-241
Cl-36	Sb-124	Pu-242
K-40	Sb-125	Mixed Gamma
K-42	I-131	
Sc-46	Ba-133	
Ca-45	Xe-133	
Cr-51	Cs-134	
Mn-54	Cs-137	
Co-56	Ba-La-140	
Co-57	Ce-141	
Co-58	Ce-Pr-144	
Fe-59	Eu-152	
Co-60	Eu-154	
Zn-65	Hf-181	
Se-75	Hg-203	
Kr-85	Tl-204	
Sr-85	Bi-207	
Y-88	Pb-210	
Sr-89	Po-214	
Sr-90	Ra-226	
Y-90	Ra D+E	
Zr-Nb-95	Th-natural	
Tc-99m	U-natural	
Ru-103	Pu-236	

APPENDIX II

SOME NECESSARY REFERENCE STANDARDS IN THE MEDIA ENCOUNTERED

MEDIUM	MATRIX TYPE	ISOTOPES
Water	True Solution	Mixed γ emitters Sr-89-90 Ra-226-228
Water	Mixture of suspended-dissolved	Mixed γ emitters Sr-89-90 Ra-226-228
Milk	Typical organic bound/non-bound mixture	I-129-131
Milk		Mixed γ emitters Sr-89-90 Ra-226-228.
Air	Particulate	Mixture of α,β,γ emitters on filter impregnated with normal dust loading.
Air	Iodine	Charcoal absorbers impregnated with various materials (KI, TEDA, etc.) suitable for both direct γ analysis as well as chemical separation.
Sediments		Mixtures of both natural and man-made γ,β,α emitters most likely to be found in sediments
Plant and animal tissue	Dried and/or ashed tissue	Mixture of those most likely to be concentrated by the organism.

Three levels of concentration of radioactivity are needed:

1. $\simeq$ 10 x normal background for equipment calibration purposes.
2. Approaching the lower limit of detection (LLD) for a check of analytical methodology. (LLD as defined by the USNRC)
3. 100-1000 times normal background to test accuracy.

FOOTNOTE:

Many of the radionuclides are available from the common sources but may not be considered "Standards". Traceability to NBS must be established with these sources before they can be considered acceptable for calibration. (See Ref. 21)

APPENDIX III

GLOSSARY

aluminum	- (ASTM Type 1100)
BENT	- Breast Exposure: Nationwide Trends
bkg	- background
BRH	- Bureau of Radiological Health
CABINET	- Enclosed x-ray machine for radiography
CFR	- Code of Federal Regulations
Ci	- Curie
DCPA	- Defense Civil Preparedness Agency
DENT	- Dental Exposure Normalization Technique
DOT	- U.S. Department of Transportation
dpm	- Disintegrations per minute
EPA	- Environmental Protection Agency
FAA	- Federal Aviation Administration
Film Badge	- Personnel dosimeter containing film
HVL	- Half Value Layer
ICRP	- International Commission on Radiological Protection
kV	- Kilovolt
kVp	- Kilovolts peak
MeV	- Million electron volts - energy
MPBB	- Maximum permissible body burden
MPC	- Maximum permissible concentration
mR	- 1/1000 of a roentgen (milliroentgen)
mrem	- 1/1000 of a rem (millirem)
NEXT	- Nationwide Evaluation of X-ray Trends
NRC	- Nuclear Regulatory Commission
NRC (10 CFR 20)	- Nuclear Regulatory Commission (Title 10, Code of Federal Regulations, Part 20)

pCi/l - Picocurie per liter (10^{-12} Curie /l)

QTR - Quarter

R - roentgen

rem - roentgen equivalent man

RF - Radio frequency

RSO (or RPO) - Radiation Safety Officer

S.S.R. (or State Regs) - Suggested state regulations for the control of radiation

TLD - Thermoluminescent dosimeter

α - alpha particle

β - beta particle

γ - gamma ray

m = milli (1×10^{-3})

μ = micro (1×10^{-6})

p = pico (1×10^{-12})

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12. SPONSORING ORGANIZATION NAME AND COMPLETE ADDRESS (Street, City, State, ZIP) National Bureau of Standards Department of Commerce Washington, DC 20234	13. Type of Report & Period Covered Final 14. Sponsoring Agency Code

15. SUPPLEMENTARY NOTES

☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

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.)

A number of approaches could have been made for providing the reader with the information contained in this publication. In the interest of brevity, it was deemed necessary to develop definitions and tabularize the material that could be most easily utilized by those persons enforcing certain regulatory requirements and guides as well as those persons who are affected by the requirements and guides. To that end, this report:

1. Defines "accuracy" which is necessary for radiation control purposes
2. Lists pertinent regulatory criteria and limits
3. Lists the radiation sources that require measurements
4. Lists the expected ranges for those measurements
5. Lists the accuracy requirements
6. Lists the instrument considerations necessary to make those measurements accurately
7. Discusses some of the problems and pitfalls in radiation control measurements.

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)

Accuracy; criteria; instruments; measurements; radioactivity; regulations; x-ray.

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APPENDIX C

Growth and Economic Value of Applications Involving the Use of Ionizing Radiation: Five Examples

Five representative examples are briefly highlighted to illustrate the economic value and rapid growth of applications involving the use of ionizing radiation.

1. Selected Atomic Energy Products

Data on the monetary value of shipments of selected atomic energy products (excluding radiation detection and monitoring devices, and control and measuring devices containing radioactive sources) which are manufactured in privately owned establishments are available from the Bureau of the Census [Census, 1978]. The value of shipments of these products from 1968 through 1973 is shown in Figure 1. As indicated, there has been a 235 percent increase during the past decade, and the current worth is approximately $1.7 billion.

2. X-ray Equipment and Accessories

The total value of shipments of all x-ray and medical electronic apparatus in 1975 and 1976 [Shope, 1978] was $829 and $943 million, respectively (Table I). X-ray equipment and accessories constituted approximately half of these totals, and its value for these two years was $412 and $492 million. Dental units typically cost $4000 to $10,000; and medical units: $20,000 to $150,000. There are approximately 125,000 medical and 145,000 dental x-ray units in the country [Moats, 1978]. Since the average lifetime of these units is 20 years, approximately 13,500 x-ray units must be replaced each year.

