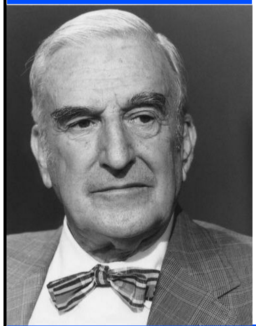


**Fiftieth**
**Annual Meeting Program**

# NCRP: Achievements of the Past 50 Years and Addressing the Needs of the Future

**March 10–11, 2014**

Hyatt Regency Bethesda
One Bethesda Metro Center
7400 Wisconsin Avenue
Bethesda, MD 20814

NCRP
National Council on Radiation Protection & Measurements

**Front cover: Past and current Presidents of NCRP [top to bottom]:**

Lauriston S. Taylor, 1929 – 1977
Warren K. Sinclair, 1977 – 1991
Charles B. Meinhold, 1991 – 2002
Thomas S. Tenforde, 2002 – 2012
John D. Boice, Jr., 2012 –

# NCRP Mission:

To support radiation protection by providing independent scientific analysis, information and recommendations that represent the consensus of leading scientists.

# Introduction

## *NCRP: Achievements of the Past 50 Years and Addressing the Needs of the Future*

### Fiftieth Annual Meeting of the National Council on Radiation Protection and Measurements (NCRP)

The program will celebrate the 50th year since our Congressional charter in 1964. Notable contributions to radiation protection policies and programs will be recalled, but the speakers will focus primarily on important challenges and opportunities to address the needs of the nation for the future. Presentations will be given by leading experts in each of the seven areas of protection to be covered with ample opportunities to ask questions verbally or textually.

- Session one addresses basic radiation protection criteria, epidemiology, radiobiology and risk. It includes presentations on integrating basic radiobiological science and epidemiological studies, challenges for radiation protection in space exploration, and the biological effectiveness of x and gamma rays as a function of energy.
- Session two covers nuclear and radiological security and safety concerns. The challenges facing an appropriate medical response to terrorist events involving improvised nuclear or radiological dispersal devices will be presented. After the emergency crisis has ended and the first responders have left, decision making for late-phase recovery following a nuclear incident with widespread radioactive contamination will be discussed.
- Session three explores both current and emerging issues in operational and environmental radiation protection. Specific topics include radiation safety and security of sealed sources (and how to protect the cowboys in the field), radiation safety associated with technologically-enhanced naturally-occurring radioactive material in the oil and gas industry (with a focus on fracking), and radiation safety in the burgeoning area of research and applications in nanotechnology.
- Session four focuses on radiation measurement and dosimetry. The first presentation emphasizes the continuing need for dosimetry and measurements in radiation protection. This will be followed by a presentation of the complex dosimetry needs and practical approaches being applied to the ongoing epidemiologic study of one million U.S. radiation workers and veterans.
- Session five opens with possibly the most important issue in radiation protection today and in medicine in particular (*i.e.*, the protection for patients in diagnostic and interventional medical imaging). Following are presentations on protection of patients in radiation therapy and radiation protection of the developing embryo, fetus, and nursing infant.
- Session six covers the topics of radiation education, risk communication, outreach, and policy.
- Two concluding presentations address historical trends in radiation protection, policy and communications from 1964 to the present and the role played by national and international organizations in guiding and influencing U.S. radiation protection standards and regulations.

In addition, there will be two featured speakers: Dr. Jerrold T. Bushberg the Warren K. Sinclair Keynote Speaker and Dr. Fred A. Mettler, Jr. is the Lauriston S. Taylor Lecturer.

Program Chair and NCRP Honorary Vice President, Kenneth R. Kase, will synthesize and summarize the diverse topics covered, and will expand on the opportunities and challenges in science, operations, and communications faced as we strive to address the needs of the nation in the 21st century.

NCRP President, John D. Boice, Jr., will close the 2014 Annual Meeting by briefly summarizing NCRP's perspective on future needs in radiation protection and mission obligations in accordance with our Congressional charter.

# Monday, March 10, 2014

## Opening Session

8:15 am **Welcome**
John D. Boice, Jr.
*President, NCRP*

## Eleventh Annual Warren K. Sinclair Keynote Address

8:30 am **Science, Radiation Protection, and the NCRP: Building on the Past, Looking to the Future**
Jerrold T. Bushberg
*University of California, Davis*

## Basic Criteria, Epidemiology, Radiobiology, and Risk (PAC 1)

Kathryn D. Held, *Session Chair*

9:15 am **Integrating Basic Radiobiological Science and Epidemiological Studies (Why and How?)**
R. Julian Preston
*U.S. Environmental Protection Agency*

9:40 am **Radiation Safety and Human Spaceflight: Importance of the NCRP Advisory Role in Protecting Against Large Uncertainties**
Francis A. Cucinotta
*University of Nevada Las Vegas*

10:05 am **Biological Effectiveness of Photons and Electrons as a Function of Energy**
Steven L. Simon
*National Cancer Institute*

