COUNCIL ON
IONIZING RADIATION MEASUREMENTS AND STANDARDS

(CIRMS)

REPORT ON

NATIONAL NEEDS IN IONIZING RADIATION MEASUREMENTS

PREPARED BY THE CIRMS SCIENCE AND TECHNOLOGY COMMITTEE

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Preface

The Council on Ionizing Radiation Measurements and Standards (CIRMS) is an open-membership, non-profit, and action-oriented society organized for educational and scientific purposes for persons, organizations, and corporations willing to support and participate in its functions. CIRMS was incorporated in January 1993 and was recognized as being tax-exempt in March 1994 under section 501(c)(3) of the Internal Revenue Code.

Advancement and dissemination of the physical measurements and standards needed for safe and effective applications of ionizing radiations is the main purpose of CIRMS. Ionizing radiations considered by CIRMS are: higher-energy ultraviolet light, x-rays, gamma-rays, and energetic particles, such as electrons, protons, and neutrons that can ionize atoms and molecules. Examples of technological applications and additional activities that give rise to the need for accurate measurements of these radiations are:

* Diagnostic Radiology	* Particle Accelerators
* Therapeutic Radiology	* Ion Implantation
* Radioisotope Imaging	* Natural Radioactivity
* Radioisotope Tracing	* Induced Radioactivity
* Nuclear Medicine	* Activation Analysis
* Industrial Radiography	* Nuclear Reactors
* Electron Microscopy	* Military Applications
* Radiation Processing	* Radiation Dosimetry
* Materials Degradation	* Radiation Protection

CIRMS can uniquely coordinate the activities of federal, state, and private-sector organizations concerned with applications of ionizing radiations and the related programs of physical measurements and standards laboratories. Examples of the organizations are:

Federal Organizations –	U.S. Departments of Energy, Defense, and Health and Human Services, the Nuclear Regulatory Commission, and the National Institute of Standards and Technology
State Organizations –	State and local radiation control programs, and secondary calibration laboratories
Private-Sector Organizations –	Hospitals, Industrial Firms, Professional and Scientific Societies, and Measurement and Standards Laboratories

By so doing, CIRMS focuses attention on current issues and supports the objectives of measurement quality assurance (MQA) in the broad field of ionizing radiations.

To accomplish its purposes, the Council functions through an annual meeting, through activities of various committees and subcommittees, and through sponsorship of seminars and workshops. The officers of CIRMS are a President, First Vice-President, Immediate Past President, and Secretary-Treasurer. The Executive Committee consists of these officers plus a NIST representative and an Executive Secretary and is responsible for the executive, financial, and general

administrative business of the Council. For example, the Executive Committee approves the appointment by the President of various standing and ad hoc committees. The standing committees are: Science and Technology, Program, Finance, Communications, Membership, and Nominating.

The members of the Executive Committee at the time it reviewed and approved this report were:

Peter R. Almond, President
R. Thomas Bell, 1st Vice President
Anthony J. Berejka, 2nd Vice President
Marshall R. Cleland, Immediate Past President
Kenneth G.W. Inn, Secretary-Treasurer
Elmer H. Eisenhower, Executive Secretary
Bert M. Coursey, NIST Representative

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NATIONAL NEEDS IN IONIZING RADIATION MEASUREMENTS

Executive Summary

This report was prepared by the Science and Technology Committee of the Council on Ionizing Radiation Measurements and Standards. It is the first in a series that will examine and document the national physical measurement and standards needs in the ionizing radiation community. Those needs arise from expanding applications of ionizing radiation, concern about radiation safety, and the increasing general interest in quality assurance.

Measurement needs are identified in four general areas of interest: medical, public/environmental radiation protection, occupational radiation protection, and radiation effects. Within those general areas, measurement program descriptions (MPDs) address needs in more specific areas of interest:

Medical - mammography, nuclear medicine, radiation therapy

Public/Environmental Radiation Protection - waste cleanup and management, survey instruments, environmental monitoring and dosimetry

Occupational Radiation Protection - personnel monitors and monitoring, neutron source calibrations, *in-vivo* radionuclide metrology, measurement quality assurance

Radiation Effects - radiation processing, hardness testing, reactor pressure vessel surveillance

Each MPD describes a measurement-related need, a possible solution, and the impact of that solution. Details are provided regarding the technical nature of the solution, relationship to existing programs, technical opportunities, challenges, and goals. Resources required to achieve the solution are also identified.

Important conclusions supported by this study are:

1) The need for ionizing radiation measurement and physical standards has grown significantly in recent years because of substantially increased applications of ionizing radiations for public benefit, and an increased concern for public safety and health.

2) The measurement and physical standards needs resulting from increased radiation applications and increased concern about radiation protection represent a significant expansion of measurement parameters. New applications and concerns have not replaced those that already existed. Instead, the new needs for measurement and standards have been added to the previously existing needs. New types of radiation are being used, higher and lower radiation energies must be measured more accurately, lower levels of radiation must be measured, and higher doses must also be known with more accuracy.

3) The status of physical measurements and standards has not improved sufficiently to meet the growing needs. Such measurements and standards are urgently in need of an expanded effort not only at NIST but at cooperating medical, industrial, and federal facilities in the U.S. This report

identifies many areas of interest where improvements are needed; three examples are mammography, electron-beam processing, and waste management.

Some of the problems in the field have resulted from cutbacks of measurement and standards support programs at the National Institute of Standards and Technology during the period when national needs for such support were increasing. It is essential that the preeminence of the NIST staff and facilities be reestablished.

4) CIRMS can play an important role in coordinating some of the activities that must be conducted to improve the status of measurements and standards. Although it is a new organization and has no history of playing such a role, CIRMS provides a unique opportunity for the coordination of varied interests. It is expected that such coordination would result in appreciably improved efficiency and effectiveness of programs implemented to satisfy national measurement and standards needs.

INTRODUCTION

The principal objectives of CIRMS are to: provide a forum for discussion of measurement and standards issues; promote cooperation and communication among interested parties; study and gather information on the measurement and standards needs of the ionizing radiation community, and define work needed to satisfy those needs; and provide information and data useful to NIST, secondary laboratories, and radiation measurers in pursuing improvement of the national support system for radiation measurement. This report represents an attempt to satisfy those objectives.

During the second annual meeting of CIRMS on November 8-10, 1993, the Science and Technology Committee agreed to prepare what is expected to become a regular series of reports entitled "National Needs In Ionizing Radiation Measurements". The present report is the first in that series. It was prepared by the Science and Technology Committee and was approved by the CIRMS Executive Committee and the CIRMS Membership for general distribution.

The members of the Science and Technology Committee at the time it prepared this report were:

Chairman: H. William Koch, University of Denver
Members: Roger L. Clough, Sandia (radiation effects subcomm chair)
Carl Gogolak, EML* (public/environmental radiation protection subcomm chair)
H. Thompson Heaton, CDRH (medical subcomm chair)
Kenneth Swinth, PNL (occupational radiation protection subcomm chair)

The functions of the Science and Technology Committee are carried out by four subcommittees, each of which concentrates on a specific area of measurement interest.

The members of the Medical Subcommittee, which prepared the Medical MPDs, were:

Chairman: H. Thompson Heaton, CDRH
Members: Peter F. Braunlich, International Sensor Technology
John Coletti, University of Wisconsin
Larry DeWerd, University of Wisconsin
James Deye, American College of Radiology
William C. Eckelman, National Institutes of Health
Kenneth P. Gall, Massachusetts General Hospital
Bennett Greenspan, Harry S. Truman VAMC
Lisa Karam, NIST
Robert Kobistek, Keithley Instruments
Michael A. Langton, Amersham
James E. Rodgers, Georgetown University
Carl Seidel, DuPont-Merck
Mary F. Shepherd, J.L. Shepherd and Associates
John J. Spokas, Illinois Benedictine College
Mary Walker, CDRH
Mohammed K. Zaidi, DOE

*See Appendix A for a list of acronyms used in this report.

The members of the Public/Environmental Radiation Protection Subcommittee, which prepared the corresponding MPDs, were:

Chairman: Carl Gogolak, EML
Members: James S. Bogard, ORNL
Peter F. Braunlich, International Sensor Technology
W. L. Bryan, ORNL
Roger W. Ferris, Amersham
Robin Hutchinson, NIST
Ross D. Jones, Amersham
Stan Jones, Martin Marietta
Carl J. Kershner, Femto-Tech Inc.
Felix Killar, United States Council for Energy Awareness
Gregory R. Komp, DOD Redstone
P. Kotrappa, RadElec Inc.
Larry Nickell, Wm. B. Johnson & Assoc.
Tom Peake, EPA
Mark Salasky, Landauer

The members of the Occupational Radiation Protection Subcommittee, which prepared the Occupational Radiation Protection MPDs, were:

Chairman: Kenneth L. Swinth, Battelle PNL
Members: James S. Bogard, ORNL
W. L. Bryan, ORNL
Robert E. Burns, Jr.
William H. Casson, Sr., LANL
Don Cool, NRC
J. Paul Farrell, Brookhaven Technology Group
Donald C. Gregory, ORNL
Ross D. Jones, Amersham
Gregory R. Komp, DOD Redstone
Dick Landfried, Wm. B. Johnson & Assoc.
Ronald LaVera, Power Authority of NY
Robert M. Loesch, DOE
Veerendra K. Mathur, NSWC
Kevin L. Reaves, ORNL
Mark Salasky, Landauer
Tham Tran, Nordion International
R. Craig Yoder, Landauer

The members of the Radiation Effects Subcommittee, which prepared the Radiation Effects MPDs, were:

Chairman: Roger L. Clough, Sandia
Members: Mohamad Al-Sheikhly, U of Maryland
Robert C. Becker, Medical Sterilization
Tony Berejka, Ionicorp

Peter F. Braunlich, International Sensor Technology
Rod Chu, Nordion International
Marshall Cleland, Radiation Dynamics
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R. Michael Dowe, Jr., Titan Systems Group
J. Paul Farrell, Brookhaven Technology Group
David M. Gilliam, NIST
Arthur H. Heiss, Bruker Instruments
Joseph C. McDonald, Battelle PNL
Joe McKeown, AECL Accelerators
William L. McLaughlin, NIST
Gary M. Pageau, Titan Scan Systems
Anna Pla-Dalmau, Fermilab
Kenneth Prestwich, Sandia
Carl Siebentritt, FEMA
A. D. Trifunac, Argonne National Lab
David Vehar, Sandia

MEASUREMENT PROGRAM DESCRIPTIONS

The measurement needs are presented in a standardized format called "Measurement Program Descriptions" or MPDs. (See Appendix B). Each MPD has four components:

First, a brief Title that identifies a measurement-related need and the radiation-related area of concern where the need exists. Both the need and the area of concern are named, as, for example, the MPD titled National Air-Kerma Standards for Mammography. In this example, the need is for national air-kerma standards, and the area of concern is mammography.

Second, a Program Summary gives a general description of the need, proposes actions that would satisfy the need, and the resulting impact they would have. This Summary can include background and criteria that can be used for establishing program significance, such as the number of people or size of the industry impacted, number of procedures per year, value of the service or product involved, availability and capabilities of technicians and funds to fulfill needs at primary and secondary standards laboratories, and the like.

Third, Detailed Program Characteristics are a detailed technical description of both the measurement need and the proposed solution. In the descriptions of the measurement needs, consideration was given to the following four measurements and standards areas and a possible CIRMS role:

a. Instruments,
b. Radiation source fields,
c. Dosimetry,
d. Written procedures, and
e. CIRMS role.

Fourth, recommendations are made of agencies, laboratories, and funding sources to satisfy the measurement needs identified above and of a role for CIRMS.

A. Medical MPDs

Introduction to Medical MPDs

One of the oldest applications of ionizing radiation is in the area of medicine. In 1895 Roentgen discovered x rays and within a few months the first diagnostic application was made by taking a radiograph of a hand. As the medical use of x rays developed, x-ray tubes became specialized for either diagnostic or therapeutic applications. For diagnostic radiology the tubes had to be designed to handle the high instantaneous energy input from small focal spot tubes, while therapy tubes had to be designed to generate much higher average energy levels using larger focal spots. To treat tumors at greater depths in the body with external radiation, high energy accelerators and radionuclide teletherapy units were pioneered in the late 1940s and '50s.

Like x rays, the radium discovered by the Curies in 1898 was quickly used as a therapeutic agent for the treatment of cancer. Radium brachytherapy sources were used for the interstitial treatment of tumors. Newer radionucides, e.g., ^{192}Ir and ^{125}I, have replaced radium for this use. Radionuclides are also used for diagnostic information, e.g., ^{99m}Tc is commonly used for many nuclear medicine procedures.

Historically the National Bureau of Standards (now NIST) played a major role in developing national standards for measuring the radiation used to treat patients. In the 1920s, the free air chamber was designed to measure the then-new radiation quantity exposure. Free air chambers with different dimensions were developed to cover the energy range from 10 to 300 keV. In the 1970s graphite cavity ionization chambers were developed to measure the exposure from ^{137}Cs and ^{60}Co.

Diagnosis

The national attention to health care and the goal of universal coverage have highlighted the need for cost effectiveness and quality assurance in the care provided to every U.S. resident. No national program demonstrates the need more than the mammography program mandated to the Secretary of the Department of Health and Human Services and specifically to the Department's Food and Drug Administration by the U.S. Congress.

Breast cancer is the second leading cause of death by cancer in women. During their lifetime, one in nine women will develop breast cancer. The Center for Disease Control estimates that breast cancer mortality could be reduced by 30 percent if all women were screened regularly. The best way to prevent deaths from breast cancer is early detection. The best methods of early detection are self-examinations coupled with periodic mammograms. The value of screening mammography is that it can detect cancers that are too small to be felt through physical examination (palpation). In fact, mammography can detect breast cancer up to two years before a woman or her doctor can feel a lump. In addition, these early-stage cancers can be 90 to 100 percent curable.

Presently there are over 11,000 mammographic units in the United States. The National Cancer Institute estimated, in background material for Congress related to requirements for facilities performing mammography, that in 1992 alone approximately 26 million mammographic examinations were to be performed. With an average cost per mammogram of $100, the annual fee for mammographic examinations totaled $2.6 billion in 1992.

In 1992, Congress passed Public Law 102-539, the Mammography Quality Standards Act of 1992. This law was passed because of Congress' concern with a wide range of problems with the current

mammography system: poor quality equipment, lack of quality assurance procedures, poorly trained technologists and physicians, false representation of accreditation, and lack of inspections and government oversight.