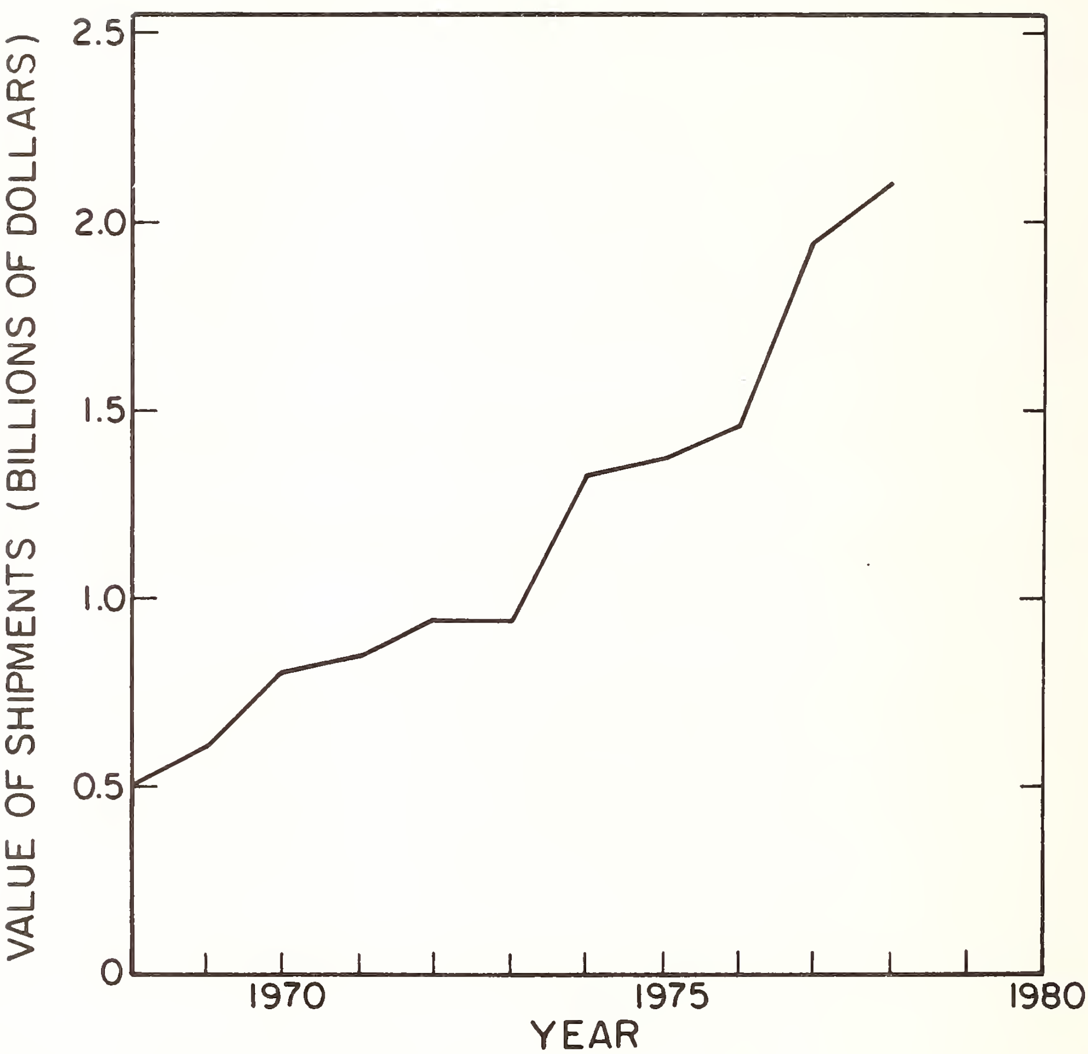

Fig. 1. Value of shipments of selected atomic energy products.

Table I

Value of Shipments of X-Ray and Medical Electronic Apparatus

	Value of Shipments ($1000)	
	1976	1975
Medical diagnostic and therapeutic electronic equipment, except x-ray:	450,693	417,568
X-ray Equipment and accessories:		
Medical and dental x-ray and gamma ray equipment	338,717	286,700
Industrial and scientific x ray	38,475	32,357
X-ray equipment accessories	58,397	42,868
X-ray tubes and valves, sold separately	56,226	49,771
Total:	942,508	829,264
X-ray equipment as a percentage of total	52.2%	49.6%

3. Computed Tomography X-Ray Systems (CT Scanners)

An area of diagnostic medicine which has undergone rapid development due to the introduction of a new technology has been that of computed-tomography x-ray systems (i.e., CT scanners). The pioneering work was done by Hounsfield in England, and the first clinical unit was installed at Wimbledon in 1971. The vast increase in diagnostic information available using CT scanners, particularly for head scans, was quickly recognized, and the first commercial scanners in this country were installed during 1973. Table II shows the growth in the number of CT scanners from 1975 to 1978. These values are based on preliminary data from the Bureau of Radiological Health [Shope, 1979] and were determined from assembler reports. They could be in error by 10 to 15% due to incomplete reporting.

Table II

Number of CT Scanners

Year	Head Scanners	Body Scanners
1975	140	40
1976	225	225
1977	310	655
1978	405	825

4. Radioactive Diagnostic Products

Another medical area experiencing rapid growth is radiopharmaceuticals used for diagnostic nuclear medicine procedures. Figure 2 shows the annual