10:30 am **Q&A**

10:50 am **Break**

## Nuclear and Radiological Security and Safety (PAC 3 & 5)

John W. Poston, Sr. & Jill A. Lipoti,
*Session Co-Chairs*

11:10 am **Response to an Improvised Nuclear Device or a Radiological Dispersal Device: Models, Measurements, and Medical Care**
C. Norman Coleman
*National Cancer Institute*

11:35 am **Decision Making for Late-Phase Recovery from Nuclear or Radiological Incidents (What's Next After the First Responders Have Left?)**
S.Y. Chen
*Illinois Institute of Technology*

12:00 pm **Q&A**

12:15 pm **Lunch**

## Operational and Environmental Radiation Protection (PAC 2 & 5)

Carol D. Berger & Ruth E. McBurney,
*Session Co-Chairs*

1:45 pm **Radiation Safety of Sealed Radioactive Sources**
Kathryn H. Pryor
*Pacific Northwest National Laboratory*

2:10 pm **Pennsylvania's Technologically-Enhanced Naturally-Occurring Radioactive Material Experiences and Studies of the Oil and Gas Industry**
David J. Allard
*Pennsylvania Department of Environmental Protection*

2:35 pm **Radiation Safety in Nanotechnology (Does Size Matter?)**
Mark D. Hoover
*National Institute for Occupational Safety and Health*

3:00 pm **Q&A**

## Radiation Measurement and Dosimetry (PAC 6)

Wesley E. Bolch, *Session Chair*

3:20 pm **Framework and Need for Dosimetry and Measurements: Quantitation Matters**
Raymond A. Guilmette
*Lovelace Respiratory Research Institute*

3:45 pm **Dose Reconstruction for the Million Worker Epidemiological Study**
Andre Bouville
*National Cancer Institute*

4:10 pm **Q&A**

4:25 pm **Break**

## Thirty-Eighth Lauriston S. Taylor Lecture on Radiation Protection and Measurements

5:00 pm **Introduction of the Lecturer**
Milton J. Guiberteau

**On the Shoulders of Giants: Radiation Protection Over 50 Years**
Fred A. Mettler, Jr.
*New Mexico Federal Regional Medical Center*

6:00 pm **Reception in Honor of the Lecturer**
Sponsored by Landauer, Inc.

# *Tuesday, March 11*

8:15 am **NCRP Annual Business Meeting**

9:15 am **Break**

## Radiation Protection in Medicine (PAC 4)

Donald L. Miller, *Session Chair*

9:45 am **Protection of Patients in Diagnostic and Interventional Medical Imaging**
Kimberly E. Applegate
*Emory University School of Medicine*

10:10 am **Protection and Measurement in Radiation Therapy**
Steven G. Sutlief
*University of Washington Medical Center*

10:35 am **Protection of the Developing Embryo and Fetus from Ionizing Radiation Exposure**
Robert L. Brent
*Alfred I. duPont Institute Hospital for Children*

11:00 am **Q&A**

## Radiation Education, Risk Communication, Outreach, and Policy (PAC 7)

Julie E.K. Timins, *Session Chair*

11:20 am **Historical Trends in Radiation Protection, Policy and Communications: 1964 to the Present**
Paul A. Locke
*The Johns Hopkins University Bloomberg School of Public Health*

11:45 am **U.S. Radiation Protection: Role of National and International Advisory Organizations and Opportunities for Collaboration (Harmony not Dissonance)**
Michael A. Boyd
*U.S. Environmental Protection Agency*

12:10 am **Q&A**

## Summary: NCRP for the Future

John D. Boice, Jr., *Session Chair*

12:25 pm **Capturing Opportunities and Meeting Challenges in Radiation Protection**
Kenneth R. Kase
*Honorary Vice President, NCRP*

12:50 pm **Closing Remarks**
John D. Boice, Jr.
*President, NCRP*

1:00 pm **Adjourn**

# Monday, March 10, 2013

## Opening Session

8:15 am

**Welcome**
John D. Boice, Jr., *President*
*National Council on Radiation Protection and Measurements*

## Eleventh Annual Warren K. Sinclair Keynote Address

8:30 am

**Science, Radiation Protection, and the NCRP: Building on the Past, Looking to the Future**
Jerrold T. Bushberg
*University of California, Davis*
*School of Medicine*