Therapy

One of the leading causes of death of Americans is cancer - over 25% of the population will die from some form of this disease. Ionizing radiation is one of the common treatment modalities, with over half of all cancer patients undergoing ionizing radiation treatment either for palliation or for cure (approximately 600,000 patients per year). The cost of these treatments is over $10 billion per year. The goal of radiation therapy is to kill the cancer while sparing normal tissue. This means using large doses of radiation which must be accurately known and precisely delivered to the tumor. Radiation oncologists have been able to see clinically acceptable differences in the treatment of patients for variations as little as ±5 % in the delivered dose.

By far the most common types of radiation presently used to treat cancers are photons and electrons. Both are most frequently produced by electron linear accelerators, although radioactive source teletherapy units still play a role for photon treatments. Photon-emitting radionuclides are the primary source of photons for brachytherapy treatments. Other radiations used include protons, neutrons, and heavy ions. These latter radiations have features that make them desirable for treating some forms of cancer. For example, as protons are slowed down in tissue, they lose more of their energy per unit length just before they stop. Thus protons can be used to deliver more dose to the tumor and less to the surrounding tissue.

New ways are being developed to use photons more effectively in the treatment of cancer. For treating tumors in the brain, the GammaKnife was developed. This uses 201 ^{60}Co sources placed in a helmet with collimators so that all of the radiation is focused at the treatment site. In a similar way, linear accelerators are being used in multiple arc rotational procedures for stereotactic radiosurgery. Both of these procedures require immobilizing the patient with respect to the radiation beam, and then delivering the radiation doses with millimeter accuracy. Being able to develop treatment plans to effectively use these and other three-dimensional delivery modalities has accelerated the development of three-dimensional dose distribution planning tools. To accurately measure and verify the doses calculated by these plans, the medical research community is developing new types of radiation measuring systems.

Nuclear Medicine

Nuclear medicine, the use of radioactively labeled pharmaceuticals in diagnostic and therapeutic applications, has undergone enormous growth since its introduction in the late 1940s. Diagnostic applications for *in-vivo* imaging have grown to 8.2 million procedures annually in the U.S. The chief reason for its continued growth is that radionuclides provide physiological information, as opposed to anatomical information (differences in tissue density) provided by the more common diagnostic x rays and magnetic resonance imaging (MRI). It has been estimated that over 80% of these diagnostic nuclear medicine procedures involve the use of six-hour half-life ^{99m}Tc. A score of other gamma-ray emitting radionuclides with half lives from a few minutes to a few days account for the other 20 percent. Some of the most prevalent procedures involve coronary imaging, tumor imaging, renal function studies, and skeletal imaging. Appropriate ^{99m}Tc-labelled radiopharmaceuticals have been developed for these and many other applications.

A second class of radionuclides used in diagnostic nuclear medicine are the short-lived positron emitters used for positron emission tomography (PET imaging). These include ^{11}C (20 minutes) and ^{18}F (2 hours), which are ideal because of the ease with which they can be incorporated into biomolecules. The

use of PET is somewhat limited at present because of the large capital investments needed in the PET camera and in the on-site cyclotron to produce the radionuclides.

Therapeutic application of radiopharmaceuticals with curative intent has been practiced since the early 1950s, mainly with ^{131}I and ^{32}P. There are presently about 60,000 nuclear medicine procedures performed per year using radionuclides for therapy. There is considerable current interest in the radiation oncology community and the private-sector radiopharmaceutical industry in developing radiolabelled monoclonal antibodies with, for example, the beta-particle-emitting nuclides ^{90}Y and ^{186}Re, used in tissue-specific agents for targeting the primary tumor.

Finally, an exciting new area is palliative radiopharmaceuticals for use in treating pain associated with bone metastases in the later stages of several types of cancers. It is estimated that up to 125,000 cancer patients per year would benefit from treatment with these bone palliation agents. Some of the nuclides already available or under investigation include ^{32}P, ^{89}Sr, ^{117m}Sn, ^{153}Sm, and ^{186}Re.

The following MPDs address measurement and standards needs in medical applications of ionizing radiation:

A.1 National Air-Kerma Standards for Mammography
A.2 Radioactivity Standards and Techniques for Nuclear Medicine
A.3 High Spatial Resolution Solid State Dosimetry for Radiation Therapy
A.4 Absorbed-Dose-to-Water Standards for Radiation Therapy

MPD A.1 *National Air-Kerma Standards for Mammography*

(a) Program Summary:

In 1992, the U.S. Congress passed Public Law 102-530, the Mammography Quality Standards Act of 1992. This Act requires that all screening and diagnostic mammographic facilities be certified by the Secretary of the Department of Health and Human Services by October 1, 1994. This certification process will involve accreditation by an approved nonprofit private organization or approved State organization. There must be a yearly on-site evaluation by a credentialed medical physicist and a yearly inspection by a credentialed government inspector.

(b) Detailed Program Characteristics:

Mammographic units used in the United States commonly use molybdenum for both the x-ray tube anode material and the additional filter used to remove unwanted low-energy bremsstrahlung x rays that contribute to patient dose but not significantly to image quality. One problem in calibrating instruments used to measure the air-kerma rate from mammographic units is that the National Institute of Standards and Technology (NIST) presently does not yet have a national standard for those mammographic beams. In fact, the only national standards laboratory in the world having appropriate national standards is the Physikalisch-Technische Bundesanstalt (PTB), the German standards laboratory. All the reference x-ray beams at NIST are produced by tungsten-anode x-ray tubes. The spectra (and therefore any measure of beam quality) are quite different for these two anode materials. For a tungsten target, aluminum filter system operated at voltages appropriate for mammography, most of the dose results from the thick-target tungsten bremsstrahlung (i.e., low energy x rays), although the L-fluorescent tungsten x rays are present. For a molybdenum target, molybdenum filter system, the K-fluorescent x rays dominate the spectra and there is very little thick-target molybdenum bremsstrahlung. For a reasonable choice of operating voltages, one can match either the half-value layer or the homogeneity coefficient but not both beam quality parameters for molybdenum anodes.

In the United States, the Food and Drug Administration's Center for Devices and Radiological Health (CDRH) is responsible for calibrating all the instruments that the government inspectors will use during the yearly inspection of each mammography facility. The CDRH X-ray Calibration Laboratory is accredited by NIST's National Voluntary Laboratory Accreditation Program. CDRH is establishing a new facility within the Mammography Calibration Laboratory explicitly to calibrate instruments in appropriate x-ray beams. Since there are no suitable national standards in the United States, CDRH has opted to send its reference ionization chamber to PTB to establish traceability to a national standard.

To perform the annual on-site evaluation, the medical physicists will presumably have their instruments calibrated at one of the American Association of Physicists in Medicine's (AAPM) Accredited Dosimetry Calibration Laboratories (ADCL). One of these laboratories, at the University of Wisconsin, is developing a free-air chamber to measure air kerma from their mammography x-ray units. In principle, the free-air chamber is an absolute device, but in practice it is necessary to determine a number of correction factors. Preliminary comparisons of this chamber with NIST standards have been made in tungsten-anode beams, and measurements of selected mammography chamber response have been made in the molybdenum and rhodium beams at CDRH.

To be able to provide national standards for all secondary laboratories wishing to calibrate mammography probes, it is desirable for NIST to develop suitable reference x-ray beams. An Interagency Agreement has been established with the Food and Drug Administration to develop these national

standards. At a minimum, these new reference beams should be identical to the beams recommended by the International Electrotechnical Commission for measuring the characteristics of diagnostic x-ray equipment and for verifying the performance requirements of ionization chambers and semiconductors used in medical radiography.

(c) U.S. Facilities, Staffing, and Funding:

The appropriate U.S. facilities can be organized into three groups:

(i) NIST – As indicated above, NIST needs major new resources in equipment and personnel to carry out this program. With the tight deadlines of MQSA, this program needs high priority. A minimum requirement is 2 person-years and $250,000 for each of two years.

(ii) CDRH – Most equipment for the new mammography facility has been ordered. Two additional person-years will be required: one to finish developing the automated computer system and the other to do routine calibrations, maintain in-house quality control, and maintain inventory. Equipment costs are estimated to be about $130,000 for each of two years.

(iii) ADCLs – To set up laboratories for calibrating instruments to measure air kerma from mammography units, it is estimated that each ADCL will need at least $100,000 for equipment and a person to operate the calibration facility. Two of the ADCLs have expressed an interest in developing mammography calibration facilities.

MPD A.2 *Radioactivity Standards and Techniques for Nuclear Medicine*

(a) Program Summary:

An important barrier to commercialization and widespread use of new radionuclides in nuclear medicine is that their physical characterization is not performed promptly in the early stages of development. Radioactivity standards, well-characterized decay schemes, and methods for measuring impurities are required before these radionuclides can reach the stage of clinical trials. The time taken for licensing is often a big commercial and human problem. For example, strontium-89, which alleviates excruciating pain in the terminally ill, was licensed 13 years after the initial application for FDA approval. This proposal aims to help minimize such deplorable delays.

Calibration methodology, nuclear data, and new technologies will be developed to enable the faster licensing of radiopharmaceuticals.

The major impact will be the faster licensing of new radiopharmaceuticals. The cost of radiopharmaceuticals will be reduced because of reduction of the cost of licensing. The quality of the measurements at the user level will be improved, contributing to a greater understanding of the operating ranges of tomography devices and reduced dose to patients with improved clinical accuracy.

(b) Detailed Program Characteristics:

Radioactivity standards for nuclear medicine in the United States are based on measurements at NIST. Each new radionuclide poses unique measurement problems depending on half life, decay scheme, chemical properties, and radionuclidic contaminants. NIST has developed standards for different radionuclides for nuclear medicine but requires new resources to meet the greater needs and increasingly sophisticated technology requirements. Currently, U.S. laboratories report that they are producing or investigating some three dozen potential radiopharmaceuticals for which the data used for assay may be suspect.

Solution of these problems will involve a number of scientific and technical challenges:

(i) develop methods of standardizing new nuclides with (a) potential therapeutic applications and (b) short half-life for use in PET and SPECT diagnostic applications;

(ii) measure radionuclide emission probabilities of significant radiations that are used for calibration by secondary laboratories by performing NIST standardizations for activity and further measurements with NIST gamma-ray and beta-particle spectrometry systems;

(iii) develop simple and rapid methods for measuring radionuclidic impurities in reactor-produced nuclides and in generator products;

(iv) develop a conceptually new pulse recording system that can be coupled to radiation detectors in coincidence experiments. This approach will enable all needed data to be recorded in one run for very short-lived radionuclides (minutes) and analyzed later;

(v) develop an inexpensive new technology based on high efficiency intrinsic detectors (e.g., CdTe) for hospital use to check impurities and calibration values. (This will provide relatively sophisticated

analytical capability at the hospital and reduce concerns during the licensing process about having elaborate assay procedures formulated in the user instructions),

(vi) determine sensitivity levels of tomography devices thereby improving the imaging characteristics and reducing dose to patients. A recently developed instrument uses highly specific triple coincidence detection of selected radionuclides at very low levels. It is proposed to develop and characterize standard radionuclides for this new device;

(vii) provide standards of ^{192}Ir, ^{90}Y, ^{186}Re, ^{211}At, ^{212}Bi and many other radionuclides.

(c) U.S. Facilities, Staffing, and Funding:

(i) Standards Laboratories – NIST and the NPL can measure radionuclidic activities to better than 1%. A number of experimental radiopharmaceutical nuclides have been fully characterized by NIST. Expansion of the program is needed.

(ii) Manufacturers – Amersham, duPont Merck, Mallinckrodt, Squibb, and the other manufacturers have systems in place to accurately assay the bulk radionuclides, and they can demonstrate traceability to national standards by intercomparisons through the NIST/NEI programs. This program will distribute standard reference materials of ^{89}Sr, ^{90}Y and ^{153}Sm.

(iii) Radiopharmacies – If the nuclide emits gamma rays, it must be measured prior to administration in a calibrated dose calibrator. For pure beta emitters (^{32}P, ^{89}Sr, and ^{90}Y), it seems that the pharmacy will rely on the manufacturer's assay.

Goals: This program is focussed on the accurate assay of medical radionuclides, in three ways: (i) the development of new techniques and equipment, (ii) new standards, and (iii) new nuclear data.

MPD A.3 *High Spatial Resolution Solid State Dosimetry for Radiation Therapy*

(a) Program Summary:

There is a need for an ionizing radiation dosimetry system for use in radiation therapy that will give quantitative information on the radiation dose to tissue with high spatial resolution (on the order of hundreds of micrometers) in two and three dimensions. The expanded use of computerized radiation treatment plans which optimize dose distributions via dynamic or multiple-beam treatment delivery present a challenge for quality assurance of these treatments. When computer-controlled multileaf collimators and multiple-arc radiation beams are used to deliver three-dimensional shaped radiation fields, it is necessary to verify that the desired radiation dose pattern is actually achieved. These treatments are most often employed in areas where critical normal structures are in close proximity to the treatment volume and spatial tolerances for treatment setup are quoted in fractions of millimeters.

Present dosimetry systems based on ionization chambers and calorimeters can give an accurate measurement of the radiation dose at a point in a homogeneous medium, but are of limited use for small-scale mapping of the spatial dose distribution in heterogeneous phantom materials. Silver halide film has long been used for relative dose maps, but it suffers from several deficiencies: it is not quantitative; accurate quantitative analysis is difficult since it has a steep energy dependence of response; it must be processed by a trial-dependent wet chemistry step; it is sensitive to light; and it has a limited dynamic range (less than two orders of magnitude). There are several systems under development that show promise for use in quantitative dose mapping including radiochromic films, radiochromic gels, thermoluminescent films, and alanine electron paramagmentic resonance (EPR) films.

Radiochromic dyes exhibit a color change that is proportional to the absorbed radiation dose, require no additional processing, and are relatively insensitive to light. Both films and gels incorporating radiochromic dyes have been developed which can be used for 2- or 3-dimensional dose mapping. Thermoluminescence dosimetry (TLD) is widely used and well established dosimetric measurement technology. TLD films have been developed along with appropriate readers to retrieve dose information from these films. Alanine EPR dosimetry has been developed for industrial and therapeutic radiation dosimetry. Films of alanine/polymer can be read with an instrument similar to an MRI device to give high spatial resolution dose information. Each of these methods offers large dynamic range and good accuracy for measurement of absolute dose (on the order of a few percent). Extensive work is needed at NIST and in major clinical facilities before these systems can be incorporated into routine clinical practice.