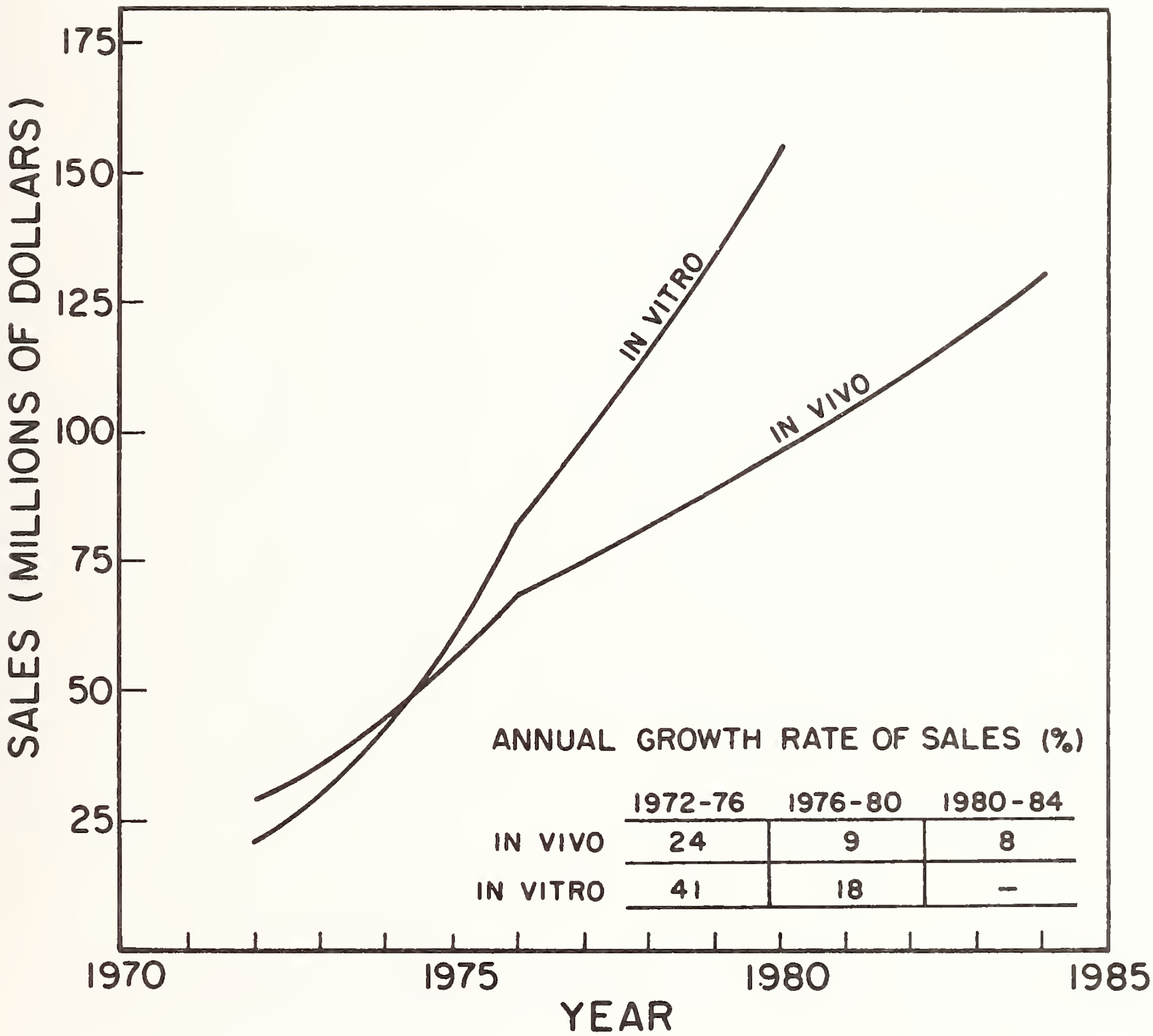

Fig. 2. Growth rate of sales of radiopharmaceuticals.

growth rate of sales of radiopharmaceuticals (in millions of dollars) used for *in vivo* and *in vitro* diagnostic procedures during 1972-1976, and the estimated growth rate for years later than 1976 [SRI, 1978]. It has been estimated [McIntyre, 1979] that the number of nuclear medicine procedures, in distinction to the value of sales, has been increasing at 20% per year from 1975 to 1979. Hence, the number of procedures has risen from 7 million in 1975 to an estimated 14.5 million in 1979.

5. Industrial Radiation Processing

Industrial radiation processing is usually performed with radiation from either intense cobalt (^{60}Co) sources or electron beam accelerators. Figure 3 shows the growth of the total installed capacity in megawatts, for both cobalt and electron beam irradiation facilities [Anon., 1977]. Historically, the primary applications have been in curing plastics and in sterilizing medical products. These two applications use roughly 80% of the total installed irradiation capacity, and in 1977 produced products worth an estimated value of $1 billion dollars. Since then, sterilization of medical products by irradiation has probably increased because of the ban placed on the use of ethylene oxide (a mutagenic gas formerly used as an antiseptic agent). There have been many new applications of radiation processing including hardening metal, disinfecting sewage, byproduct recovery, food preservation, water treatment, pollutant removal in industrial gas stacks, and sludge processing.

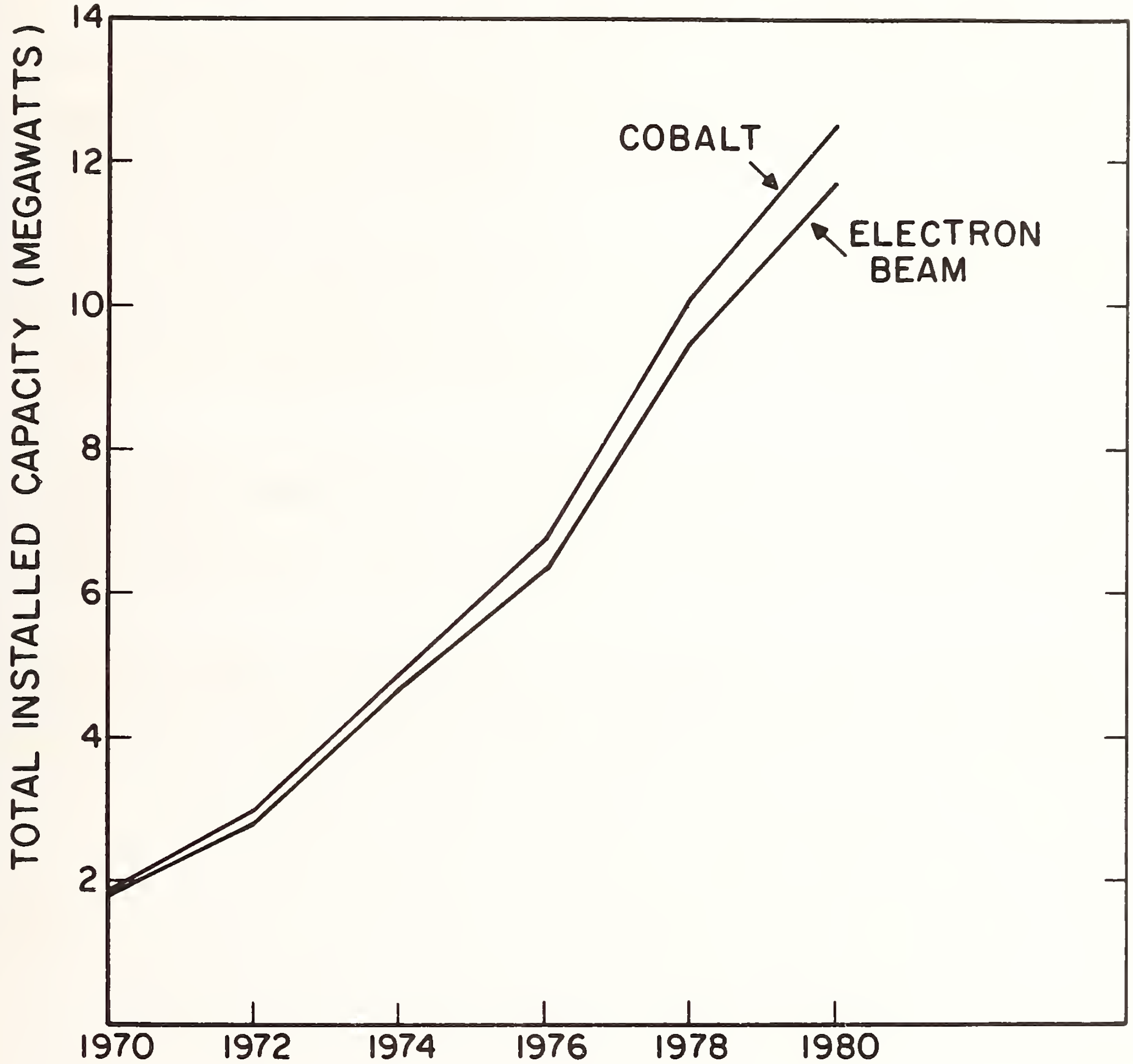

Fig. 3. Growth of installed radiation processing capacity.