This year, NCRP celebrates 50 y of service to the Nation and the radiation protection community under its Congressional charter signed into law in 1964. However, the history of NCRP and its predecessor organizations date back to 1929, 34 y after the discovery of x rays and radioactivity. While the technology transfer that led to beneficial applications of these discoveries was likely one of the most rapid and profound in modern history, the development of consensus based safety standards to protect against the adverse effects of radiation (which were all too apparent to the many early radiation pioneers) was more gradual. Some members of the international community of scientists working with these sources were keenly interested in advancing and communicating proper radiation protection principles and practices. What would become NCRP was originally established in 1929 as the U.S. Advisory Committee on X-Ray and Radium Protection whose mission was to provide a U.S. consensus of scientific opinion on radiation protection matters to the newly formed International X-Ray and Radium Protection Committee, the predecessor of the International Commission on Radiological Protection (ICRP). Dr. Lauriston S. Taylor chaired the Advisory Committee and served as the first official U.S. representative to ICRP. After World War II, development and utilization of new radiation technology in medicine and industry accelerated rapidly. In 1946 membership of the Committee was enlarged and its scope broadened to assure their activities would remain relevant. With these and other changes the Committee was renamed the National Committee on Radiation Protection (NCRP). In 1959, President Eisenhower issued an executive order establishing the Federal Radiation Council (FRC) to provide regulatory guidance on radiation protection at a national level. In recognition of NCRP's role in providing scientific advice and guidance on radiation protection policies and practices to FRC and others federal agencies, Congress chartered the NCRP in 1964 (Public Law 88-376) as "The National Council on Radiation Protection and Measurements" an independent, nonprofit organization to provide scientific guidance on radiation protection. Key elements of the NCRP charter include responsibilities to: (1) collect, analyze, develop, and disseminate in the public interest information and recommendations about radiation protection, measurements, quantities and units; (2) provide a means by which other scientific organizations with related interest and concerns may cooperate for effective utilization of their combined resources; (3) develop basic concepts about radiation quantities, units, and measurements and their application to radiation protection; and (4) cooperate with the ICRP and other international and national organizations. A set of bylaws was developed that included the election of a President and other officers of the corporation, 75 members of Council (later increased to 100 in 1997) comprised of scientific experts in a broad range of disciplines with relevance to radiation protection, and a Board of Directors. Since the establishment of its Congressional charter, NCRP has had five productive decades as evidenced by the publication of 174 reports and 90 other documents, including commentaries, statements, and conference proceedings (57 of these documents were published in the last 10 y). In addition, many of the current U.S. radiation protection standards can trace their origin to recommendations made in these NCRP publications (*e.g.*, Report No. 116). Together, these reports have provided guidance and recommendations on a broad array of topics relevant to the science of radiation protection.

The majority of the work of NCRP is accomplished through its scientific committees (SC). The SCs are organized under program area committees (PACs) or advisory committees which help identify important radiation protection issues and topics for which a report by a SC composed of relevant subject matter experts would be of value. These committees include (PAC 1) Basic Criteria, Epidemiology, Radiobiology, and Risk, (PAC 2) Operational Radiation Safety, (PAC 3) Nuclear and Radiological Security and Safety, (PAC 4) Radiation Protection in Medicine, (PAC 5) Environmental Radiation and Radioactive Waste Issues, (PAC 6) Radiation Measurements and Dosimetry, the recent (PAC 7) Radiation Education, Risk Communication, Outreach, and Policy, and an Advisory Panel on Nonionizing Radiation. Some NCRP reports have provided the basis for much needed change in the use of radiation sources. For example, NCRP Report No. 160 (2009) updated one of NCRP's most cited publications which details the doses to the U.S. population from all sources of ionizing radiation with particular attention to those sources that contribute the largest shares to the public and the radiation worker. This Report revealed that the most significant increase in the average per capita annual dose to the U.S. population in the last 30 y was due to the increased availability and use of radiation in medicine (primarily computed tomography and cardiovascular nuclear medicine). While many lives have been saved by advancements in imaging technology, it is clear that this is now the single most controllable source of radiation exposure in the United States and that continued improvement in justification and optimization are important to keep these exposures *as low as diagnostically acceptable* (ALADA). ALADA is proposed as a variation of the acronym ALARA (as low as reasonably achievable) to emphasize the importance of optimization in medical imaging.

Using the lessons from the past to help guide our future, NCRP has embarked on a number of initiatives (both scientific and operational) to assure Council and staff will be well prepared to continue its exemplary service to the Nation. Examples of operational initiatives include:

- improvements in NCRP's utilization of the expertise of Council members;
- modifications to our committee structure to improve efficiency and allow for greater cross-discipline communications;

- enhancements to our web presence and the use of social media to keep up with trends in information access;
- collaborate with other organizations to encourage young scientists to become engaged in professional development of scientific disciplines related to radiation protection;
- developing a deeper understanding of the radiation protection challenges faced by NCRP's federal agency sponsors; reviewing current radiation protection guidance for the United States;
- closer coordination with our national and international partners; and
- rightsizing and timely preparation of reports and streamlining the Council report review process.

Council members and any other interested parties are encouraged to contact NCRP leadership with any suggestions for improving NCRP's ability to fulfill its mission.

NCRP has recently broadened its scope to respond to some of the pressing needs of today's radiation protection environment. NCRP's role in the WARP initiative (Where are the Radiation Professionals: A National Crisis?) to help address the rapidly diminishing workforce of radiation professionals and NCRP's engagement in epidemiological research to extend our knowledge of the potential health effects of low dose radiation by way of the Million Worker Study are just a few of such visionary activities.