(b) Detailed Program Description:

The first element in the program is to investigate the radiation response of the dosimetry systems. Energy dependence, dose response, temperature dependence, humidity dependence, useful dose range, dosimeter perturgation effects, and signal lifetime need to be accurately quantified for the given system. Each system has its own peculiarities which are largely understood. Alanine and TLD have been studied as individual point dosimeters and radiochromic films have been reported on extensively. The goal is to quantitatively specify parameter ranges for the given system so that measurements can be made in the clinic with a known spatial and total dose accuracy.

The second element of the MPD will be to investigate requirements of the reading devices. Several types of readers have been developed and put to use for mapping radiochromic film response. Radiochromic gel can be sliced and read in a similar fashion. Bulk 3D gel readers have been proposed. Readers for TLD film need to be further developed and characterized, as do alanine film readers.

MPD A.3 *Continued*

Appropriate readout techniques for a dosimeter/reader combination need to be specified to assure a known spatial and total dose accuracy.

A key element in the program is modeling the systems with electron-photon transport Monte Carlo codes to determine in-phantom behavior. These codes will require careful investigation of the input data on cross sections for low-energy radiations, where the dosimetry systems may exhibit a strong dependence.

(c) Summary of Measurements Needed:

Benchmarking is needed against other dosimetry systems used for similar purposes. Four treatment modalities that should be investigated at major US medical facilities are: the ^{60}Co Gamma Knife, proton beams, stereotactic accelerator photons, and a variety of sources used in brachytherapy. These are four areas in radiation therapy where 2- and 3-dimensional dose maps would be of immediate aid in therapy planning.

U.S. Facilities, Staffing and Funding:

(i) NIST: NIST has extensive experience with the use of radiochromic dosimetry systems for high-dose applications such as radiation processing and sterilization. To extend these systems for use in dose mapping, NIST has acquired a laser scanning microdensitometer. This has become the *de facto* standard for reading radiochromic films, but several other film readers are under evaluation. One of these is a LED-back lighted system, which utilizes a CCD camera to capture the entire image in a single exposure. This system is being tested at NIST under a CRADA with the manufacturer. NIST also maintains the national reference sources for ^{60}Co gamma rays in the form of two teletherapy sources. These are used to administer standard doses to radiochromic systems. NIST should acquire other systems for comparison of direct calibration capabilities. Additional staffing should be added as required to maintain a directed effort in this area.

(ii) US Medical Centers: Several US medical centers have invested in staff research time and equipment budgets to build the expertise necessary to incorporate 2- and 3-dimensional dosimetry mapping systems into their overall therapy planning strategies. They also offer reference sources for the different types of radiation that will be investigated: accelerator-generated photons and elections, proton beams, the Gamma Knife, and well-characterized brachytherapy sources of ^{125}I, ^{192}Ir, and ^{103}Pd. Additional support is needed to complete the characterization of the dosimetry systems in clinical use.

(iii) ADCL's: To maintain control over the quality of dosimetry systems used in clinical practice, there should be some mechanism for measurement quality assurance using the five Accredited Dosimetry Calibration Laboratories of the AAPM. This will necessitate that at least one of these provides standard irradiations and reading of the developed dosimetry system. For brachytherapy source calibrations, this would be a significant improvement over the present ADCL practice of calibration in terms of source strength at some reference distance.

MPD A.4 *Absorbed-Dose-to-Water Standards for Radiation Therapy*

(a) Program Summary:

Approximately 500,000 cancer patients are treated annually in the United States with high-energy electron or photon beams from electron accelerators or ^{60}Co teletherapy units. These measurements are carried out in 1300 therapy facilities, using 2000 high-energy accelerators. These facilities are required to have a reference ionization chamber measured at least once every two years at one of the AAPM Accredited Dosimetry Calibration Laboratories, or at NIST.

The modality of megavoltage photons and electrons for cancer therapy has largely replaced ^{60}Co teletherapy which had been used from the early 1950s. Radiation therapy has been practiced in the U.S. since the turn of the century. But, quantities and units in radiation therapy dosimetry have evolved very slowly, as have the national standard detector systems at NIST. In the 1930s photon beam energies available for use in treatment were only a few hundred thousand electron volts. The national standard was a free-air ionization chamber, and the quantity measured was exposure. With the advent of ^{60}Co 1.25-MeV gamma-ray beams, there was a need for a different measurement system, a Bragg-Gray cavity ionization chamber, to realize the quantity exposure.

In 1993 NIST completed extensive development of an absorbed dose water calorimeter. This standard detector system can realize the quantity absorbed dose for both ^{60}Co beams and, in principle, higher energy photon beams. It will now be possible for NIST to offer calibrations to the secondary laboratories of the AAPM which are closer to the conditions needed for calibrations at existing therapy facilities.

The changeover from in-air-kerma calibrations to in-phantom absorbed dose calibrations is a logical and necessary evolutionary step in radiation dosimetry. Nevertheless, the pathway to the new standard must be carefully planned to avoid confusion for the end users. The foremost goal must be to make the new standard system logical, straightforward, and as simple (and familiar) as possible for the medical physicist in the hospital. Such a system can alleviate problems with current practices.

(b) Detailed Program Description:

The program has several components. Some of these can proceed independently, but there is a logical sequence for the following steps.

1) Characterization of the standard detector (calorimeter) and reference source (^{60}Co) at NIST.

2) In-phantom measurements of reference ionization chambers for the ADCLs at NIST and in-phantom measurements at the ADCLs at the ^{60}Co beam quality.

3) Preparation of a new protocol (to replace AAPM TG#21) for use by therapy facilities, which instructs the medical physicist on the use of the absorbed dose calibration factor.

4) Characterization of the standard detector (calorimeter) and a reference photon beam from the MIRF accelerator at 25 MeV.

5) Measurements of a parameter that characterizes the beam for selected ionization chambers on the MIRF as a function of beam quality.

(c) Summary of Measurements Needed:

Measurements are needed with the Domen water calorimeter in a horizontal photon beam. This will require completion of the second prototype calorimeter. Other critical measurements include:

- Demonstrated stable operation of MIRF accelerator at 25-MeV photon setting.
- Measurements of the parameter k_Q, which is the ratio of two calibration factors, the absorbed dose calibration factor for an accelerator beam of quality Q to that for a ^{60}Co reference beam. This parameter will have to be measured for each type of ionization chamber in use in reference measurements.
- A round-robin of absorbed dose in-phantom measurements at ^{60}Co energies by NIST and all of the ADCLs.
- A second round-robin at a selected megavoltage photon energy by NIST, the NRC-Ottawa, and other participants.

U.S. Facilities, Staffing, and Funding:

(i) NIST. NIST has available reference sources of ^{60}Co, a high-energy electron accelerator (the MIRF), the prototype Domen absorbed dose water calorimeter, and staff who can contribute to the project.

(ii) U.S. Medical Centers. Several U.S. medical centers have expressed interest in measurements with absorbed dose calorimeters. These include the two leading proton therapy centers: Harvard - Massachusetts General Hospital and Loma Linda University Hospital. Strong experimental and theoretical collaborations are also expected with Yale University and the National Research Council - Ottawa.

(iii) ADCLs. At present the ADCLs use ^{60}Co sources to perform in-air calibrations in terms of kerma for the therapy facilities. Initially, they could offer absorbed dose calibrations in-phantom based on their present ^{60}Co sources. The hospital-based ADCLs may wish to make a transition to calibrations based on accelerator measurements. This will depend largely on staffing, funding, and instrument time available at the individual ADCL.

B. Public/Environmental Radiation Protection MPDs

Introduction to Public/Environmental Radiation Protection MPDs

The opportunities and problems associated with environmental technologies are enormous. They involve large industries and impact on most of the publics in the industrialized world. As the November 9, 1993 issue of Chemical & Engineering News reported, Commerce Secretary Ronald H. Brown at a joint news conference with leaders of the Environmental Protection Agency and the Department of Energy "noted that Germany, Japan, and several other nations do far more than the U.S. to help their environmental technology industries compete internationally in what is a huge market." He estimates that the world-wide technology market - which includes goods and services used to clean up and monitor the environment and prevent pollution - will grow from its current $200 billion in sales to $600 billion by the year 2000.

A large part of the environmental technologies that need development and application and that could lead to large markets for U.S. products are in the province of the CIRMS Subcommittee on Public/Environmental Radiation Protection. Energy Secretary O'Leary is moving ahead with aggressive attention to toxic waste cleanup and remediation. Any inadequacies of U.S. environmental technologies in handling these efforts will need to be addressed.

Radioactive Tank Waste Remediation Systems (TWRS) and radioactive ground contamination removal systems (GCRS) have many technical problems as well as enormous potential costs and extensive time scales. For example, according to a General Accounting Office (GAO) letter dated March 8, 1993 and attached report, the "DOE has been developing a program to dispose of 61 million gallons of highly radioactive waste stored in 177 underground tanks at its Hanford site in Washington State." "In 1988 DOE estimated that disposing of tank wastes could cost as much as $14 billion. According to 1992 internal estimates, the cost could amount to nearly $50 billion." The time scale for completion is estimated to be decades. Similar estimates and time scales are attributed to GCRS at various sites around the country.

These enormous estimates have such profound national implications and the measurement problems are so challenging that it is essential that CIRMS examine and coordinate solutions to some of the measurement problems that involve, particularly, the use of primary and secondary radioactive sources in the form of point sources of alpha, beta, and gamma rays as well as large-area sources of similar radioactive standards. Such sources are essential for certain situations in which contractors and regulators must declare when a remediation and removal program has been completed.

The following MPDs address measurement and standards needs in public/ environmental radiation protection:

B.1 Non-Destructive Analysis of Waste Containers for Waste Cleanup
B.2 Radioactivity Standards for Waste Cleanup
B.3 Site Specific Soil Reference Materials for Waste Management
B.4 Capabilities of Field Radiation Survey Instruments for Decommissioning
B.5 Atom-Counting Measurement Techniques for Environmental Monitoring
B.6 Calibration and Transfer Standards for Environmental Dosimetry

MPD B.1 *Non-Destructive Analysis of Waste Containers for Waste Cleanup*

(a) Program Summary

A top need in the non-destructive analysis (NDA) area is to define traceability of NDA measurements. Both written and physical standards are needed in this area. Written standards should be developed that will set the parameters of 55-gallon drum standards and test materials including matrix, configuration, radionuclides, activity levels and chemical forms. Built into the written standard would be requirements for physical standards. There is a clear need in this area to establish intercomparison programs which perform simple tests initially, but which graduate to more realistic measurement challenges in later stages.

Calibration standards are necessary and important components of a successful waste certification program. Standards or reference materials are used to 1) relate known waste matrix/source characteristics to instrument response; 2) quantify systematic measurement bias due to waste matrix; 3) perform daily checks of gross instrument response; 4) verify compliance, programmatic, and facility QA requirements; 5) aid in characterizing instrument development; and 6) validate neutron and photon transport code models.

Significant effort is in progress at several DOE sites to build ever more sensitive NDA package counters for waste barrels and various bulk shipping containers. Issues concerning internal absorber effects and non-homogeneity have arisen. The key issues in the performance testing needs for NDA are as follows:

- Calibrations and error assessment for NDA
- Calibration standards for bulk, non-destructive methods
- Matrix effects and calibration standards, which influence the number of different calibrations required
- The extent that matrix effects be compensated for by computational methods
- Data available to determine the matrix corrections needed
- Information available to determine if a waste container falls outside the applicable range of either physical standards or computational assumptions
- Design of an Interlaboratory Performance Testing Program for distribution of bulk radioassay test materials
- The practical, regulatory, and site-specific difficulties in initiating such a program
- The physical characteristics of standards distributed under such a program
- Preparation of inventory and distribution of standards

(b) Detailed Program Characteristics

To fabricate calibration standards for waste assay instrumentation two phases are suggested:

1) carefully select matrix constituents to test a specific effect on a particular waste assay device (e.g., hydrogenous *vs*. non-hydrogenous for active neutron interrogation) and

2) simulate actual waste streams accounting for matrix components, relative weight fractions, and geometrical distribution.

The waste matrix must be chemically stable and reproducible. One must ensure that it can be modeled and that construction support material is minimized and the entire process is well documented. The chemical

MPD B.1 *Continued*

form of the radioactive component must be chosen carefully to mimic as closely as possible the actual waste radioactive component species (e.g., metal or oxide). The physical form must be carefully chosen to minimize self-shielding effects. The intensity, isotopes, mass range, and spatial location of the source(s) must also be considered.

Options for Performance Test Materials:

- Prepare a single standard drum and circulate among participants.
- Prepare sets of identical standard drums, one for each participant.
- Prepare drum phantoms with insertable standards and circulate only standard inserts.
- Prepare drum phantoms with removable media and standards inserts.
- Circulate a team to the participant locations to emplace media and/or standards and seal phantom.

There would be a need for an impetus for participation, and an organization to control, score and report the results of the program.

MPD B.2 *Radioactivity Standards for Waste Cleanup*

(a) Program Summary

Radioactivity measurements that support environmental restoration must be credible to withstand stakeholder and public scrutiny. To fulfill this goal, analytical methodology should be validated. Intercomparisons of environmental radioactivity measurements have shown discrepancies even between the most prestigious laboratories. During the development of the NIST natural matrix standards discrepancies between laboratories participating in their characterization were found in every sample type. Much work was required to resolve these discrepancies, which were caused by inadequate radiochemical techniques or methodology that had not yet been certified.

Measurement instruments should be calibrated with appropriate standards and reference materials to provide traceability to national radioactivity standards. This is important for compliance with regulatory guides, written standards, and other QA requirements. Furthermore, reference, secondary, or QA laboratory operations should periodically be evaluated against programmatic objective criteria by third-party technical experts to provide independent assessments.

The major impact will be to place environmental measurements throughout the country on the same basis so that results can be intercompared with confidence. Additionally, new standard source types and nuclides not now available for calibration of new instrumentation will be made available.

(b) Detailed Program Characteristics

Radiochemical Analysis Needs:

Primary radioisotope standards for the isotopes are required for waste characterization for WIPP and other DOE waste programs. In particular, the standards needed for low-level perimeter environmental monitoring are:

- low-energy long-lived (exotic) radionuclides as yet uncharacterized in waste storage tanks, e.g., ^{41}Ca, ^{53}Mn, ^{60}Fe, ^{59}Ni, ^{63}Ni, ^{79}Se, ^{93}Zr, ^{94}Nb, ^{93}Mo, ^{99}Tc, ^{107}Pd, ^{113}Cd, ^{126}Sn, ^{129}I, ^{135}Cs, ^{151}Sm, ^{231}Pa.