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Appendix D

Summary of Recent Estimates of Occupational Exposure to Ionizing Radiation

In a current study to reevaluate occupational exposure limits for ionizing radiation, the Environmental Protection Agency [Garcia, 1979; Cook, 1979] divided the work force into five broad categories:

--medicine

--industry

--government

--education

--nuclear fuel cycle.

All workers within a given category are not necessarily exposed to radiation. For example, not all physicians in the medical category may be exposed. Further, many workers who may be exposed receive less than a measurable amount of radiation on their personnel monitors. Therefore, within each category, the workers were considered in two ways:

°all workers who may be exposed (or "potentially exposed") to radiation

°only those workers who actually receive a measureable amount of radiation

The EPA estimates that there are 1.2 million workers who may be occupationally exposed. Of these, about 400,000 workers receive measurable amounts of radiation. Figure 1 shows the distribution of these workers in each of the five major categories. It can be seen that the category with the largest number of workers is the medical profession. This category constitutes 45% of the work force which may be exposed, and 38% of the work force which is measurably exposed. The nuclear fuel cycle workers comprise 6% of the work force which may be exposed, but 19% of the workers actually receiving measurable amounts of radiation.

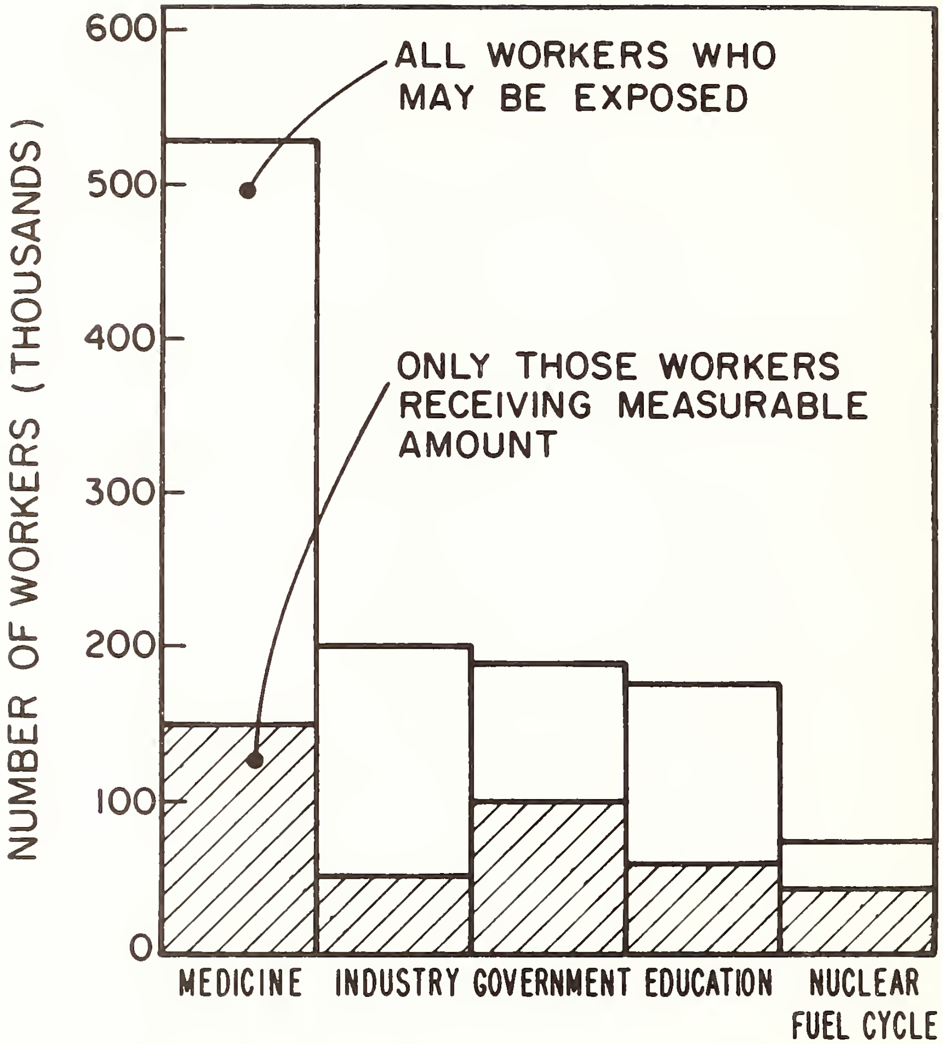

Fig. 1. Categories of workers who may be exposed to radiation.

The EPA estimate [Cook, 1979] of the approximate dose received by workers in the five categories is shown in Figure 2. As before, the average dose to workers is estimated for all workers within a category who may be exposed, and for those workers who receive a measurable dose. Of the five broad categories, the workers in the nuclear fuel cycle receive the highest average dose: 0.34 rem for all workers who may be exposed; 0.63 rem for those workers receiving measurable amounts.

Although the results are not provided here, the average dose received by workers in specific occupations within each of the five categories show considerable variation [Cook, 1979]. The occupational group which has the largest average dose is industrial radiographers who receive measurable amounts of radiation: 0.85 rem.

Considering the entire 1.2 million workers who may be occupationally exposed to ionizing radiation

°65% receive less than measurable doses

°95% receive less than 0.5 rem per year

°99.8% receive less than 5 rem per year

The average annual per capita dose to all occupationally exposed workers is 0.11 rem. The average annual per capita dose to those receiving measurable amounts of radiation was 0.31 rem. This is in addition to the 0.2 rem annual per capita dose due to natural background and man-made sources of radiation.