While many advances have been made, there are still many questions of importance to radiation protection that have not been fully resolved despite years (sometimes decades) of effort. NCRP will play an important role in helping to develop a consensus view regarding complex issues such as:

- estimating and effectively communicating the health risk from "low dose" radiation;
- implications of nontargeted effects, the concerns about sensitive subpopulations;
- biological effectiveness of low energy photons;
- challenges of applying justification and optimization in diverse environments such as medical imaging and environmental remediation of contaminated sites;
- long-term storage and monitoring of high level radioactive waste
- practical considerations and benefits from harmonization of units and dose limits;
- risks of space travel;
- implications of nanotechnology in radiation safety; and
- many others that will no doubt extend far into the 21st century.

These uncertainties will continue to influence the cost and benefits derived from the ever expanding use of radiation in everything from medical imaging and cancer treatment to manufacturing and homeland security. There will be a continuing need for NCRP to identify the principles upon which radiation protection is to be based and to provide guidance on best practices for the practical application of those principles for the many beneficial uses of radiation in society. The unique and invaluable resource that is NCRP is in large part due to the selfless dedication and numerous contributions of its Council and SC members. The multidisciplinary composition of these leading experts' and their collective input on complex questions provides a unique synergy that result in a comprehensive and well balanced approach to addressing current and future radiation protection challenges. Subsequent presentations covering a broad range of relevant topics will review sentinel accomplishments of the past as well as current work and future challenges that are in keeping with NCRP's mission to advance the science of radiation protection in the public interest.

# Basic Criteria, Epidemiology, Radiobiology, and Risk (PAC 1)

Kathryn D. Held, *Session Chair*

9:15 am

**Integrating Basic Radiobiological Science and Epidemiological Studies (Why and How?)**

R. Julian Preston
*U.S. Environmental Protection Agency*

On the one hand, there is a quite extensive set of epidemiology studies conducted for a range of different exposure scenarios and in some cases at doses that can be considered to be in the low dose range (<100 mGy). There are uncertainties associated with these studies, for example with the dosimetry, potential confounding factors, and models used for extrapolation to effects at environmental doses and for chronic exposures. On the other hand, there is extensive literature on the effects of radiation at the animal and cellular levels. In addition, there is an expanding knowledge of the underlying mechanisms of disease formation (both cancer and noncancer). Here also there are uncertainties associated with the ability to extrapolate from these studies to predict adverse health outcomes in radiation-exposed human populations. A significant concern is that these two areas of study have rarely been linked to support each other — to enhance low dose/low dose-rate extrapolation and reduction of uncertainty in risk estimates. A significant reason for this is that basic radiobiology research generally has not been designed to support the risk assessment process but rather it is used *post facto* in an attempt to provide such support. In general, this is not a very satisfactory approach. It is proposed that there be an area of research that uses experimental designs that would provide specific types of data to support the epidemiology and thereby would enhance the radiation risk assessment process.

Such an approach is one that can be adapted from that used for chemical exposures and that was developed largely because there are very few epidemiological data available especially at environmental exposure levels and for which risk assessment is required by the U.S. Environmental Protection Agency, for example. The approach is based on the concept of adverse outcome pathways (AOP) for the formation of adverse health outcomes. The AOP conceptual framework is considered to be a logical sequence of events (so called key events) or processes within biological systems which can be used to understand adverse effects and refine the current risk assessment practice. This approach shifts the risk assessment focus from traditional apical endpoints (*e.g.*, cancer and cardiovascular disease) to the development of a mechanistic understanding of a chemical's effect at a molecular and cellular level for potentially predicting disease outcome, at a qualitative and quantitative level. This approach has been developed into one whereby key events can be used to describe low-dose responses for induced cancer — the Key Events Dose Response Framework (KEDRF). In addition, more recent efforts are designed to provide quantitative predictions of low-dose response in a Q-KEDRF approach. This general approach can be applied also to the estimation of radiation-induced cancer at low doses and dose rates based on the current knowledge of key events for the development of these cancers. It is also possible that a similar approach could also be used for noncancer effects.

The need for developing such a key event-based approach for risk estimation is to further knowledge of the key events in radiation-induced carcinogenesis and to provide information on the dose response for these. It is proposed that the key-event approach be used in conjunction with enhanced radiation epidemiology data to reduce overall uncertainty in low dose/low-dose rate cancer and noncancer risk estimates.

9:40 am

**Radiation Safety and Human Spaceflight: Importance of the NCRP Advisory Role in Protecting Against Large Uncertainties**

Francis A. Cucinotta
*University of Nevada Las Vegas*

Long-duration space missions present unique challenges for radiation safety due to the complexity of the space radiation environment, which includes high charge and energy (HZE) particles and other high linear energy transfer (LET) radiation such as neutrons, the nature of space missions, and the distinct characteristics of astronauts compared to ground-based radiation workers. For 25 y NCRP has provided important guidance to the National Aeronautics and Space Administration (NASA) on radiation safety. NASA reviews past NCRP recommendations, how these recommendations have been implemented, and the major challenges for the future where the role of NCRP should continue to be pivotal to the success of NASA's goals for space exploration. Recommendations by NCRP have guided NASA in the development of a risk-based system for radiation protection that limits individual occupational radiation exposures to a lifetime 3 % fatality risk. Based on NCRP recommendations, NASA has implemented gender and age-at-exposure specific dose to risk conversion factors as the basis for radiation limits. Because of the much higher exposure of astronauts compared to ground-based workers, this approach places the risk estimates rather than dose as the primary quantity in safety programs. Methods have been developed to estimate uncertainties in risk estimates and the 95 % confidence level applied to the limiting risk due to the large uncertainties in estimating cancer risks from HZE particles. NASA also reviews NCRP recommendations related to spaceflight dosimetry, acceptable risk, and goals for research in space radiobiology.