- tracer materials (yield monitors) such as ^{239}Pu and ^{243}Am.

- air filter standard with radioactivity containing dust particulates on the surface. Simulated radon progeny interferences should also be placed on the filter.

Intercomparison programs are needed to establish the quality of radiochemical measurements. An important goal of some intercomparisons would be the assessment of techniques and analytical procedures. There is a need to establish traceability of measurements. This could be accomplished through a traceability program with the QA laboratories and other selected laboratories. Intercomparisons and the use of the NIST natural matrix standards used as blinds could be used to initiate this activity. Since there are many sites to be tested, which differ radically one from the other in radiochemical challenges, another approach was considered. This was to develop a small suite of such standards that would cover the range of possible radiochemical problems.

Long-lived beta-emitting radionuclides will require a combination of beta particle metrology and mass spectrometry. Long-lived beta-emitting radionuclides are not as yet calibrated.

This program will bring together, coordinate, and initiate technical components, efforts and plans that are being implemented in a variety of laboratories, both government and commercial.

MPD B.3 *Site Specific Soil Reference Materials for Waste Management*

(a) Program Summary:

The performance requirements for performing chemical and radiological analyses for environmental and waste management programs are varied. For radionuclide analyses they fall into three levels:

- environmental levels for perimeter environmental monitoring,
- relatively high levels for characterization of radioactive waste drums,
- and a level in-between for environmental restoration.

The current supply of environmental-level soil Standard Reference Materials (SRMs), primarily from NIST, EML, and the IAEA, is adequate for the environmental monitoring and some of the environmental restoration work. However, new SRMs are needed that are specific to the types of radiochemical analyses, such as direct counting and for digestion prior to counting. SRMs developed for direct counting may not be adequate for uses where the sample is either totally or partially digested and purified before counting. In addition, SRMs based upon soil types found in the eastern part of the U.S. are not applicable to the southwest. The best type of reference materials for work associated with specific sites is site-specific materials. These materials can be used as blind quality control samples since they will resemble the actual samples more closely. Also, few, if any, reference materials are available for the DOE waste form types. Water standard needs are similar to the soil standard needs. *Spiked matrix* standards are presently available to a very limited degree from DOE (EML) and INEL (DOE).

(b) Detailed Program Characteristics:

The INEL Sample Management Office has a project for the preparation of site-specific soil performance evaluation (PE) samples. These PE soil samples are being prepared using residual samples that were collected from the Warm Waste Pond and Retention Basin areas of the Test Reactor Area as the source materials. The residual samples will be combined, blended, and fortified (if necessary) or diluted if necessary prior to being aliquoted into new containers. The homogeneity of the materials will be checked and then the materials characterized according to requirements specified in EGG-ER-10720 (in draft form) quality assurance project plan. Specifics for the preparation of the materials and the homogeneity check have been outlined.

The goals of the program are:

- Create site-specific QC soil materials for use with radionuclide and metals analyses
- Provide a source of soil QC samples containing analytes at expected environmental concentration levels
- Create a tool to assist radiochemical laboratories in maximizing their method performance at low levels
- Provide a soil QC tool to analytical laboratories for real-time QC management

MPD B.3 *Continued*

- Provide an inventory of soil PE samples for either periodic or real-time assessment of laboratory performance through the use of various types of INEL indigenous diluent soils.

Natural matrix standards (NMS) will require new developments in radiochemistry. Preparation of the materials will be performed by RUST Geotech and they, the Environmental Measurements Laboratory in New York, and the Radiation and Environmental Sciences Laboratory in Idaho Falls will participate in their characterization. A recent conference recommended that this and other such materials be made traceable to NIST.

MPD B.4 *Capabilities of Field Radiation Survey Instruments for Decommissioning*

(a) Program Summary:

In August 1994, the NRC published a proposed rule containing specific radiological criteria for the decommissioning of lands and structures. The intent of this rulemaking is to provide a clear and consistent regulatory basis for determining the extent to which lands and structures must be decontaminated before a site can be decommissioned. The criteria would apply to the decommissioning of most types of facilities licensed by NRC and the Agreement States. If adopted in final form, these criteria would be applied to determine the adequacy of remediation of residual radioactivity at NRC-licensed facilities.

Certain proposed radiological limits approach levels found naturally in the environment, which could pose technical challenges for determining compliance using existing radiological survey methods. For measurement and analysis of residual radioactivity at or near background concentrations, alternative radiological survey methods may be required to demonstrate that a site or facility has achieved appropriate decontamination levels. This will likely entail the application of nuclide-specific measurements for increased detection sensitivity, such as *in situ* spectrometric survey techniques. Although such techniques are more sophisticated than current radiological survey practice, their use may lead to a decrease in overall survey costs for certain sites and facilities.

(b) Detailed Program Characteristics:

The minimum detectable limits of a variety of *in situ* monitoring instruments (e.g., total alpha, beta, gamma, total exposure rate and field gamma spectrometry) must be identified. This is important, especially for regulatory purposes because it establishes an activity level at which the cost of assays starts increasing rapidly. Acceptable levels of radioactivity at restoration sites would be partially determined by these values.

Needed standards are:

- wide area, to test *in situ* monitoring instruments
- bore hole standards for fixed and moving instruments

Again, intercomparisons and QA efforts among the DOE laboratories and selected others is critically needed.

MPD B.5 *Atom-counting Measurement Techniques for Environmental Monitoring*

(a) Program Summary:

Radiochemical analyses are generally slow and costly. With the expectation that cleanup and site remediation programs will require millions of assays over a period of 30 or more years, costing many billions of dollars, a need exists for reducing the cost of the program by developing techniques that (i) use atom counting to reduce time spent by factors of 10 per assay and (ii) perform measurements *in situ* if possible, thus avoiding laboratory analyses.

New atom counting, neutron interrogation, and radiochemical techniques including calorimetry and a pulse recording instrument for coincidence measurements will be developed. These will provide new technology and reference materials for the assay of environmental radioactivity. Critical support will be provided for a fast growing industry associated with waste clean-up and site remediation by developing new techniques for *in situ* measurement of environmental radioactivity.

The potential impact is enormous. A proposed atom counting technique could lead for the first time to direct compositional analysis of environmental radioactivity *without* radiochemistry. It could lead to a dramatic reduction in costs and improvements in accuracy of environmental radioassays. This proposal could also lead to an order-of-magnitude improvement in sensitivity of *in situ* measurements of environmental radioactivity.

(b) Detailed Program Characteristics:

An atom counting technique aims to incorporate environmental materials into a Resonance Ionization Mass Spectrometry system which has sensitivities in the PPT range or better. This will require development of a source that can generate neutral atoms with appropriate beam intensity, width, and other characteristics. Recently a "proof-of-principle" experiment performed at NIST demonstrated for the first time that a Glow Discharge source with external laser interrogation and selection is possible and this would be the basis for the first investigations; development of procedures will present the environmental material of interest in a suitably compacted form which can be accepted by the ion source. A further aim is to develop speedy exchanges of sources for quicker turnaround times; development of a c.w. laser system for selective ionization of the neutral beam. The sensitivity is limited at present by the low duty cycle ($\sim 10^{-6}$) of pulsed lasers. If diode lasers (cw) can be adapted to the RIMS problem, the sensitivity should increase dramatically. Preliminary measurements at NIST have supported the eventual feasibility of the atom counting of environmental materials.

MPD B.6 *Calibration and Transfer Standards for Environmental Dosimetry*

(a) Program Summary:

Humans are constantly exposed to gamma rays and must be protected from excessive health risks. Thermoluminescent dosimeters (TLD) have long been employed in the vicinities of nuclear power plants, for decommissioning and decontamination activities, and in radioactive waste storage areas as well as off-site locations. This dosimetry is focused on direct measurement of gamma radiation being emitted from cosmic, terrestrial, and man-made sources in areas where the general public has unrestricted access with respect to radiation control, and those areas that are monitored to detect any changes in the environment to which radiation workers are exposed. A secondary measurement method, field instrumentation, should be used for development and testing of the dosimeters to verify exposure fields to which the dosimeters are subjected. Both environmental dosimeters and field instrumentation are calibrated incorporating high-level high-energy gamma-ray ^{137}Cs and ^{60}Co sources, even though low-fluence low energy gamma-rays are encountered in the actual environment. Technology and quality assurance programs need to be developed for use in the calibration of field instrumentation for low- level varied-energy gamma fields. Transfer standards need to be developed to establish quality assurance for environmental gamma ray monitoring.

This program will provide reliable site-specific evaluation of gamma doses which approach natural background radiation levels to which the public is exposed. The public and government will receive these measurements with greater confidence when a quality assurance program has been established. This will cause industry to move towards production of reliable instrumentation and dosimetry to specifically meet the needs of environmental concerns.

(b) Detailed Program Characteristics:

Environmental dosimetry applications involve low-fluence gamma fields of varied energies in the 1 - 25 μR/h range. With the national move towards cleanup and the turning over of the land to public entities, the challenge of correctly assessing low-fluence fields is presented. A low- fluence gamma source or methods of reducing the fluence of current gamma sources must be developed. Protocol for x-ray units must be developed to allow for testing of dosimeter and instrument response over a range of energies. Secondary field instrumentation must be developed and tested over a wide range of environmental conditions which would include temperature, humidity, pressure and light variations to ensure its stability. Transfer standards must be developed for use with both gamma and x-ray sources which will hold up to the above environmental conditions.

Development of instrumentation and a quality assurance program will require the development of a low-scatter low-background facility.

This program will bring unity of measurement capabilities to existing environmental dosimetry programs located at nuclear facilities, laboratories, and testing programs such as the International Intercomparison of Environmental Dosimeters series and other environmental intercomparisons performed by the Commission of the European Communities (CEC) and other agencies. The National Institute of Standards and Technology (NIST) is initiating its program to develop standard low- fluence gamma fields and to develop a quality assurance program which will include standard transfer instrumentation, a low-background low-scatter facility, and an environmental chamber; the Environmental Measurements Laboratory (EML) is moving ahead with field instrumentation development and characterization of low level fields; and Battelle Pacific Northwest Laboratory (PNL) is preparing to initiate the pilot testing in preparation for ANSI N13.29 Environmental Dosimetry Performance - Criteria for Testing (draft).

Instrumentation needed to carry out the plan includes semi-conductor/diode gamma-ray detection equipment and recording pressurized ionization chambers. TLD or other materials suitable for environmental dosimetry will be required to compare results as they would be incorporated in the field. Technology to measure low-fluence gamma fields and x-ray fields for the instrumentation and dosimetry will need development. Procedures for the preparation of low-fluence gamma fields, for assessing measurement capabilities of dosimeters and instrumentation in low-fluence gamma fields over a range of energies and under varied environmental conditions, and for the calibration of dosimeters and instrumentation will, need to be developed and standardized.

C. Occupational Radiation Protection MPDs

Introduction to Occupational Radiation Protection MPDs

Radiation workers must be adequately protected to ensure the viability of nuclear and nuclear-related industries. The cumulative number of radiation workers in the nuclear industry, distributed among DOE facilities and the various and diverse licensees of the NRC or the states, is approximately 1.3 million. Currently, there are approximately 100,000 radiation workers in the DOE. Since radiation cannot be detected by the human senses, we must have measurement tools and techniques available to adequately protect the worker in the work environment. Planning and controlling exposures to ionizing radiation requires accurate, reliable instrumentation to establish dose rates, indicate high exposure-rate areas, and control the spread of contamination in both the workplace and the uncontrolled environment. The day-to-day control of the radiation environment, established with sophisticated portable and installed instruments, is verified by bioassay and dosimetry programs that also rely upon sophisticated instrumentation. The dosimeter and bioassay results constitute the legal record of the workers' exposures. However, measurements made with reliable instrumentation prior to entry and during work in a radiation area are essential in minimizing workers' exposures and in complying with the principle of keeping radiation exposures As Low As Reasonably Achievable (ALARA). ALARA is used throughout the industry as a guiding principle in the control of workers' radiation exposures.

In recent years we have seen the increasing development and availability of sophisticated instruments and dosimeters. These improvements are the result of increasing sophistication and miniaturization of electronics. However, performance evaluations and intercomparisons have shown that response characteristics are dependent on such factors as the environmental conditions, the dosimeter processor, and the quality of calibrations. Unfortunately, the reliability of measurements has not kept pace with the increasing sophistication of the measurement tools. In the case of personnel dosimeters, recognition of the deficiencies led to the establishment of an accreditation program for dosimeter processors. This program, administered by NVLAP, has measurably improved the overall performance of dosimeter processors in the U.S.

The workplace is moving from the structured work environment in many facilities to more open areas as efforts move from development and production into environmental cleanup. Work in environmental cleanup requires a different mix of radiation measurements than for the typical work environment. Contamination measurements have become a larger share of the monitoring work, and dose rates are lower and must be monitored accurately at lower levels than typically encountered in previous activities.

Expansion of accreditation programs, improvement of calibration techniques and capabilities, improvement of the control or understanding of measurement techniques, and development of new measurement techniques can all result in improved measurement reliability. In turn, improved measurement reliability will assist in protecting the occupational radiation worker.

The following MPDs address measurement and standards needs in occupational radiation protection:

C.1 Improvement of Neutron Personnel Monitors
C.2 Extremity Radiation Dosimetry for Personnel Monitoring
C.3 Intercomparison Transfer Standards for Neutron Source Calibrations
C.4 Phantom Standards and New Detector Technologies for *In-vivo* Radionuclide Metrology

C.5 Comparability of Secondary Calibration Laboratory Accreditation Programs for MQA
C.6 Intercomparisons Among Secondary Standards Laboratories in lieu of Proficiency Tests for MQA
C.7 Measurement Assurance for Radiation Standards not Directly Supported by NIST for MQA
C.8 Type Testing of Personnel Dosimetry Systems for MQA

MPD C.1 *Improvement of Neutron Personnel Monitors*

(a) Program Summary:

Neutron personnel dosimeters are designed to be worn by radiation workers to monitor the neutron dose equivalent received during their daily activities. (Dose equivalent is a measure of the adverse biological effects of radiation, including cancer induction.) Clearly, any device to measure dose equivalent should have an energy-independent dose equivalent response. Unfortunately, this is far from true for the most commonly used neutron dosimeter—the "albedo" dosimeter. This dosimeter over-responds to low energy neutrons by factors of 10 to 100. Thus, in any working environment, a relatively small number of low energy neutrons can greatly inflate the reading of the dosimeter.