The Nuclear Regulatory Commission (NRC), in a detailed study of occupational radiation exposure at NRC-licensed facilities for 1975 [Cool, 1978], made estimates of the dose received by workers in various licensee categories involving NRC-licensee material (Byproduct, Source, and Special Nuclear Material). An abbreviated summary of the results of this study is provided in Table I. The table lists those occupational categories at NRC-licensed facilities in which

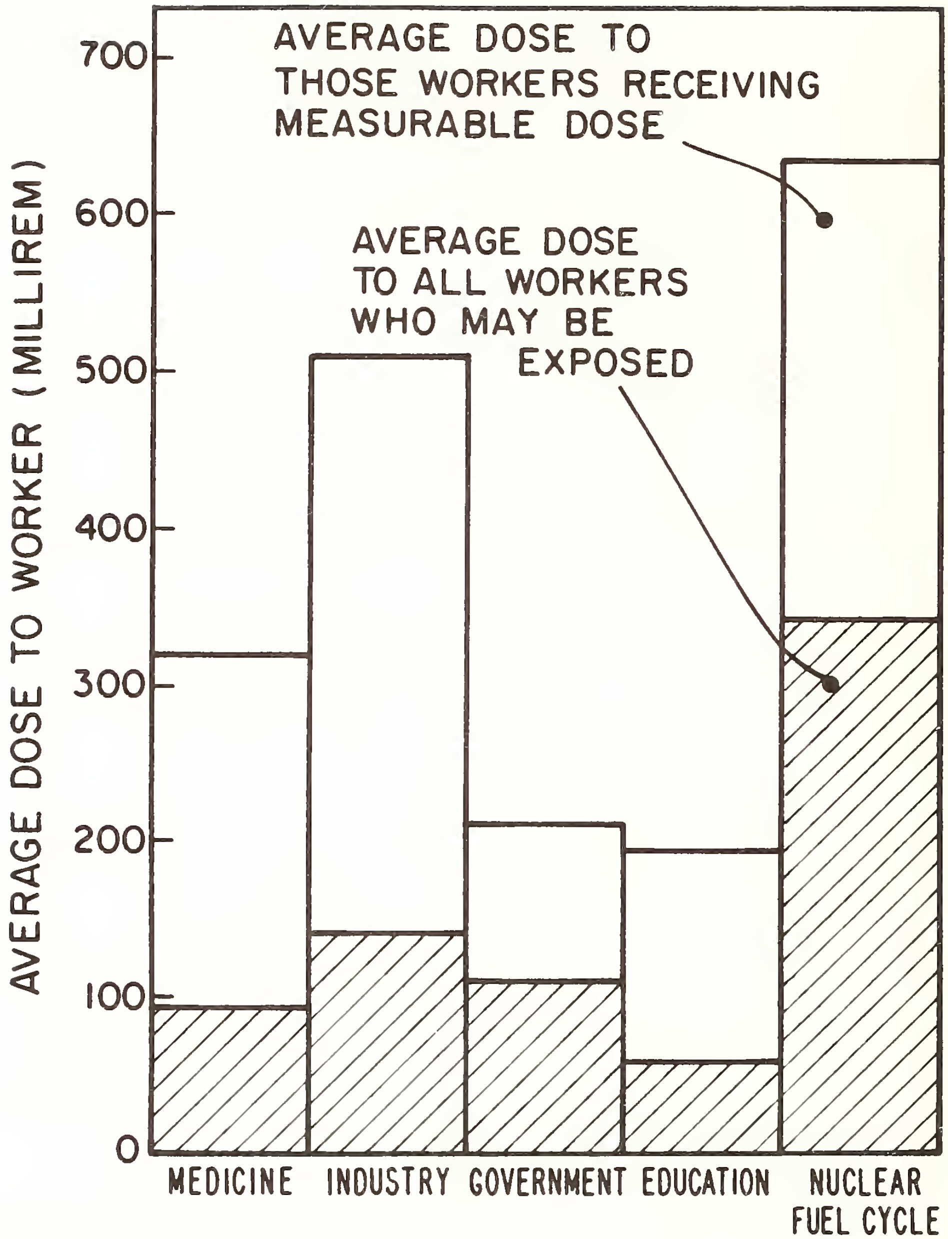

Fig. 2. Estimated approximate dose received by workers occupationally exposed to ionizing radiation.

Table 1

NRC License Material with Average Measurable Dose Greater Than 0.25 rem or Individuals Receiving Greater Than 1 rem in 1975[(1)]

Category of Licensee	Number of* individuals monitored	Average measurable dose	Less than measurable	0-1	1-5	Greater Than 5	Precent Greater Than 1 rem	Precent Greater Than 5 rem
Byproduct Material								
Waste Disposal-Burial	65	1.26	1	38	26	0	40.0	0.0
Well Logging	1514	0.50	186	1161	163	4	11.0	0.3
Irradiator ($>10^4$ Ci)	134	0.38	133	1	0	0	0.0	0.0
Private Practice	486	0.35	94	362	26	2	5.8	0.4
Teletherapy	1716	0.29	789	872	55	0	3.2	0.0
Instit. Other Med.	9643	0.28	3463	5881	290	9	3.1	0.09
Marketing Other	1195	0.28	902	274	19	0	1.6	0.0
Other Medical	356	0.27	188	159	8	1	2.5	0.0
Marketing Board	703	0.26	563	129	11	0	1.6	0.0
Other Measurement Systems	2594	0.14	1541	1048	5	0	0.2	0.0
Source Material								
U Mills	437	0.41	33	363	41	0	9.4	0.0
UF_6 Processing	522	0.22	192	328	2	0	0.4	0.0
Other U (>150 kg)	149	0.17	41	104	4	0	2.7	0.0
Special Nuclear Material								
Unencapsulated SNM	204	1.54	190	6	8	0	3.9	0.0
Power Reactors	54763	0.76	26729	20797	6971	266	13.2	0.5
Fuel Storage	13	0.69	0	12	1	0	7.7	0.0
Manufacture & Distribution	3367	0.64	1508	1545	287	27	9.3	0.08
Radiographers	9178	0.60	4485	3847	808	38	9.2	0.4
Fuel Proc. and Reproc.	11614	0.57	6012	4856	667	79	6.4	0.7
Other SNM	203	0.13	126	76	1	0	0.5	0.0

* Actual number of individuals monitored by reporting fraction. Total number monitored by individuals will be higher.

(1) From NUREG-0419, Occupational Radiation Exposure at NRC-Licensed Facilities: 1975

the average dose for the category exceeded 0.25 rem per year and those categories in which individual workers were exposed to more than 1 rem per year. For each category, the table provides the number of individuals monitored, the average measurable dose in rem, and the distribution of the dose in four broad ranges.

For the monitored workers in all occupational categories of Byproduct Material licensees (18,400 workers)

°43% received less than measurable doses

°97% received less than 1 rem per year

°99.9% received less than 5 rem per year.

For the monitored workers in all occupational categories of Source Material licensees (1100 workers)

°24% received less than measurable doses

°96% received less than 1 rem per year

°all received less than 5 rem per year.