More than 50 y after the initial missions into low-Earth orbit, spaceflight may seem routine. However in reality space exploration is in its infancy with the most important goals to be realized in the future. Similarly how to protect individuals from long-term space exposures remains a primary challenge for space flight and one where new knowledge is needed to enable missions. Similar to occupational safety on Earth which has improved over recent decades, spaceflight safety has improved with NASA now projecting <1 in 270 probability of loss of crew (LOC) for current spaceflights. In 2010 the NASA Aerospace Safety Advisory Panel recommended that <1 in 750 LOC risk is achievable through smart technology investments. Such improvements in other areas of safety should inspire NASA to maintain the 1 in 33 fatality limit for space radiation exposures that was recommended by NCRP in 1989. However to achieve exploration goals for Mars and farther destinations within acceptable radiation risks will require new knowledge to significantly reduce the uncertainties in estimates of cancer risks and to address emerging issues for noncancer risks. In-flight and late effects to the central nervous system are an emerging area of critical importance based on ground-based experiments at particle accelerators simulating space radiation. Qualitative differences in the biological effects of HZE particles compared to terrestrial radiation remains the largest uncertainty and hinders the development of effective countermeasures. This presentation will highlight the major challenges in these areas and likely roles for NCRP guidance in helping NASA prepare for the future.

10:05 am

**Biological Effectiveness of Photons and Electrons as a Function of Energy**

Steven L. Simon
*National Cancer Institute*

An unresolved question in evaluating the risk of cancer in humans from exposure to low linear-energy transfer (LET) radiation (*i.e.*, photons and electrons) is the dependence of the biological effectiveness on energy. This dependence is relevant for estimating risks of cancer from exposure to low-LET radiation at the lower energies used in mammography as well as certain sources of occupational and public exposure. Because of the broad importance of this topic to the basic responsibilities and interests of NCRP, the Council created a scientific committee (SC 1-20) to evaluate this question. Other expert groups and investigators have also considered this question, and several have concluded that the biological effectiveness of lower-energy low-LET radiation based on radiobiologic data and biophysical considerations may be two or more times greater than for higher-energy low-LET radiation. However, biological systems used in the experiments and biophysical analysis provide only indirect evidence and may not be strictly applicable to cancer in humans, particularly considering that there are many types of cancer. Epidemiologic studies that, in theory, could demonstrate that lower-energy photons and electrons are biologically more effective than high-energy photons are inherently difficult to conduct when very large study populations and highly accurate estimates of cancer risks are required to observe a presumably small effect. Because of the enormous complexity of the phenomena that are involved in the development of cancer following exposure to ionizing radiation, it is unlikely that any single area of study can provide a clear understanding of the relative biological effectiveness of different energy radiations. For these various reasons, an important aspect of the evaluation by SC 1-20 is the combined assessment of multiple lines of evidence and their related uncertainties. SC 1-20 is basing its analysis on five different lines of evidence:

- microdosimetric calculations;
- studies of damage to DNA, including theory, calculations, and experimental data;
- radiobiologic studies in cellular systems;
- radiobiologic studies in animal systems; and
- human epidemiologic studies.

Accordingly, the Committee has developed a means of assessing a probability density function (PDF) of the biological effectiveness for selected energies (photons of energy ~1.5 keV, ~15 to 30 keV, ~40 to 60 keV, ~50 to 150 keV, and the spectrum of electrons produced in beta decay of tritium) using all available information from the different lines of evidence. Methods for this purpose have been drawn from the field of probability assessment that utilizes the elicitation of expert input and the synthesis of data from multiple sources of information *via* Bayesian analysis. In this context, the PDF is intended to represent the current state-of-knowledge about the relative biological effectiveness of the specified low-LET radiations. While the most recent publications in radiation research will provide SC 1-20 with only very limited data that previous expert groups and other investigators did not evaluate, the derivation of a composite PDF based on multiple lines of evidence may provide a unique contribution that can be used to assess the uncertainty in estimates of radiation-related cancer risk. This presentation will summarize the current status of the analysis by SC 1-20.

10:30 am **Q&A**

10:50 am **Break**

## Nuclear and Radiological Security and Safety (PAC 3 & 5)

John W. Poston, Sr. & Jill A. Lipoti, *Session Co-Chairs*

11:10 am

**Response to an Improvised Nuclear Device or a Radiological Dispersal Device: Models, Measurements, and Medical Care**

C. Norman Coleman
*National Cancer Institute*

Prior to September 11, 2001, largely because of the ending of the Cold War, there was limited attention given to preparedness for a nuclear detonation or large-sized radiation incident other than ongoing programs related to nuclear power plants. To address potential threats, the U.S. government developed 15 National Planning Scenarios of which No. 1 was a 10 kt nuclear detonation and No. 11 a radiological dispersal device.