There are two solutions to this problem. The first, obviously, is to design a better dosimeter. This has been a long-standing effort at many laboratories. The requirements are very severe: in addition to having a very particular response as a function of energy (covering seven to eight decades of neutron energy!), a dosimeter must have high sensitivity and be inexpensive and easy to process, since any major installation may have thousands of people "badged." Further work along these lines should continue to be encouraged.

The second solution, which has also been used for a number of years, involves careful measurement of the neutron spectrum in the particular workplace, and use of a well-characterized dosimeter so that accurate calibration factors can be developed. This approach suffers from requiring many very careful, difficult, neutron spectrum measurements. On the other hand, it can be employed using existing technology.

Since the general trend is for the allowable dose equivalent to be lowered, it is becoming increasingly important to have more accurate dose equivalent measurements.

(b) Detailed Program Characterization:

An essential part of any solution to the dosimeter problem is the accurate characterization of dosimeter response as a function of neutron energy. At present, no facilities exist in the United States for these kinds of measurements. The unique filtered beams at the NIST Reactor have fallen into disuse, largely for lack of support, as have the monoenergetic neutron beams from the NIST 3 MeV Van de Graaff generator. It is, therefore, now necessary to use the facilities at the national standards laboratories in Germany (PTB) or England (NPL) to determine a dosimeter energy response function. It seems clear that it is very important to have adequate calibration facilities available in the United States so that dosimeter designs can be checked without the complications inherent in working at a foreign laboratory. The NIST filtered beams should be reactivated, and support provided for the NIST Van de Graaff, or for a (preferably) higher energy accelerator at one of our national laboratories. While there may be other Van de Graaff generators better suited for this work than the one at NIST, the NIST Reactor is uniquely suited for the production of filtered beams, with the filters themselves still in place.

This program would be closely related to the existing efforts of NVLAP and DOELAP for accrediting processors of personnel radiation monitors. It is also related to efforts at NIST to work with Secondary Calibration Laboratories to insure that calibration and testing sources are consistent with those at NIST.

MPD C.1 *Continued*

The goal is to develop a research program to investigate possible nuclear or chemical reactions that duplicate the dose equivalent response function and to develop monoenergetic neutron beams for quantifying response *vs*. energy.

Either of these programs would require about three years of steady funding before results could be expected.

Summary of Measurements Needed:

(1) Initiate a research effort to investigate reactions that might have an energy response similar to that of dose equivalent. This could be accomplished at a university or at one of the national laboratories.

(2) Develop a set of filtered-beam sources up to 144 keV and monoenergetic sources from 250 keV to 14 MeV. The former requires a research reactor, while the latter requires a Van de Graaff accelerator. These could be located at NIST or at one of the national laboratories. NIST has both a working reactor and an accelerator that is currently shut down. Time to make these facilities operational would probably be less at NIST than at a laboratory that had to start from scratch. This program would require a 3-year effort at the level of one person-year per year and a cost of $200k/y.

MPD C.2 *Extremity Radiation Dosimetry for Personnel Monitoring*

(a) Program Summary:

Radiation workers are sometimes required to manually manipulate or work in close proximity to radioactive materials (sources) when such manipulations or work can not be done remotely. This results in increased radiation exposure of the worker's extremities such as fingers, forearms, toes and lower legs. Present methods of monitoring such exposures are considered to be inadequate. There are currently no guidelines or regulations on the monitoring of radiation dose to extremities for occupational radiation personnel. A draft standard has been developed by the Health Physics Society to address this problem. It is designated as ANSI N13.32 and closely follows the existing ANSI N13.11 standard on whole body dosimetry. The existing NIST National Voluntary Laboratory Accreditation Program (NVLAP) on whole body personnel dosimetry that accredits dosimeter processors and the processor calibration laboratory uses ANSI N13.11 as the criteria for their current accreditation program. NVLAP proposes to add extremity dosimetry to the existing program using the draft ANSI N13.32 as the criteria for performance for the processors and the processor calibration laboratory. A research program needs to be initiated to verify the validity of the criteria in the draft ANSI N13.32 document and to develop transfer dosimetry measurement techniques for proficiency testing of the processor calibration laboratory.

(b) Detailed Program Characteristics:

The current NVLAP personnel dosimetry program accredits approximately 80 dosimeter processors that supply personnel dosimeter badges (whole body dosimetry) to the 1.3 million occupational radiation workers in the U.S. Performance tests of these processors are conducted by the NVLAP proficiency testing laboratory, the Battelle Pacific Northwest Laboratory (PNL) in Richland, WA. PNL's performance is accredited by NVLAP by means of audits and NIST proficiency tests.

The addition of extremity dosimetry to the existing NVLAP program by adoption of ANSI N13.32 will include only photons and beta particles; neutrons have been excluded for the present. There are also some other minor differences between the existing criteria and the new requirements.

The draft N13.32 document specifies a solid cylindrical rod phantom of PMMA, 19 mm in diameter by 300 mm length, to represent a finger. It specifies a solid cylindrical rod of aluminum, 60 mm in diameter by 300 mm length, nested inside a tube of PMMA with an inner diameter of 60 mm and outer diameter of 73 mm and 300 mm in length to represent bone and soft tissue of an arm or lower leg. In addition, the ISO recently proposed that the arm/leg phantom be represented by a water-filled pillar made up of a PMMA cylinder of 73 mm outer diameter, 2.5 mm wall thickness, 300 mm overall length, with 10 mm end walls. There are no known dosimeter response data for this latter ISO phantom.

There is a need for appropriate dose equivalent conversion factors for the various irradiation geometries discussed above. Thus, the conversion factors for air kerma (or exposure) to individual dose equivalent, superficial, in ICRU tissue need to be determined. This is addressed in the ANSI N13.32 draft by a set of factors derived from measurements. There is clearly a need to perform calculations of these factors as well in order to verify the validity of the experimental values.

A research program should be initiated to study the responses and characteristics of the different types and configurations of extremity dosimeters now in use. One type now used at NIST is the single-chip TLD in a ring. This design tends to under-respond to low-energy betas because of its thickness and to under-estimate the dose to the tips of the fingers because it is worn at the base of the finger. A more

appropriate design is the "band-aid" type which is very thin and is mounted in a sheath slipped over the end of the finger.

The proposed program includes construction of three types of phantoms (the two specified in the ANSI N13.32 draft and the water-pillar type by ISO) and measure the responses of the various types of dosimeters and configurations available mounted on the phantoms. The dosimeters will be irradiated with photons and beta particles as specified in the N13.32 document and will include angular dependence studies. Consideration should also be given to neutron studies. Calculations of dose equivalent conversion factors will be undertaken for the various irradiation configurations and types of dosimeters.

(c) U.S. Facilities, Staffing, and Funding:

The proposed program will require 2 persons ($300k/yr) for two years plus appropriate equipment funding for suitable TLDs, TLD readers, phantoms, mounting jigs with reproducible angular mobility, and computers for data analysis ($300k).

MPD C.3 *Intercomparison Transfer Standards for Neutron Source Calibrations*

(a) Program Summary:

The program will determine the feasibility of using LiF thermoluminescent dosimeters (TLDs) as transfer standards for intercomparisons of neutron dose equivalent resulting from moderated ^{252}Cf sources at NIST and other calibration laboratories.

(b) Detailed Program Characteristics:

The project will determine the reproducibility and stability of response of LiF (both ^{6}Li and ^{7}Li) TLDs used as albedo dosimeters when irradiated on a PMMA phantom with moderated californium sources. This will be accomplished with a multi-variable experimental design involving repeated cycles of irradiation and readout of the TLDs while varying numerous parameters, including (1) preheat temperature and period; (2) acquisition heating rate, duration, and final temperature; (3) anneal time and temperature; and (4) response fade *vs*. time characteristics.

Follow-up experiments will determine optimal reader parameters and appropriate irradiation and readout protocols for use of the TLD system as transfer standards in intercomparison measurements and for proficiency testing of calibration laboratories seeking accreditation by NVLAP.

(c) U.S. Facilities, Staffing, and Funding:

NIST will need to establish appropriate irradiation facilities, TLD analysis instrumentation, and data analysis computers. The program will require one person-year per year ($200k/y) and appropriate equipment funds ($150k).

MPD C.4 *Phantom Standards and New Detector Technologies for In-vivo Radionuclide Metrology*

(a) Program Summary:

Non-invasive *in-vivo* radiobioassay (whole-body counting) of personnel working with radionuclides or materials with potential radioactive contamination is a primary method dosimetrists employ for routine occupational monitoring and crisis assessment. The variability among "homemade" and *de facto* reference phantoms can account for upward to 200 percent differences among measurement laboratory results. Measurement comparability and consistency can be ensured through calibrations based on national standard realistic human-surrogates (phantoms). In addition, site-specific (organ-specific) quantitative assessment requires new measurement technology and 3-D tomography. The solution to these problems is the development of the technological and measurement quality assurance bases for quantitative site-specific *in-vivo* radiobioassay. This is a recommendation of the International Workshop on Standard Phantoms for *In-Vivo* Radioactivity Measurements [Health Physics, **61**, 893 (1991)].

The benefits of this initiative to personnel safety include: comparable quality of dosimetry assessments; assessment of dose to individual critical organs; transferable dosimetry histories for employees; refinement and verification of biokinetic models. Technologies developed for methods, software, and hardware will be directly transferable to the national radioactivity waste management initiative where hundreds of thousands of containers must be handled for documentation and accountability purposes. Transfer of the technology will also be of importance to the medical diagnostics community.

(b) Detailed Program Characteristics:

Application and R/D Challenges:

Success will depend on meeting new research and development challenges that include innovations in radioactive polymer manufacturing and quality control technology; new high-resolution miniature photon probe technology; flexible Monte Carlo based calibration of all detection systems; and 3-D topography technology for irregular/heterogeneous subjects. The results of materials and computational research and instrument development will yield rewards in many related fields. Polymer science and industry will be challenged to develop advanced formulation and quality assurance technologies because: (i) techniques are needed to manufacture polymer-based phantoms that accurately simulate the density, radiation scatter (effective Z) and attenuation of human tissues; and (ii) manufacturing techniques must be developed to ensure consistency and reproducibility. Radiation detection scientists must develop detectors that produce high resolution x-/gamma-ray spectra without having to be refrigerated at liquid nitrogen temperatures, and instrumentation manufacturers must develop thin-walled moisture-proof encapsulation technology for the miniaturized detectors. Topography science and related industries will be challenged to develop hardware and software for multiple detector arrays for low-contrast imaging. Measurement quality assurance and accreditation programs for *in-vivo* radionuclide metrology will depend on standard phantoms and Monte Carlo modeling techniques to ensure measurement consistency.

In-vivo radionuclide measurement depends on direct measurement of radiation emitted from internal depositions. This initiative will be directed at these measurements and will be the summation of several separate but coordinated efforts. Preparation of the American National Standard on manufacturing criteria for BOMAB and Realistic Human Torso Phantoms, development of methods to label phantom inserts homogeneously, development of methods to assess homogeneity of phantom inserts, and development of internal detection probes for lung counting will require 3 years. Development of a

standard phantom family and comparative measurements with Monte Carlo calculations plus interlaboratory comparisons and calibrations will require 7 years. Comparison of calibrations of standard phantoms to surrogates in the phantom library and to real animal/human exposures, and development of quantitative 3-D topography technology will require 10 years.

This program will bring together, coordinate and initiate technical components, efforts and plans that are being implemented in a variety of laboratories among different agencies. While NIST is initiating its program to develop standard reference materials, the BRMD is initiating the development of a family of BOMAB phantoms, DOE and RESL are piloting a radiobioassay laboratory accreditation program; LLNL has been moving ahead with Monte Carlo expressions of calibrations of individual subjects, and PNL is establishing a national phantom library.

Measurements and Standards Needed:

Instruments: Internal high temperature semi-conductor/diode gamma-ray detection probes; high resolution gamma-camera for lung counting and quantitative 3-D topography.

Source Fields: Spiked phantom inserts

Procedures: Spike inserts homogeneously; assess homogeneity of inserts; advanced Monte Carlo modeling techniques.

(c) U.S. Facilities, Staffing, and Funding:

Currently work is ongoing on new phantom materials, American National Standards, techniques for assessing homogeneity and content of phantom inserts, and Monte Carlo calculations. These efforts need coordination and communication to ensure that measurement quality assurance aspects are properly coordinated and that measurement methods are addressed. Coordination and detector development will require an estimated 1 to 2 person years per year for approximately 10 years. This is in addition to ongoing efforts. Equipment – Standard BOMAB and Realistic Human Torso Phantom; micro-high resolution high temperature semi-conductor/diode gamma-ray detection probes; high resolution gamma-camera and software, advanced Monte Carlo software ($10M). Laboratories – NIST, LLNL, BRMD, RESL, PNL.

MPD C.5 *Comparability of Secondary Calibration Laboratory Accreditation Programs for MQA*

(a) Program Summary:

There are presently four national programs that accredit secondary calibration laboratories in the area of ionizing radiation. Although the critical elements of a complete measurement quality assurance (MQA) program are required for accreditation under each of these programs, they do not use the same general or specific criteria to evaluate candidate laboratories. The criteria are similar, but not identical. Questions have been raised about the comparability (equivalence) of accreditation granted by the various programs. An obvious major improvement would be the adoption, by all the programs, of ISO Guide 25, which establishes general criteria for laboratory performance. Other related questions are not as easily resolved, and need further study.

(b) Detailed Program Characteristics:

In chronological order, the four national programs developed to accredit secondary calibration laboratories are administered by the American Association of Physicists in Medicine (AAPM), the Conference of Radiation Control Program Directors (CRCPD), the Health Physics Society (HPS), and the National Voluntary Laboratory Accreditation Program (NVLAP). Respectively, the criteria used to evaluate laboratory performance for each program were developed by an AAPM committee, a CRCPD committee, an HPS committee, and a national consensus group. The fact that NIST was closely involved in the development of each set of criteria provided a degree of uniformity, and guaranteed that each program required inclusion of the critical elements of a complete MQA program. Thus, the four sets of criteria are similar, but not identical. This gives rise to questions about the comparability (equivalence) of accreditation granted by the four programs. However, it is not clear whether it is desirable that these different accreditations be equivalent. This topic needs further consideration.