For the monitored workers in all occupational categories of Special Nuclear Material licensees (79,340 workers)

°49% received less than measurable doses

°88% received less 1 rem per year

°99.5% received less than 5 rem per year.

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Appendix E

Summary of State and Local Radiological Health Program Activities

Each year, a report of "State and Local Radiological Health Programs" is published by the Bureau of Radiological Health to provide information on State and local efforts in achieving and maintaining comprehensive programs to reduce or control population exposure to ionizing and nonionizing radiation. The reports also provide a national profile of resources expended and activities performed in certain aspects of radiation control. The most recent report, the seventeenth in the series, is for fiscal year 1977 [Moats, 1978]. This summary highlights results from this series of publications.

- °In addition to Federal regulation, the States maintain their own regulatory authority which in many cases is more comprehensive. The number of State enabling acts for radiation protection regulations from 1950 through 1976 is shown in Figure 1. States can implement model regulations as provided in the Suggested State Regulations for Control of Radiation [SSRCR, 1978] with or without modification, or they can develop the regulations independently.
- °State and local expenditures for radiological health activities since 1965 are shown in Figure 2. The total expenditures have dramatically increased from approximately $6 million in 1965 to nearly $13 million in 1977.
- °In 1977, State and local radiation control programs had a total full-time equivalent of about 600 professional and semi-professional personnel, and have been gradually, but steadily increasing since 1965 (Figure 2).
- °The distribution of expenditures into various program areas is shown in Figure 3. In recent years (1975-77), program expenditures have been roughly

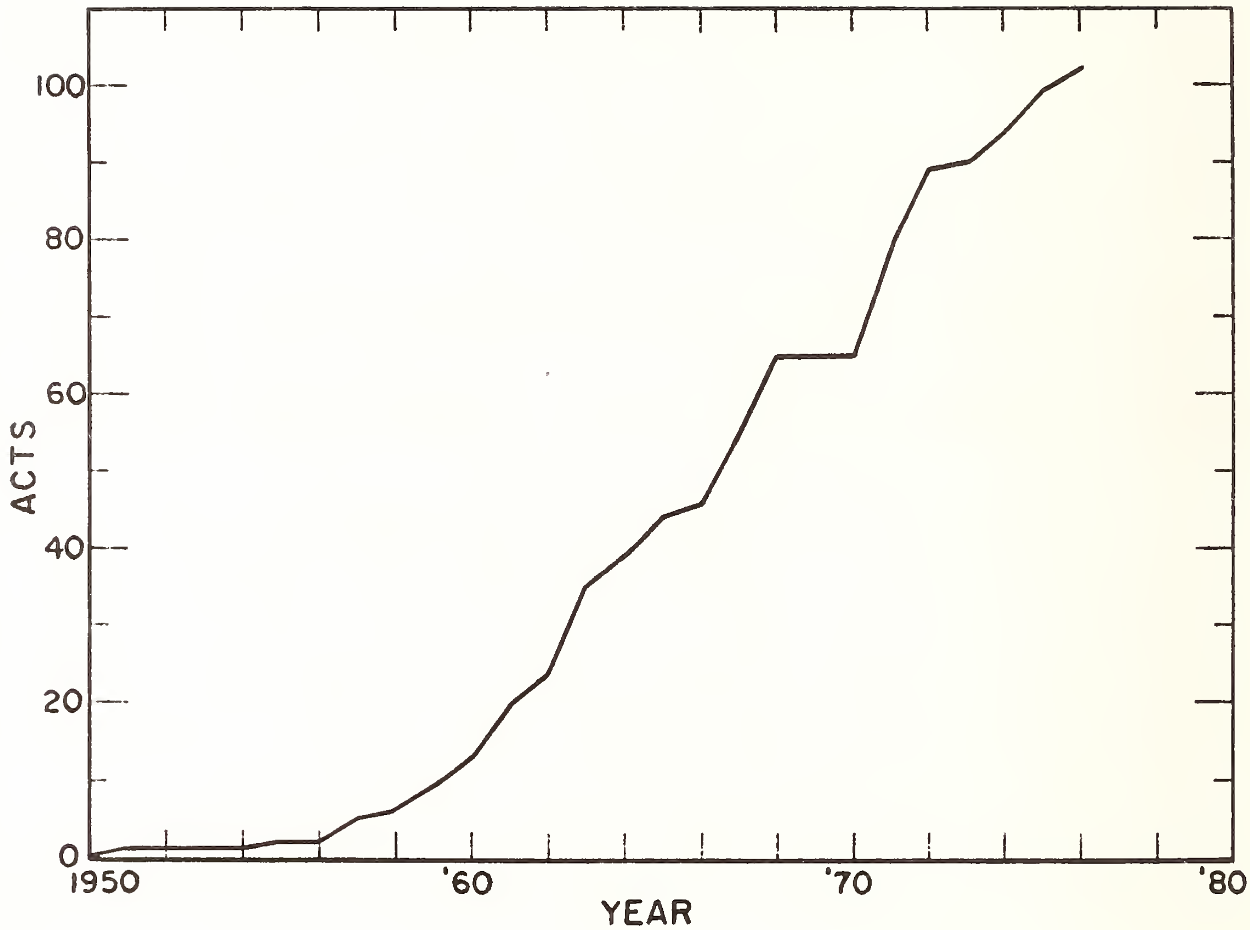

Fig. 1. History of state enabling acts for radiation protection regulations.