The U.S. health and medical response is under Emergency Support Function No. 8 with the U.S. Department of Health and Human Services as the lead agency in collaboration with interagency partners. Four key aspects of the planning have been:

- building on the best possible science;
- developing research and development programs (mostly through the National Institute of Allergy and Infectious Diseases, the Biomedical Advanced Research and Development Authority, and the U.S. Department of Defense);
- publishing in the peer review literature; and
- making the information understandable and usable for responders who may not have sophisticated training in the radiation sciences.

The knowledge and expertise needed ranges from radiation physics, physical models of detonations, radiation normal tissue injury, medical countermeasure development, mass casualty planning, triage/scarce resource allocation, radiation epidemiology, information management and technology and emergency management. In the aggregate, what we call "REMS" (Radiation Emergency Management System) has been developed which is a complex system that is continuously evaluated and improved.

Health and medical planning and response for radiological and nuclear incidents have been helped by contributions from NCRP. Indeed, both the research and service missions of the federal agencies have expanded, providing new opportunities for investigation and implementation by government, academia, and the private sector. Furthermore, international collaborations have been strengthened and there have been spin-offs that could benefit cancer treatment. This presentation will review how the REMS approach was developed and how it is continuing to evolve. The radiation teams were involved in responding to the disaster in Japan in 2011, the experience from which has lead to the proposal of a "Medical Decision Model" for effectively managing rapidly evolving radiological and nuclear incidents. Newer issues for consideration are estimating and potentially mitigating risk from radiation-induced cancer and developing a comprehensive "National Concept of Operations."

11:35 am

**Decision Making for Late-Phase Recovery from Nuclear or Radiological Incidents (What's Next After the First Responders Have Left?)**

S.Y. Chen
*Illinois Institute of Technology*

In the United States, effort on radiological emergency preparedness has focused primarily on initial responses to an incident; the guidance on the more complex, long-term issues relating to the late-phase recovery has been lacking. It is clear from the recent major accidents at Chernobyl (Ukraine 1986) and Fukushima (Japan 2011) nuclear power plants that the magnitude of the radiological impact can affect extended areas and last for many years, thus making planning for recovery a necessary component to the overall response. Similar challenges likewise may be encountered in the illicit incidents involving the use of radioactive or nuclear material such as those could be posed by a radiological dispersal device (RDD) or improvised nuclear device (IND). In 2010 NCRP established a scientific committee (SC 5-1) to prepare a comprehensive study that establishes the framework of and recommends an approach to optimizing decision making in late-phase recovery from major nuclear or radiological incidents. The study, to be published as NCRP Report No. 175, addresses all relevant dimensions in all aspects of long-term recovery: health, environmental, economic, psychological, cultural, ethical, and socio-political. Consistent with the recommendations by the International Commission on Radiological Protection, NCRP considers optimization to be the fundamental approach to decision making in late-phase recovery for balancing the multiple factors in situations involving wide-area contamination. The Report describes optimization as an iterative process that consists of a series of steps, all of which involve deliberations with stakeholders as a necessary element for a community-focused recovery. Above all, the Report elicits a new paradigm that specifically addresses a long-term approach to managing the challenging radiological conditions experienced by the communities. In conclusion, the Report makes a series of recommendations aimed at enhancing and strengthening late-phase recovery efforts following a major nuclear or radiological incident.

12:00 pm

**Q&A**

12:15 pm **Lunch**

# Operational and Environmental Radiation Protection (PAC 2 & 5)

Carol D. Berger & Ruth E. McBurney, *Session Co-Chairs*

1:45 pm

**Radiation Safety of Sealed Radioactive Sources**

Kathryn H. Pryor
*Pacific Northwest National Laboratory*

Sealed radioactive sources are used in a wide variety of occupational settings and under differing regulatory/licensing structures. The definition of a sealed radioactive source is not consistent among U.S. regulatory authorities and standard-setting organizations. Potential problems with sealed sources cover a range of risks and impacts. The loss of control of high activity sealed sources (radiography, medicine) can result in very high or even fatal doses to members of the public who come in contact with them. Sources that are not adequately sealed, and that fail, can cause spread of contamination and potential intake of radioactive material. There is also the possibility that sealed sources may be (or threatened to be) used for terrorist purposes and disruptive opportunities.

Until fairly recently, generally-licensed sealed sources and devices received little, if any, regulatory oversight, and were often forgotten, lost, or unaccounted for. Nonetheless, generally licensed devices can contain fairly significant quantities of radioactive material (*e.g.*, 500 mCi of $^{137}$Cs, 1,000 mCi of $^{241}$Am), and there is some dose potential associated with activities of this magnitude if a device is treated in a way that it was never designed.