At the time the four programs were developed, there was no national or international recommendation or guidance regarding criteria for calibration laboratories. Subsequently, ISO Guide 25 was issued, entitled General Requirements for the Competence of Calibration and Testing Laboratories. Laboratories meeting the requirements of that Guide comply, for calibration and testing activities, with the relevant requirements of the ISO 9000 series of standards. Since ISO Guide 25 applies to all types of calibration laboratories, it is general in nature. Those *general* criteria are of considerable value, but additional criteria that are *specific* to ionizing radiation calibrations are also needed to assure meaningful, consistent evaluations of laboratories that perform such calibrations.

The comparability of the four national programs would be substantially improved if each adopted ISO Guide 25 as its general criteria. That would not, however, address the question of what, if anything, should be done regarding the use of differing specific criteria. Examples of relevant considerations that seem to require further study are:

(i) The relative importance of specific criteria.

(ii) The different communities served by the four programs. For example, the AAPM program serves primarily the medical physics community, and the other programs serve the radiation protection community. Within that area, the CRCPD serves state laboratories, the HPS serves the private sector, and the NVLAP program was developed by and for federally-owned laboratories.

(iii) The nature of the grantor of comparability (or equivalence). It is not evident that the individual programs have the desire or authority to grant comparability to any other program.

Any additional relevant considerations should also be studied.

The program administered by the HPS has taken action to adopt ISO Guide 25 as its general criteria, and has developed pertinent specific criteria. This action could serve as a model for the other programs.

It is recommended that the four programs adopt ISO Guide 25 as their general criteria as soon as practical. In addition, a study should be initiated that will address the considerations identified above, plus any additional pertinent considerations. This study should be conducted during the next year, after which the recommendations made as a result of the study should be implemented.

(c) U.S. Facilities, Staffing, and Funding:

Adoption of ISO Guide 25 by the four programs should be coordinated by the CIRMS Occupational Radiation Protection Subcommittee. The recommended study should be coordinated by the same subcommittee, which has the necessary broad representation. The study group should consist of persons who are actively involved in laboratory accreditation programs and have a working knowledge of performance criteria. Representatives of each of the four programs should serve in the study group. The estimated cost for the necessary meetings and coordination is $12,000 over the next year.

MPD C.6 *Intercomparisons Among Secondary Standards Laboratories in lieu of Proficiency Tests for MQA*

(a) Program Summary:

One of the essential elements of a complete measurement quality assurance (MQA) program for secondary laboratories is a periodic proficiency test of the secondary laboratory by the National Institute of Standards and Technology (NIST). If each test is conducted as a one-on-one interaction, it is relatively expensive and may not be practical when the number of secondary laboratories increases. Alternative, more efficient, methods of testing laboratory performance should be explored and implemented. Periodic intercomparisons among secondary laboratories may be a satisfactory alternative method of verifying performance.

(b) Detailed Program Characteristics:

Three national MQA programs that accredit secondary standards laboratories to perform calibration services for ionizing radiation require an annual proficiency test of each accredited laboratory, by NIST. These programs are administered by the Conference of Radiation Control Program Directors (CRCPD), the Health Physics Society (HPS), and the National Voluntary Laboratory Accreditation Program (NVLAP). Proficiency tests are used to demonstrate that a laboratory's performance is within prescribed accuracy limits for a particular type of service it provides. Accuracy is considered to be adequate if the laboratory's measurement result is sufficiently close to the true value, as defined by comparison with a national standard.

Presently, the proficiency tests are conducted through a one-on-one interaction between a secondary laboratory and NIST. As an example, if the quantity of interest is gamma exposure (air kerma) rate, NIST will calibrate an ionization chamber using an identified photon source, send that chamber to the participating laboratory for its calibration, and the calibration factor determined by the latter will be compared with that determined by NIST. The ionization chamber will be returned to NIST, and the process will be repeated with another participating laboratory. Although this process is highly effective, its cost and efficiency should be examined, particularly, as the number of secondary laboratories continues to increase. Alternative methods for testing laboratory performance should be considered to determine whether they could be sufficiently effective at lower cost.

Perhaps the most obvious alternative is a form of laboratory intercomparison, in which a common transport standard (i.e., instrument, radiation source, or dosimeter) is circulated among several secondary laboratories, each of which makes a prescribed determination and reports its result to the test coordinator. Factors that must be considered for this alternative are:

(i) Who will supply the transport standard?

(ii) How frequently will such an intercomparison be done?

(iii) How will consistency with the national standard be achieved?

(iv) Should NIST be a participant in each intercomparison?

MPD C.6 *Continued*

(v) Should the present type of proficiency test (i.e., the one-on-one interaction with NIST) be done less frequently, supplemented by intercomparisons among secondary laboratories in intermediate years?

These and any additional relevant questions need to be addressed.

An addendum to this MPD describes models for proficiency testing established by the American Association of Physicists in Medicine (AAPM).

It is recommended that an alternative to the yearly proficiency tests required by the three MQA programs mentioned above be studied in depth during the next year. If an alternative is found to be desirable and feasible, implementation should be proposed subsequent to completion of the study. The nature of the implemented alternative (or alternatives) will determine what the associated instrumentation and manpower costs will be.

(c) U.S. Facilities, Staffing, and Funding:

The recommended study should be coordinated by the CIRMS Occupational Radiation Protection Subcommittee, since that group has the broad representation required to achieve a true national perspective. The study group should include persons who are directly involved in the operation of secondary laboratories and in the development and administration of laboratory accreditation programs. Assuming a study group consisting of eight persons meeting twice during the next year, the estimated cost would be approximately $10,000 for travel and per diem. Additional costs for salaries must be contributed by the various organizations.

Addendum

Models for Alternate Proficiency Tests

The experience of the American Association of Physicists in Medicine (AAPM) accreditation program for secondary dosimetry laboratories (ADCL's) has established models for measurement assurance testing (proficiency testing) of the laboratories that may be applicable to other accreditation programs in ionizing radiation.

The AAPM accreditation program in 1971 formally accredited procedures already in existence in several medical physics laboratories. NIST was initially involved in the establishment of the accreditation procedures and has continued its involvement to the present. In 1976, a program for measurement assurance tests was initiated. In this testing procedure, an appropriate dosimeter is calibrated at NIST, then shipped sequentially to all of the ADCL's for calibration, and then returned to NIST where the calibration is verified. All reports of calibrations are forwarded to NIST where the results are compiled. The results are then sent to the chairman of the accreditation body for review and archiving.

Since 1985, a measurement assurance test has been carried out in alternate years among the laboratories without NIST involvement. The procedure is the same, with the exception that it is initiated by one ADCL using a detector approved by the accrediting committee. The initiating ADCL calibrates the dosimeter, ships it to the next ADCL, and upon completion of the cycle verifies the calibration. All reports are sent to the chairman of the accrediting committee for collection, review, and archiving.

The dosimeters for these "round robin" measurement assurance tests have been provided by NIST, an ADCL, or a manufacturer. Both transfer quality and field instruments have been used. Initially two dosimeters were sent for redundancy. However, this was found to be unnecessary so now only one dosimeter for each energy range and/or modality is sent.

There have been three occasions when the community has required a working standard; however, none existed at NIST. The three standards required were: 1. High dose rate ^{192}Ir brachytherapy, 2. Radium brachytherapy (after NIST had discontinued its radium standard), and 3. Plane parallel plate chambers for application to electron-therapy beams. These working standards were each introduced with a different approach but with involvement of NIST and following deliberation by the accreditation committee.

Whenever a laboratory was found to be outside the acceptance criteria in these measurement assurance tests, the cause was investigated by the accreditation committee. In all of these cases the accrediting committee, NIST, and the ADCL's learned new information about their procedures or dosimeters.

MPD C.7 *Measurement Assurance for Radiation Standards not Directly Supported by NIST for MQA*

(a) Program Summary:

Many laboratories maintain radiation standards which are not directly traceable to NIST because of operational needs and a lack of a relatable national standard. Although in an ideal world NIST would provide direct support for all necessary standards, this is neither probable nor realistic. In all likelihood, these standards will continue to exist regardless of the implementation of a formal program of quality assurance since they meet specific measurement needs. The purpose of the subject proposal is to provide a methodology to ensure the level of quality assurance expected by regulatory agencies.

As legal and regulatory pressures continue to increase, the importance of having a unified and acceptable quality assurance program for each radiation measurement related to health protection, medical physics, national and international commerce, and environmental protection becomes a more pressing need. Development of a structured system or method is needed to relate the current system of primary and secondary standards to the specific radiation standard (type, energy, etc.). Guidance is also needed in assigning related measurement uncertainties.

(b) Detailed Program Characteristics:

It is proposed that a system be developed which provides a formal method for the assurance of measurement quality for radiation standards other than those maintained directly by NIST, and for the recognition of these standards at various levels appropriate to their application. The method must also permit an acceptable statement of uncertainty. The structure of such a system or methodology can take many forms but, in any case, it should involve both the NIST and the secondary calibration laboratory programs. Two examples of the types of structure proposed are given to provide an illustration of the types of systems which can be considered.

Multi-standards program – For this method, NIST would provide national standards deemed appropriate to the broad interest of the nation and required for the general conduct of commerce and radiation protection. Priority would be given to standards which the laboratories are not capable of developing as independent standards. Accredited secondary calibration laboratories would be allowed to maintain alternative standards which have been carefully reviewed and approved as part of the secondary laboratory accreditation process. The participating laboratory would agree to continue support of the standard and to make the standard available to other users at a reasonable cost. Other laboratories may maintain independent standards which have been reviewed by a secondary laboratory program or NIST and have been acknowledged by letter to meet minimum requirements for quality assurance.

Independent standards quality assurance program – This method would provide guidelines for establishment and maintenance of individual quality assurance programs directed specifically to the need for independent radiation standards. Although the fundamental requirements under this program are much the same as the previous program, no formal recognition or certification will be given. It would be desirable for the NIST to provide an additional service which would allow review of these standards by qualified NIST personnel as part of the participating laboratories quality assurance program. Guidelines for this quality assurance program could be established by ANSI, ISO, HPS, AAPM, or other established standards organization. Several related standards already exist and could be combined or referenced.

(c) U.S. Facilities, Staffing, and Funding:

The Council of Ionizing Radiation Measurements and Standards can assume a leadership role in the establishment of such a program and can help ensure that the resulting program meets the national needs. Implementation of such a program will also be a tremendous boost to identification of needs and establishment of new national standards. In addition it will provide a bridge from the time that a new need arises to when the need can be addressed with a new national standard.

A committee with representatives for specific measurement needs (special x-ray beams, pulsed neutron sources, etc.) and representatives of NIST should be convened to identify the specific requirements to establish such standards, methods for determining uncertainties, and the requirements for measurement quality assurance, including documentation. It is expected that establishing fundamentals for such a program will require two meetings of a committee. Translating the basic recommendations into an acceptable criteria document will require an additional three or four meetings.

MPD C.8 *Type Testing of Personnel Dosimetry Systems for MQA*

(a) Program Summary:

The first American National Standard for the performance testing of dosimetry services ANSI N13.11, was published in 1983. Formalized accreditation programs were later introduced by both NVLAP and the DOE. The NVLAP program is based directly on N13.11 whereas the DOE's DOELAP program is based on an enhancement of N13.11 (DOE, 198886). ANSI N13.11 was revised and updated in 1993 to include additional sources and dosimeter performance specifications.

Accreditation in Europe is progressing along slightly different lines. Germany has implemented a system of pattern approval of all dosimetry systems that requires type testing to be performed.

(b) Detailed Program Characteristics:

Characteristic of dosimetry systems can be divided into two distinct categories: (i) those that are processor independent and; (ii) those that are processor dependent.

The personnel dosimetry accreditation programs currently in place in the U.S. are based upon a set of reference performance tests designed to establish a uniform approach and minimum levels of acceptable performance for personnel dosimetry. Initial accreditation includes three rounds of proficiency testing, an on-site inspection, and a one-time evaluation of the dosimeter and angular response. Dosimetry processors are required to be reaccredited every two years.

In December 1992, the Physikalisch-Technische Bundesanstalt (PTB) established requirements for the pattern approval (type testing) of thermoluminescence dosimetry systems. These requirements are designed to test a system's overall design capabilities and limitations. Facilities in Germany cannot utilize dosimetry systems (combinations of reader, badge, holder and algorithm) that have not received pattern approval.

If one compares the PTB and N13.11 requirements, one will see an overlap. Some of the U.S. accreditation requirements test characteristics of the dosimetry system that are, for all intents and purposes, processor independent and need not be repeated. It is suggested that a type testing program (American National Standard) be developed in the U.S. for personnel dosimetry systems. This standard would outline those characteristics of a dosimetry system that are processor independent and the criteria for testing. In addition, ANSI N13.11 could be revised to test only those aspects of dosimetry processing that are under control of or are influenced by the processor.

(c) U.S. Facilities, Staffing, and Funding:

The U.S. facilities and organizations involved would be:

- ANSI/HPSSC – An American National Standard would be required that specifies the protocol and scope of type testing of personnel dosimetry systems.

- ANSI/HPSSC – The current ANSI N13.11 will have to be revised to encompass only the process dependent aspects of dosimetry performance.

MPD C.8 *Continued*

- DOE/NRC – Adopt the concept of Type Testing/Accreditation and incorporate accordingly into their respective regulatory frameworks.

- At least one laboratory must be identified with the expertise and equipment to perform the type testing of personnel dosimetry systems.

D. Radiation Effects MPDs

Introduction to Radiation Effects MPDs

The interaction of ionizing radiation with materials (polymers, ceramics, metals, electronics) and other commercial products (such as sewage, food, drinking water) is critical to a wide range of different technologies. Radiation-effects applications can be divided into two categories. These are: (i) *industrial processing*, in which products are subjected to radiation as a part of the manufacturing process, in order to beneficially improve their properties, and (ii) *radiation damage*, in which materials are unavoidably exposed to radiation in the course of their useful lifetimes.