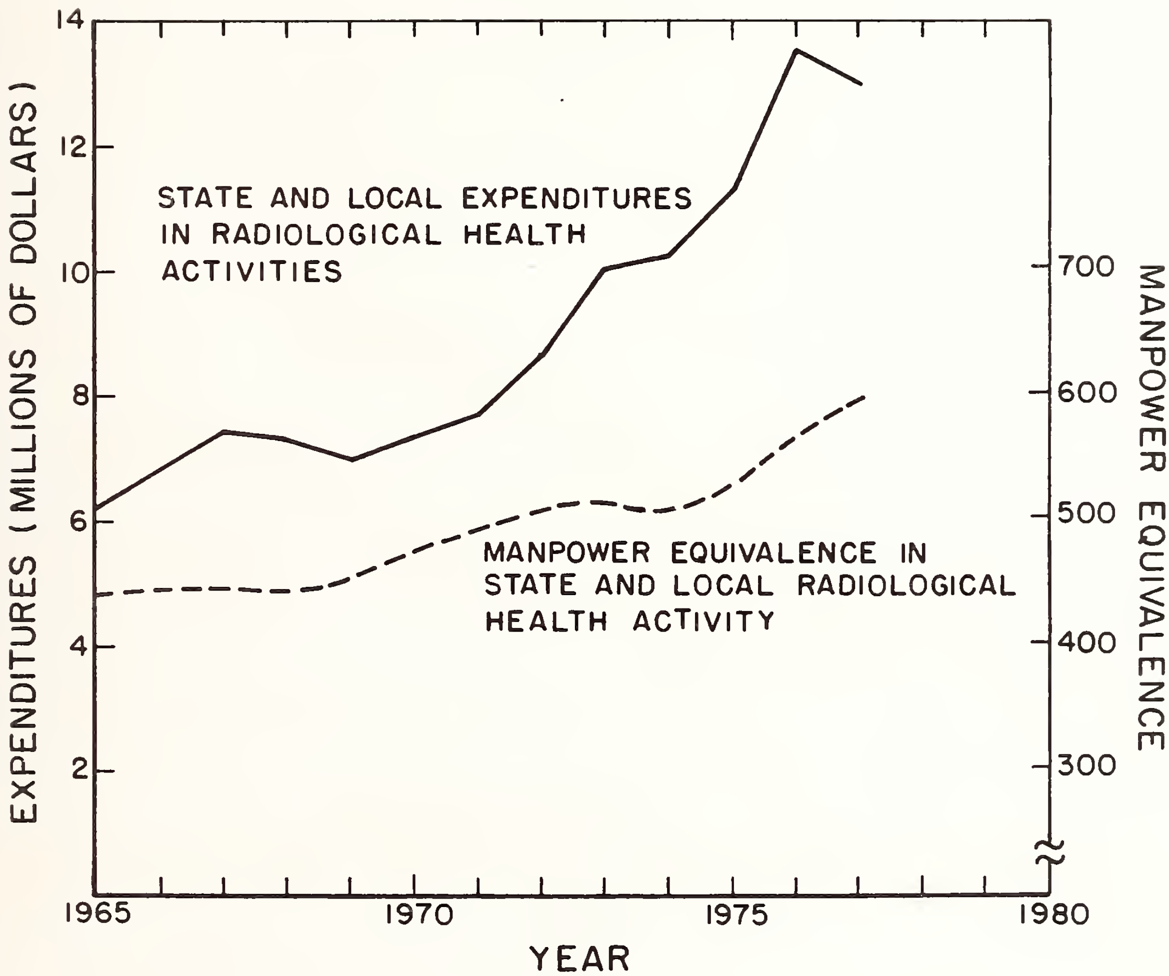

Fig. 2. Total expenditures for state and local radiological health activities.

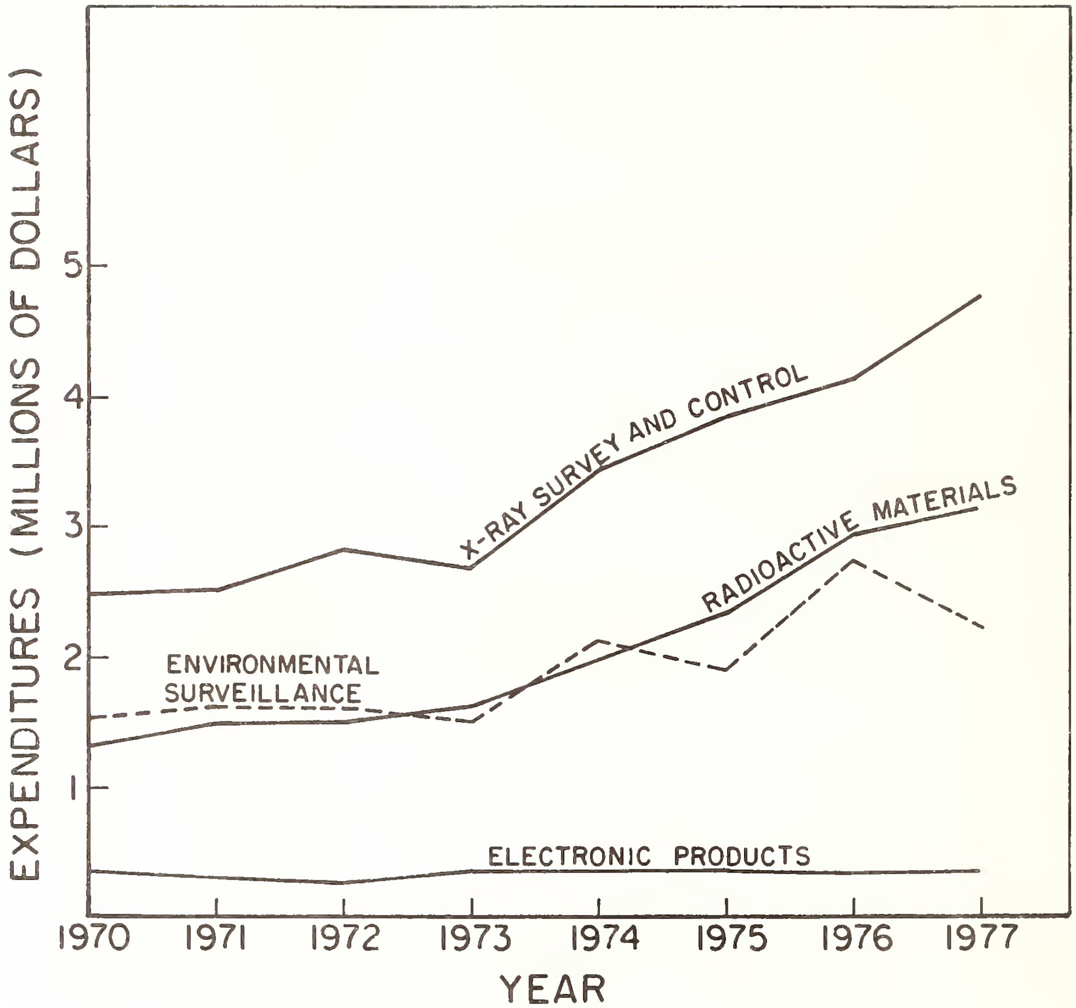

Fig. 3. Selected area expenditures for state and local radiological health activities.

34% x-ray survey and control

22% radioactive material

18% environmental surveillance

3% electronic products

with the remainder for basic planning and administrative (16%) and other radiological health activities (7%).

°Figure 4 shows the number of licenses issued by the Nuclear Regulatory Commission (or formerly AEC) and the 25 NRC Agreement States for byproduct, source and special nuclear material. As of December 31, 1977, the Agreement States issued 11,473 licenses which represents nearly 57% of the total licenses issued for such material. In 1977, these States performed 1817 inspections of which 59.6% were found to be in noncompliance with State regulations (Table I).

°In 1977, State and local personnel made over 50,000 inspections of x-ray units, and nearly 10,000 inspections for radioactive materials. For x-ray units 22% of the inspections found noncompliance with some aspect of State regulations, while 59% of the initial inspections for radioactive materials found cases of noncompliance (Table I).