Industrial radiographers use and handle large, high-dose sealed sources in the field with a high degree of independence and minimal regulatory oversight. Failure to follow operational procedures and properly handle radiography sources can and has resulted in serious injuries and death. Industrial radiographers have experienced a disproportionately large fraction of incidents that result in unintended exposure to radiation.

NCRP has not previously provided overarching guidance on the radiation safety aspects of the fabrication, certification, use and control of sealed radioactive sources. Program Area Committee 2, Operational Radiation Safety, is preparing a report to provide comprehensive guidance on the radiation safety of sealed radioactive sources from "cradle to grave." Recommendations will be provided on the definition of a sealed radioactive source, design and fabrication, acquisition, safe handling, storage, tracking, and control of sealed sources. The report will also present a set of "lessons learned" regarding what has gone wrong with sealed sources, what caused those events, and what could be done to prevent them in the future.

2:10 pm

**Pennsylvania's Technologically-Enhanced Naturally-Occurring Radioactive Material Experiences and Studies of the Oil and Gas Industry**

David J. Allard
*Pennsylvania Department of Environmental Protection*

This presentation will provide an overview of the Commonwealth of Pennsylvania's experiences and ongoing studies related to technologically-enhanced naturally-occurring radioactive material (TENORM) in the oil and gas industry. It has been known for many years that Pennsylvania's geology is unique, with several areas having relatively high levels of natural uranium and thorium. In the 1950s a few areas of the state were evaluated for commercial uranium production. In the late 1970s scoping studies of radon in homes prompted the Pennsylvania Department of Environmental Protection (DEP) Bureau of Radiation Protection (BRP) to begin planning for a larger state-wide radon study. The BRP and Oil and Gas Bureau also performed a TENORM study of produced water in the early 1990s for a number of conventional oil and gas wells. More recently BRP and the Bureau of Solid Waste developed radiation monitoring regulations for all Pennsylvania solid waste disposal facilities. These were implemented in 2001 prompting another evaluation of oil and gas operations and sludges generated from the treatment of conventional produced water and brine, but mainly focused on the disposal of TENORM solid waste in the state's Resource Conservation and Recovery Act Subtitle D landfills. However since 2008, the increase in volumes of gas well wastewater, and levels of $^{226}Ra$ observed in the unconventional shale gas well flow-back frac water, has compelled DEP to fully re-examine these oil and gas operations. Specifically, with BRP in the lead, a new TENORM study of oil and gas operations and related wastewater treatment operations has been initiated. This study began in early 2013, and will examine the potential public and worker radiation exposure and environmental impact, as well as re-evaluate TENORM waste disposal. This presentation will summarize conventional and unconventional oil and gas well operations, geology and respective uranium/thorium content, radium content in oil and gas wastewater, treatment solids, radon in natural gas, the scope of other TENORM issues in the state, regulatory framework, national regulations and guidance, as well as, provide an overview of past and status of ongoing TENORM studies in the Commonwealth.

2:35 pm

**Radiation Safety in Nanotechnology (Does Size Matter?)**

Mark D. Hoover
*National Institute for Occupational Safety and Health*

NCRP has established Scientific Committee 2-6 to develop a report on the current state-of-knowledge and guidance for radiation safety programs involved with nanotechnology. Nanotechnology is the understanding and control of matter at the nanoscale, at dimensions between ~1 and 100 nm, where unique phenomena enable novel applications. In recent years man-made nanoparticles, including those that are radioactive, have been developed and incorporated into a wide variety of engineered nanomaterials. Applications are being found in a broad range of medical, industrial, educational and consumer products; their use is rapidly expanding. In some cases, radiation is being used to create or alter materials at the nanoscale. Nano-engineered structural materials, metals, coatings, coolants, ceramics, sorbents and sensors may be particularly enabling in radiation-related applications.

Areas of interest for the report include programs where radiation or radioactivity are being used to characterize or alter materials at the nanoscale, to radiolabel nanomaterials for tracking or evaluation of physicochemical and biological behavior, or to use nano-formulated materials in situations involving radiation or radioactivity. The focus is on operational information of practical value to radiation safety officers, operational health physicists, dosimetrists, workers, management, and regulators. Knowledge gaps regarding information needed to implement appropriate radiation safety programs in these settings will be identified.

Questions of interest include how traditional health physics program practices may need to be modified to provide adequate safety for working with radioactive nanomaterials or working with radiation in nanotechnology applications. To the extent possible, the report will provide guidance on contamination control, engineered and administrative controls, personal protective equipment including respiratory protection, training, waste disposal, and emergency response. The report will also provide specific guidance on conducting internal dosimetry programs if radioactive nanomaterials are being handled. Possible differences in the biological uptake and *in vivo* dissolution or translocation of radioactive nanoparticles, compared to more commonly encountered micrometer-sized particles, may impact the design and conduct of dosimetry programs. In particular, how nanometer-sized particles are addressed in current respiratory tract and systemic dosimetry models will be evaluated. Model parameters and considerations including deposition efficiency, total and regional retention patterns, and cells and tissues at risk; dose calculation methods; and the potential for multifactorial biological effects from radiation, chemical, and physical particle properties of the nanoparticles are also being considered. It is intended that the report will also inform the broader nanotechnology knowledge infrastructure community.