There are a number of processing advantages of radiation. These include cost-efficient alteration of molecular structure, room-temperature treatment of materials which otherwise suffer unwanted effects of temperature (such as pharmaceuticals, which thermally decompose, and composite materials, which experience residual stress when cured at high temperatures), and the penetrating nature of radiation in opaque materials, compared with UV light. Industrially important radiation processing technologies span a diverse spectrum of products and applications. Current major technologies include: sterilization of medical devices, drugs and cosmetics; processing of foods; curing of coatings and inks; cross linking of rubbers and plastic products; surface grafting; x-ray and e-beam lithography; waste treatment (stack gasses, toxic chemicals, explosives, infectious hospital wastes, municipal wastes); drinking water purification; treatment of blood; sterilization of insects; ion implantation and doping of semiconductors; and joining of metals (welding and brazing). Radiation damage applications include: nuclear power plants (steel vessels, cable insulation); space applications (electronics and structural materials); future fusion reactors; as well as high-energy physics facilities (Fermilab, CERN), and other radiation-producing equipment.

Reliable radiation measurement is critical to most of the applications described above. Effective radiation processing depends upon proper application of absorbed dose. All locations in a product having complex 3-dimensional geometry, and possibly consisting of a number of different material types, must be considered. The applied dose must not fall below a lower limit, in which case the exposure is insufficient to accomplish the desired effect. At the same time, the dose in any given location must not exceed an upper limit, in which case adverse effects on quality may result. Thus, "average dose" is a term that is seldom of interest.

Over the past decade, 17 standard practices and guides for radiation-processing dosimetry have been developed and published by Subcommittee E10.01 of the American Society for Testing and Materials (ASTM). These include guides on the selection and calibration of dosimeters, and separate practices on how to perform dosimetry in gamma, electron beam, and x-ray/bremsstrah-lung commercial irradiation facilities. Nevertheless, more standard practices and guides are needed. ASTM is currently developing some on how to treat uncertainties and how to perform dose mapping. Standard practices will be required for new dosimetry systems as they become commercially available, and guides for performing dosimetry in other irradiation environments will eventually be needed.

A collection of different dosimetry systems are required to meet a number of measurement challenges. For example, several orders of magnitude in dose often need to be determined, and very high dose rates are frequently involved. Energy spectrum is important in a number of applications. Source characteristics (angular distribution, current and time dependency) must be taken into account. Imaging and profilometry is important in a number of applications; interface effects may be significant. Continuous, real-time monitoring of dose would be an enabling capability for some

processes where process control is especially critical. Other specialized measurement needs are important to radiation-damage applications, including the ability to define mixed neutron-gamma fields. General improvements in dosimetry technology are needed throughout the various applications, particularly with regard to cost and improved tolerance to storage time, temperature, and humidity variables. Formal traceability for secondary standards laboratories, through primary and transfer standards, needs to be put into place.

The following MPDs address measurements and standards needs in radiation effects:

D.1 High-Dose Calibrations for Electron-Beam Processing
D.2 Radiation Measurements for Gamma-Radiation Processing
D.3 Gamma-Ray Dosimetry in Mixed Fields for Radiation Hardness Testing
D.4 Neutron Dosimetry for Reactor Pressure Vessel Surveillance

MPD D.1 *High-Dose Calibrations for Electron-Beam Processing*

(a) Program Summary:

There are now many electron accelerators installed in industrial irradiation facilities. A reasonable estimate is between 700 and 1000 such facilities. The aggregate value of materials and products being irradiated with electrons in the U.S. is currently estimated to exceed 10 billion dollars annually.

Chemical dosimeters are used to measure absorbed doses in a variety of industrial irradiation processes, such as the modification of polymeric materials, the sterilization of medical devices, the preservation of foods and the treatment of waste materials. These types of dosimeters are typically liquids or solids that undergo changes in optical density at specific wavelengths of visible light or ultraviolet radiation when exposed to ionizing radiation.

The chemical reactions that cause these changes in optical density are influenced by the dosimeter composition and irradiation conditions, such as temperature, humidity, oxygen content, light exposure, dosimeter size and shape, dose rate or dose per pulse (for very short irradiations), particle and photon energies, and the linear stopping power of dosimeter materials for high-energy particles.

In order to avoid or minimize errors in using chemical dosimeters to measure absorbed doses in practical applications, standard procedures such as those published by ASTM should be used. The irradiation conditions used for calibrating the dosimeters should be similar to those prevailing in the irradiation facility. If this is not feasible, the calibration should be conducted in the irradiation facility itself using reference or transfer dosimeters as described in ASTM Standard E1261. Alternatively, the different conditions should be noted and correction factors should be applied to the calibration data to account for these differences.

Of particular concern here is the common practice of calibrating plastic film dosimeters with gamma rays and then using such dosimeters to measure absorbed doses with high-energy electrons at much higher dose rates. This procedure has led to significant errors in some industrial irradiation processes. Because dose rates in electron-beam facilities can be many orders of magnitude higher than dose rates in gamma-ray irradiations, it would be better to use electrons instead of gamma rays to calibrate film dosimeters if they are intended for use in electron-beam facilities.

Some electron-beam calibration services have recently become available. However, there are still problems due to the substantial differences in dose rate or dose per pulse between various types of electron accelerators which are now being used or may soon be used for radiation processing. These include low energy (100 to 300 keV) extended beam dc accelerators, medium energy (300 keV to 5 MeV) scanning beam dc accelerators and high energy (5 to 25 MeV) microwave, very high frequency or induction linear accelerators operating in either pulsed or continuous wave mode. Average beam currents may range from less than 1 mA to more than 1 A and peak beam currents may be as high as 25 kA. Dose rates may be as high as 100 kGy per pulse with pulse durations as short as 50 ns.

The diversity of electron accelerator types presents practical problems for the users in obtaining accurate dosimeter calibration services. It may be impracticable for any calibration laboratory to be equipped with all types of accelerators that may be used for these purposes. Still, the need exists for electron-beam calibration services that are known to be appropriate for each situation.

Perhaps this need can be met by establishing secondary calibration laboratories in or closely associated with the industrial irradiation facilities where particular types of electron accelerators are used. Standard or reproducible electron-beam fields can be established and their dose rates measured with calorimeters, which are relatively insensitive to differences in dose rate. Then transfer and routine film dosimeters can be calibrated in these standard fields.

The accuracy of the dosimeter calibration should be established with regard to variations in the energy spectrum and the dose rate or dose per pulse of the electron-beam facility where the dosimeters will be used. This kind of information should be provided along with the calibration data. This may enable users to have their dosimeters calibrated with electron accelerators that are somewhat different from their own and still have confidence in the results.

(b) Detailed Program Characteristics:

Instruments Needed: Calorimeters, spectrophotometers, thermometers, hygrometers, thickness gauges, ammeters, Faraday cups, oscilloscopes, chart recorders, ESR spectrometer, etc.

Sources of Electron-Beam Fields, as Required:

Low energy (100 to 300 keV), high dc current (100 mA to 1 A), extended beam accelerators, such as the BroadBeam made by RPC Industries, the Electrocurtain made by Energy Sciences and the Electron-Processing System made by Nissin High Voltage.

Medium energy (300 keV to 5 MeV), medium dc current (20 mA to 200 mA), scanning beam accelerators, such as the Insulating Core Transformer made by Vivirad High Voltage, the Cockcroft Walton made by Nissin High Voltage and the Dynamitron made by Radiation Dynamics.

High energy (5 MeV to 15 MeV), low average current (1 mA to 20 mA), microwave and very high frequency linear accelerators, such as the MegaRay made by Varian Associates, the SureBeam made by Titan Beta, the Circe made by CGR-MeV, the Impela made by Atomic Energy of Canada Limited and the Rhodotron made by Ion Beam Applications.

Medium to high energy (1 to 10 MeV), very high peak current (1 kA to 25 kA), linear induction accelerators, such as the prototype machines now being developed by Lawrence Livermore National Laboratories, Sandia National Laboratories, Science Applications International, Science Research Laboratory, and Titan PSI.

Dosimetry Required: Comparisons of absorbed dose measurements made with chemical dosimeters and calorimeters with various types of electron accelerators, such as those listed above.

Statements of Measurements or Calibrations Needed: Dose rate, temperature, and energy response data for chemical dosimeters, especially thin plastic films, are needed for the types of accelerators listed above. Direct current, very high frequency and microwave linear accelerators are being used for electron-beam processing of commercial products, bulk materials, agricultural commodities, and toxic wastes. Linear induction accelerators will probably be used for these purposes and for x-ray processing in the near future.

MPD D.1 *Continued*

Absorbed doses must be measured accurately in suitable materials and products in order to control the irradiation processes. In order to meet this objective, the calibration procedures must be appropriate for the accelerators being used for particular applications.

MPD D.2 *Radiation Measurements for Gamma-Radiation Processing*

(a) Program Summary:

Gamma-radiation processing is a well-established world-wide industry, which began in the U.S. and the U.K. more than 30 years ago. The design of large ^{60}Co sources of intense gamma radiation fields, shielded buildings and product conveyor assemblies led to successful industrial sterilization of health-care products such as hospital supplies, disposable medical devices, and pharmaceuticals. Presently, there are nearly 180 gamma-ray plants in 45 countries, with about one-quarter of these being in the U.S. The annual domestic market alone exceeds one billion dollars, with a total product volume of 90 million cubic feet. Besides medical products, the wide variety of goods includes polymers, sealants, ceramics, composites, adhesives, food and food packaging, drugs, cosmetics, electronics, aeronautic and automotive components, blood products, waste products, propellants and fuels, electrical insulator materials, and drinking water supplies.

Most U.S. gamma-ray processing plants operate at capacity, 24 hours per day. Good process control for these facilities relies heavily on dosimetry. Economically, improvements in quality control (QC) would increase process efficiency and product throughput. Improvements of even 1 or 2 percent in the accuracy and precision of some dosimetry systems could translate into tens of millions of dollars collectively. Advances in dosimetry measurement assurance would prevent facility shutdowns due to regulatory audits and would reduce product rejection, a benefit to the end-user. Moreover, both the industry and the consumer would benefit from development of new materials with properties amenable to radiation processing. These improvements would also facilitate transfer design of a new process to its production stage and replace cumbersome and impractical endpoint testing.

A national measurement quality assurance (MQA) program that takes advantage of existing dosimetry standards should be established to promote confidence and efficiency in the industry. A well-documented MQA program would improve marketability, trade potential, and public trust.

(b) Detailed Program Characteristics:

Gamma-radiation treatment that is both product-safe and cost-effective relies on delivering the required minimum dose while adhering to the product's maximum dose. These boundaries are validated by dose mapping and verified by dosimetry sampling techniques. Quality control for routine dosimetry is critical to efficient application of operational parameters (conveyor speeds, etc.) and ensures proper processing. In addition, health-care products, pharmaceuticals, and foods must meet regulatory requirements, especially with regard to dose uniformity within the product. The dose uniformity is influenced by material density and geometry, as well as product heterogeneity. These influences all contribute to complex processing issues such as edge and interface effects, and the presence of voids, composites, and metals.

Traceability to national standards is the centerpiece of an MQA program. This necessitates implementation of a reliable transfer system. Alanine dosimetry is a relatively new system expected to meet this need. Further development of this system as a transfer standard should be encouraged. Other dosimetry advances that would benefit the industry include: 1) miniaturization of dosimeters for interface measurements; 2) dosimeter materials which simulate the product; 3) interactive real-time on-line dosimetry probes; 4) the development of a label dosimetry system, suitable for calibration, that

enables accurate readout of a dosimeter while it remains attached to a surface; and 5) improved analytical techniques, including imaging.

There are a number of technological issues which arise when one considers the ability of product materials to tolerate the harsh environments encountered in radiation processing. A number of material properties (e.g., thermal, mechanical, electrical, optical) may be changed by the process. Unfortunately, immediate testing of radiation effects is not adequate. Latency effects on the order of 6 to 12 months are commonplace. Greater ties are needed between material design/testing and dosimetry. Another issue for different product materials is energy-dependence effects. The degraded spectrum of a ^{60}Co source and secondary scattering of photons and electrons should be considered in a combined theoretical and experimental study of materials effects.

(c) U.S. Facilities, Staffing, and Funding:

Some of the program characteristics described above relate to existing programs at NIST (imaging, transfer dosimetry, remote monitoring, source facilities) and Sandia National Laboratory (source design, materials effects).

Long-term research efforts in the development of new dosimeter materials/methods and the study of radiation effects on materials are necessary due to the complexity of the issues. Interactive dialog and coordinated research between government and industry would be the most efficient use of manpower. Due to the size of the project (approximately 50 person-years) it is recommended that a consortium be formed to coordinate the effort.

Finally, with regard to current industrial operations, a cooperative government-industrial effort could produce a fully-functioning MQA service within 2 years. This program would require staffing at the 3 person-year level and $1.5 M.

MPD D.3 *Gamma-Ray Dosimetry in Mixed Fields for Radiation Hardness Testing*

(a) Program Summary:

A number of applications require irradiations in neutron fields produced by ^{252}Cf or nuclear test reactors. These include radiation hardness testing of electronics both for military uses and for use in space and commercial radiation environments, testing of neutron detector systems for environmental and reactor monitoring, and radiation processing of silicon wafers for improving the response characteristics or lifetime of electronic devices. In all cases, a measurement of the photon radiation dose is needed independent of the neutron exposure.

High-absorbed-dose gamma-ray dosimetry is typically done using thermoluminescence dosimeters, radiochromic films or other dosimeters read by spectrophotometric analysis, electron-spin resonance spectroscopy, or various means of chemical dosimetry. These methods have been well-developed for radiation-processing irradiations with moderate to high photon energies such as those produced by radioactive isotopes or bremsstrahlung x-ray sources.

Unfortunately, procedures and standard methods for these dosimeters often specifically exclude their use in mixed fields. The difficulty arises from the fact that any material is sensitive to neutrons and that separating neutron effects from gamma-ray effects is not trivial. The problem is complicated further by inadequately determined photon and neutron spectra in the test environments. Thus, there is a need for a systematic characterization of neutron response functions for the various dosimeters used in mixed gamma/neutron environments, and procedures for use of these dosimeters that minimize the need for detailed information on the radiation environments.

(b) Detailed Program Characteristics:

Investigation of neutron response functions for dosimeters used in mixed gamma/neutron environments should be undertaken in several steps:

(i) Identification of the techniques and dosimeter configurations most widely used for measurements in mixed environments, so that efforts can be focused on a few representative configurations.

(ii) Detailed calculations of energy-dependent neutron response for each configuration, and identification of possible discriminators that can be used to separate gamma-ray and neutron responses.

(iii) Experimental verification of calculated response functions using well-characterized fields such as the NIST ^{252}Cf facility. A variety of neutron spectra should be used, including accelerator-produced neutron sources if possible.