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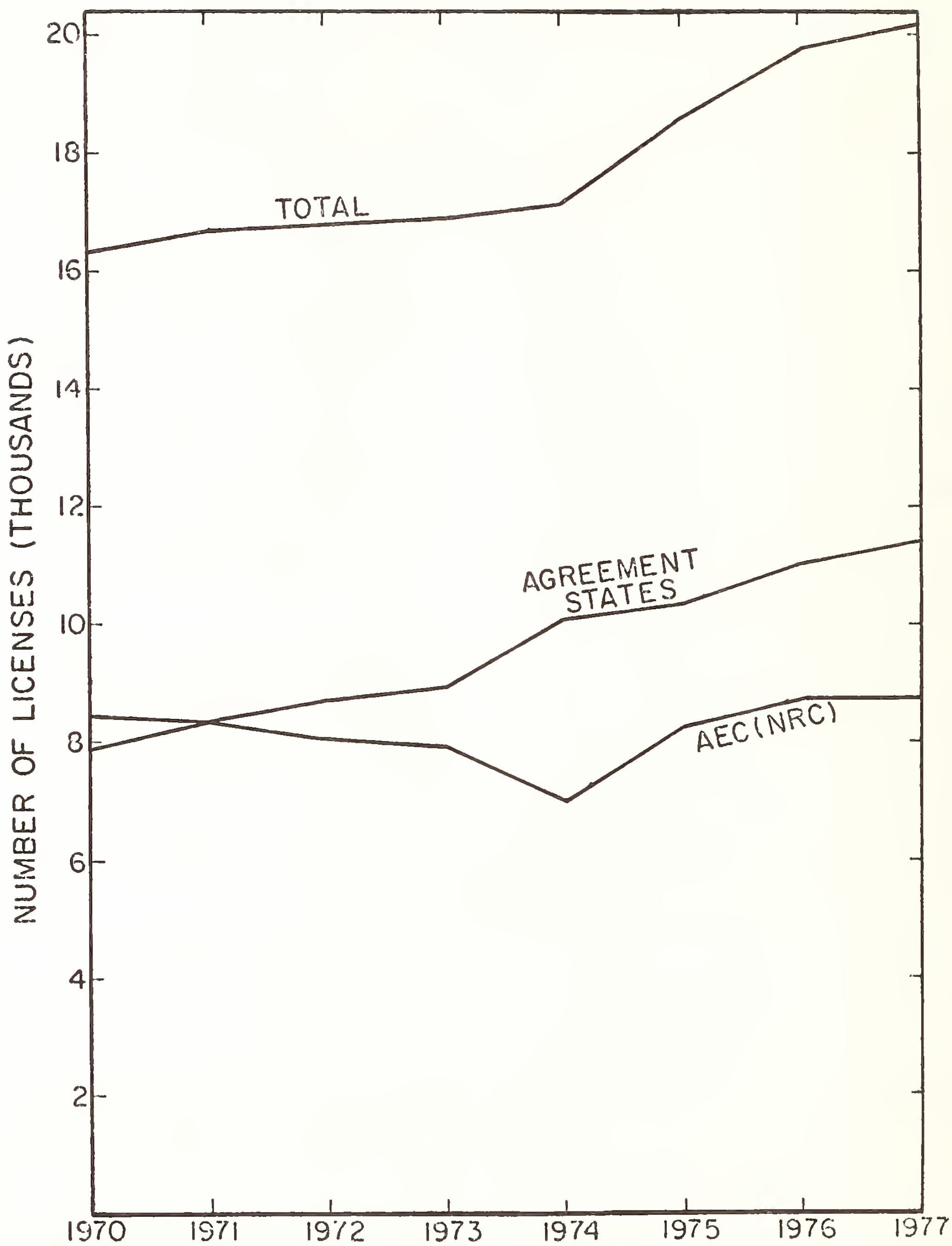

Fig. 4. Licenses issued by the NRC and states.

Table I

Summary of Ionizing Radiation Inspection Activities for 1977(1)

	estimated number of units	actual number of inspections	percent of inspections which found noncompliance*
Dental	144,600	24,800	16.8
Medical	128,200	26,000	27.2
Diagnostic	123,900		
Therapeutic	4,325		
Nonhealing X-Ray	6,682	1,101	35.1
Particle Accelerators	1,113	183	29.5
Radioactive Materials	8,752	1,335/2,062**	59.0/38.2
Nuclear Medicine	4,306		
Other Medical	910		
Industrial	2,585		
Other	972		
Licensing (Total)	20,239	3,199	
NRC	8,766	1,382	43.3
Agreement States	11,473	1,817	59.6

* May be in noncompliance with state regulation for failure to register, film development, shielding, etc.; no data on equipment noncompliance.

** Initial inspections/reinspections

(1) From Report of State and Local Radiological Health Program Fiscal Year 1977, HEW (FDA) 78-8034.

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4. TITLE AND SUBTITLE

Requirements for an Effective National Ionizing Radiation Measurements Program
A Report to the Congress by the National Bureau of Standards

5. PERSON TO CONTACT

Elmer H. Eisenhower, Chief, Office of Radiation Measurements

6. PERFORMING ORGANIZATION *(If joint or other than NBS, see instructions)*

NATIONAL BUREAU OF STANDARDS
DEPARTMENT OF COMMERCE
WASHINGTON, D.C. 20234

7. Contract/Grant No.

8. Type of Report & Period Covered

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9. SPONSORING ORGANIZATION NAME AND COMPLETE ADDRESS *(Street, City, State, ZIP)*

10. SUPPLEMENTARY NOTES

Prepared for the U.S. Senate Committee on Commerce, Science, and Transportation, the Honorable Howard V. Cannon, chairman.

☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

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

This report was prepared for the Senate Committee on Commerce, Science, and Transportation in response to its recommendation that the National Bureau of Standards review in cooperation with the Conference of Radiation Control Program Directors the need for intermediate calibration laboratories for ionizing and nonionizing radiation. Conclusions relevant to the measurement of nonionizing radiation are presented in a separate report. This report is a description of the elements of an effective support system for ionizing radiation measurements, an evaluation of current needs in this area, a description of necessary measurement accuracies for specific applications, and a discussion of possible options to improve the support system. The focus is on institutional and technical actions needed to assure the accuracy of ionizing radiation measurements for the protection of workers and the general public.

12. KEY WORDS *(Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)*

Beta rays; Federal and State laboratories; gamma rays; instrument calibrations; intermediate calibration laboratories; ionizing radiation measurements; measurement accuracies; neutrons; radiation dosimetry; radiation protection; radiation standards; x rays.

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