(iv) Parameterization of neutron response for each dosimeter configuration in terms of equivalent gamma-ray absorbed dose.

(v) Development of procedures and/or standard methods for application of the dosimeter in mixed fields.

MPD D.4 *Neutron Dosimetry for Reactor Pressure Vessel Surveillance*

(a) Program Summary:

Reactor pressure vessel steels become increasingly brittle after many years of service, primarily because of neutron-induced atomic displacements. Reactor operators must monitor the changes in ductility of test specimens and the neutron spectral fluences at the locations of those test specimens and at key locations in and around the pressure vessel to assess the fracture toughness of the pressure vessel. A program of measurement assurance is essential to guarantee the integrity of this most critical reactor component.

Heavy-section steel testing programs, supported by both industry and government, are also of importance for pressure vessel surveillance by reactor operators. These programs improve the understanding of steel embrittlement under conditions of accelerated neutron exposure. They are carried out at test reactors whose neutron field characteristics can vary over wide ranges. Neutron fluence monitoring for these expensive, special-purpose irradiations has been largely unregulated and is seriously in need of measurement assurance.

A solid basis of experimental data will permit safe extension of operating license periods or insure timely retirement in the case of more heavily damaged plants, within safety margins that are in the best long-term interests of both the industry and the public.

(b) Detailed Program Characteristics:

Over the past fifteen years, neutron dosimetry for reactor pressure vessel surveillance has evolved from a loosely regulated procedure to a more tightly regulated one, with the appearance in September, 1993 of a Nuclear Regulatory Commission (NRC) *Draft Regulatory Guide, DG-1025.* This draft guide references many Standards which have been developed by the American Society for Testing and Materials (ASTM) during the past decade. The Regulatory Guide is expected to go into effect in 1995. The flexible provisions of this guide will probably be chosen as the method of NRC compliance by most reactor operators and their subcontractors in the U.S. The draft requires that industrial dosimetry methods be validated by periodic measurements in standard or reference neutron fields, such as the fission spectra at NIST and the Materials Dosimetry Reference Facility (MDRF), which is maintained jointly by NIST and the University of Michigan (U.M.). The analysis of the neutron dosimetry from the 108 operating reactors in the U.S. will be performed by approximately 15 industrial laboratories. These laboratories (not the individual reactor operators) will be the customers for periodic validation irradiations at the standard and reference neutron fields.

Certified fluence standards from irradiations in the standard and reference neutron fields will be shipped to participating laboratories for their derivation of fluence values by means of radiometric or track counting analyses. If the fluence derived by a participating laboratory agrees with the certified value within the experimental uncertainty, then that dosimetry system has been validated. If the results do not agree, then the counting techniques and the assay of the dosimetry material have to be re-examined. If after re-examination, a persistent bias is still present, the bias may be used as a detector calibration factor.

For dosimeters irradiated within an operating reactor vessel or in the cavity surrounding the vessel, the derived fluence value should be compared with a detailed calculation, made in accordance

with Section C.1. of DG-1025. If the calculation-to-experiment ratio (C/E) differs from unity by more than 20% in the case of in-vessel dosimeters or more than 30% for ex-vessel dosimeters, then both the measurement and calculation must be re-examined.

(c) U.S. Facilities, Staffing, and Funding:

The U.S. effort can be described in three parts:

(i) NIST maintains several standard and reference neutron fields of which four are employed for certified fluence irradiations related to reactor pressure vessel dosimetry: a thermal-neutron-induced ^{235}U fission-spectrum field, a ^{252}Cf spontaneous fission neutron field, the MDRF (in cooperation with U.M.), and well-thermalized neutron beams or cavity fields. NIST also maintains a supply of well-characterized activation dosimeters, a gamma ray spectroscopy system, and fission chambers for absolute fluence measurements. Approximately 3 person-years are committed to this program.

(ii) Power reactor operators and test reactor experimenters are responsible for irradiating suitable dosimetry packages and metallurgical specimens and obtaining appropriate calculations to establish reliable dose-toughness correlations and fluence exposure values for critical components. Estimated U.S. effort: 500 person-years.

(iii) Reactor materials dosimetry analysis at industrial metrology laboratories currently employs about 50 person-years, for all of the U.S., but the size of this effort could grow with adoption of the NRC Regulatory Guide.

Summary of Roles Proposed for CIRMS

One of the principal functions of CIRMS is to "provide a forum for the discussion of common national ionizing radiation measurement and standards issues, and for the promotion of cooperation and communication among people interested in ionizing radiation measurement". CIRMS is uniquely suited for this role because of the wide range of interests represented by its members and participants. No other national organization brings together the diverse interests that exist in the ionizing radiation measurement community. Cooperation among the various concerned parties is essential for efficient and effective response to identified measurement needs. For a single case where a measurement need has been identified, the concerned parties may well include manufacturers, regulators, radiation users, measurement support laboratories, national societies, and the public.

The coordinating role that CIRMS could play in solving a particular measurement need was identified in several of the MPDs contained in this report. A general need for coordination was expressed in the introduction to the environmental/public radiation protection MPDs, where it was stated that "it is essential that CIRMS examine and coordinate solutions to some of the measurement problems that involve, particularly, the use of primary and secondary radioactive sources in the form of point sources of alpha, beta, and gamma rays as well as large area sources of similar radioactive standards". The area of interest referred to by this statement is the cleanup of environmental contamination at nuclear facilities.

Another area where coordination by CIRMS was recommended is occupational radiation protection. This particular area has benefitted from coordination provided in the past by an interagency policy committee which oversaw development of the current NVLAP program for personnel dosimetry, and by the NIST Office of Radiation Measurement which coordinated development of MQA programs for secondary calibration laboratories in the state, private, and federal sectors. MPD C.5 recommends that the CIRMS Occupational Radiation Protection Subcommittee coordinate adoption of ISO Guide 25 by the four existing programs that accredit calibration laboratories. MPD C.6 recommends that this same subcommittee study the feasibility of intercomparisons in lieu of proficiency tests, and coordinate implementation of this alternative method if it is found to be feasible. MPD C.7 recommends that CIRMS form a representative committee to identify specific requirements and develop criteria needed to establish radiation standards not directly supported by NIST.

These recommendations for coordination by CIRMS should be considered for adoption and implementation by the appropriate subcommittees of the Science and Technology Committee.

Conclusions

Several important conclusions are supported by this study of physical measurement and standards needs in ionizing radiation.

1. The need for physical measurement and standards has grown significantly in recent years because of substantially increased applications of ionizing radiation for public benefit, and the increased concern for public safety and health. Increased applications have resulted from the many unique benefits provided by ionizing radiations. Increased concern about safety and health has resulted primarily from the discovery of radioactive contamination in or near nuclear facilities.

2. The physical measurement and standards needs resulting from increased radiation applications and increased concern about radiation protection represent a significant expansion of measurement parameters. New applications and concerns have not replaced those that already existed. Instead, the new needs for measurement and standards have been added to the previously existing needs. New types of radiation are being used, higher and lower radiation energies must be measured more accurately (e.g., mammography and radiation therapy), lower levels of radiation must be measured (e.g., environmental cleanup), and higher doses must also be known with more accuracy (e.g., radiation processing). Many more examples of measurement parameter expansion are described in the various MPDs.

3. The status of physical measurements and standards has not improved sufficiently to meet the growing needs. Such measurements and standards are urgently in need of an expanded material effort not only at NIST but at cooperating medical, industrial, and federal facilities in the U.S.

The status of the field can be exemplified by the following quotations from this report:

a. Mammography (MPD A.1) -- "One problem in calibrating instruments used to measure the air-kerma rate from mammographic units is that the National Institute of Standards and Technology (NIST) presently does not yet have a national standard for those mammographic beams. In fact, the only national standards laboratory in the world having appropriate national standards is Physikalisch-Technische Bundesanstalt (PTB), the German standards laboratory."

b. Electron-Beam Processing (MPD D.1) -- "Absorbed doses must be measured accurately in suitable materials and products in order to control the irradiation processes. In order to meet this objective, the calibration procedures must be appropriate for the accelerators being used for particular applications. The diversity of electron accelerator types presents practical problems for the users in obtaining accurate dosimeter calibration services. It may be impracticable for any calibration laboratory to be equipped with all types of accelerators that may be used for these purposes. Still, the need exists for electron-beam calibration services that are known to be appropriate for each situation."

c. Waste Management (MPD B.3) -- "The current supply of environmental-level soil standard reference materials (SRMs), primarily from NIST, EML, and the IAEA, is adequate for the environmental monitoring and some of the environmental restoration work. However, new SRMs are needed that are specific to the types of radiochemical analyses, such as direct counting and for digestion prior to counting. SRMs developed for direct counting may not be adequate for uses where the sample is either totally or partially digested and purified before counting. In addition, SRMs based upon soil types found in the eastern part of the U.S. are not applicable to the southwest... Also,

few, if any, reference materials are available for the DOE waste form types. Water standard needs are similar to the soil standard needs."

d. Personnel Monitors (MPD C.1) -- "The unique filtered beams at the NIST Reactor have fallen into disuse, largely for lack of support, as have the monoenergetic neutron beams from the NIST 3 MeV Van de Graaff generator. It is, therefore, now necessary to use the facilities at the national standards laboratories in Germany (PTB) or England (NPL) to determine a dosimeter energy response function."

Some of the problems in the field have resulted from cutbacks of measurement and standards support programs at NIST during the period when national needs for such support were increasing. In 1974, the Ionizing Radiation Division (then called the Center for Radiation Research) had a staff of 120 persons with a vast array of ionizing radiation facilities (including 11 different radiation sources) at their disposal. The staff is now 50 persons with some of the 1960s-vintage sources being inoperable and many of them being inadequate to satisfy new needs. It is essential that the preeminence of the NIST staff and facilities be reestablished, and that the coupling of NIST programs with a strong program of Secondary Calibration Laboratories (SCLs) be adequately supported. Such an SCL program and coupling was outlined in the important 1981 report entitled Requirements for an Effective National Ionizing Radiation Measurements Program (NBS Special Publication 603).

4. CIRMS can play an important role in coordinating some of the activities that must be conducted to improve the status of measurements and standards. Although it is a new organization and has no history of playing such a role, CIRMS provides a unique opportunity for the coordination of varied interests. It is expected that such coordination would result in appreciably improved efficiency and effectiveness of programs implemented to satisfy national measurement and standards needs.

In addition to the conclusions described above, it is important to recognize that increasingly sophisticated computer models have become an invaluable tool in almost every aspect of radiation measurements and physical interactions. These codes, such as the general radiation transport code, MCNP, provide the ability to optimize geometry and response without expensive and time-consuming iterative laboratory measurements. The widespread applicability of these techniques crosses into each of the four general areas in this report and affects most of the MPDs described. Although most of the codes currently receive adequate support, the majority of the support has come historically through weapons programs whose funding is currently undergoing constant realignment. CIRMS recognizes the continuing need for these programs and encourages appropriate action be taken to transfer funding responsibility to more suitable and stable sources.

Appendix A - Acronyms Used in This Report

The acronyms used in this report are as follows:

AAPM - American Association of Physicists in Medicine
ADCL - Accredited Dosimetry Calibration Laboratory
AECL - Atomic Energy of Canada Limited
ALARA - As Low As Reasonably Achievable
ANSI - American National Standards Institute
ASTM - American Society for Testing and Materials
BOMAB - Bottel Manikin Absorption (Phantom)
BRMD - Bureau of Radiation and Medical Devices
CCD - Charge Coupled Device
CDRH - Center for Devices and Radiological Health
CEC - Commission of the European Communities
CERN - Centre European de Recherche Nucleaire
CIRMS - Council on Ionizing Radiation Measurements and Standards
CRADA - Cooperative Research and Development Agreement
CRCPD - Conference of Radiation Control Program Directors
DOD - Department of Defense
DOE - Department of Energy
DOELAP - Department of Energy Laboratory Accreditation Program
EML - Environmental Measurements Laboratory
EPA - Environmental Protection Agency
FDA - Food and Drug Administration
FEMA - Federal Emergency Management Agency
GAO - General Accounting Office
GCRS - Ground Contamination Removal Systems
HPS - Health Physics Society
HPSSC - Health Physics Society Standards Committee
IAEA - International Atomic Energy Agency
ICRU - International Commission on Radiation Units and Measurements
INEL - Idaho National Engineering Laboratory
ISO - International Organization for Standardization
LANL - Los Alamos National Laboratory
LED - Light-Emitting Diode
LLNL - Lawrence Livermore National Laboratory
MIRF - Medical-Industrial Radiation Facility
MPD - Measurement Program Description
MQA - Measurement Quality Assurance
MQSA - Mammography Quality Standards Act
MRI - Magnetic Resonance Imaging
NDA - Nondestructive Analysis
NEI - Nuclear Energy Institute
NIST - National Institute of Standards and Technology
NMS - Natural Matrix Standard
NPL - National Physical Laboratory (U.K.)

NRC - Nuclear Regulatory Commission
NRC-Ottawa - National Research Council
NSWC - Naval Surface Weapons Center
NVLAP - National Voluntary Laboratory Accreditation Program
ORNL - Oak Ridge National Laboratory
PE - Performance Evaluation
PET - Positron Emission Tomography
PMMA - Polymethyl methacrylate
PNL - Pacific Northwest Laboratory
PPT - Part per trillion
PTB - Physikalisch-Technische Bundesanstalt (Germany)
RESL - Radiological and Environmental Sciences Laboratory
RIMS - Resonance Ionization Mass Spectrometry
SPECT - Single Photon Emission Computed Tomography
SRM - Standard Reference Material
TLD - Thermoluminescent Dosimeter
TWRS - Tank Waste Remediation Systems
UV - Ultraviolet
VA - Veterans Administration
WIPP - Waste Isolation Pilot Plant

Appendix B - Format of a Measurement Program Description (MPD)

The format for an MPD that was the basis of work by Committee members is as follows:

MEASUREMENT PROGRAM DESCRIPTION

Title (Measurement-Related Need for a Radiation-Related Area of Concern)

Example: National Air-Kerma Standards for Mammography

(a) Program Summary

Statement of measurement-related need
Brief statement of physical-measurement solution
Impact on science, industry, people of providing a physical-measurement solution to the problem

(b) Detailed Program Characteristics

Technical description of solution, including technical opportunities, challenges
Relationship to existing programs
Goals
Expected completion dates

(c) Summary of Measurements Needed

Types
U.S. facilities, staffing, and funding