3:00 pm **Q&A**

# Radiation Measurement and Dosimetry (PAC 6)

Wesley E. Bolch, *Session Chair*

3:20 pm

**Framework and Need for Dosimetry and Measurements: Quantitation Matters**

Raymond A. Guilmette
*Lovelace Respiratory Research Institute*

It has always been recognized that radiation measurements and dosimetry play a crucial role in developing radiation protection programs for workers and the public particularly as they relate to mitigating potential health risks from exposure to radiation. NCRP has always devoted significant resources to these scientific disciplines in terms of its published reports, and it is anticipated that this emphasis will continue. This includes focus on both external and internal radiation exposure as well as radiation and radioactivity measurement methodology. NCRP, as part of its management of scientific activities, has designated Program Area Committee (PAC) 6 to focus on both radiation measurements and dosimetry (membership comprises all authors).

This presentation will briefly describe how radiation measurements and dosimetry were addressed historically in terms of NCRP activities and reports, how the emphases have changed over the years, and how NCRP has worked effectively with other radiation protection organizations such as the International Commission on Radiological Protection to leverage its expertise in advancing the science of measurements and dosimetry, particularly the latter. For example, recent reports have focused on the state-of-the-art in radiation dose assessment as well as elucidating methodologies for evaluating uncertainties in assessing radiation doses from exposure to both external and internal sources of radiation.

Currently the activities of PAC 6 in dosimetry have focused on working with other PACs, bringing its dosimetry and measurement expertise to address larger radiation protection issues, such as radiation protection issues relating to exposure to radioactive nanoparticles, contributing to the development of comprehensive dose assessment methods to deal with the wide range of exposures encompassed by various populations (*e.g.*, those being studied in the Million Worker Study) and performing a quality assurance function for dose assessments (*i.e.*, Operation Tomodachi) performed by other agents and agencies.

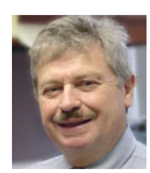
Moving forward, it is clear that the needs for expertise in radiation measurements and dosimetry will not diminish, but will continue to be associated with larger scope projects in which measurements and dosimetry play pivotal roles. Thus it is anticipated that collaborations with other PAC activities will continue. In addition, there are also initiatives in which PAC 6 is playing a lead role. These include:

- developing guidance on frameworks for licensing biophysical devices and/or biological and pharmacological endpoints for biomarkers of radiation exposure and radiation-induced disease;
- elucidating data collection strategies and dose assessment methods for following up potentially exposed members of the public;
- revising the classic NCRP Report No. 58 on radioactivity measurements; and
- exploring emerging issues in measurement and dosimetry relating to medical radiation treatments and diagnostics.

3:45 pm

**Dose Reconstruction for the Million Worker Epidemiological Study**

Andre Bouville
*National Cancer Institute*



The primary aim of the epidemiologic study of one million U.S. radiation workers and veterans (the Million Worker Study) is to provide scientifically valid information on the level of radiation risk when exposures are received gradually over time, and not acutely as was the case for Japanese atomic-bomb survivors. The primary outcome of the epidemiological study is cancer mortality but other causes of death such as cardiovascular disease and cerebrovascular disease will be evaluated. The success of the study is tied to the validity of the dose reconstruction approaches to provide unbiased estimates of organ-specific radiation absorbed doses and their accompanying uncertainties. The dosimetry aspects for the Million Worker Study are challenging in that they address diverse exposure scenarios for diverse occupational groups being studied over a period of up to 70 y. The dosimetric issues differ among the varied exposed populations that are considered: atomic veterans, U.S. Department of Energy workers exposed to both penetrating radiation and intakes of radionuclides, nuclear power plant workers, medical radiation workers, and industrial radiographers. While a major source of radiation exposure to the study population comes from external gamma- or x-ray sources, for certain of the study groups there is a meaningful component of radionuclide intakes that require internal radiation dosimetry measures.

Scientific Committee 6-9 has been established by NCRP to produce a report on the comprehensive organ dose assessment (including uncertainty analysis) for the Million Worker Study. The Committee's report will cover the specifics of practical dose reconstruction for the ongoing epidemiologic studies with uncertainty analysis discussions and will be a specific application of the guidance provided in NCRP Reports Nos. 158, 163, 164, and 171. The main role of the Committee is to provide guidelines to the various groups of dosimetrists involved in the various components of the Million Worker Study to make sure that certain dosimetry criteria are respected: calculation of annual absorbed doses in the organs of interest, separation of low- and high linear-energy transfer (LET) components, evaluation of uncertainties, and quality assurance and quality control. It is recognized that the Million Worker Study and its approaches to dosimetry are a work in progress and that there will be flexibility and changes in direction as new information is obtained, both with regard to dosimetry and with regard to the epidemiologic features of the study components.

This presentation focuses on the description of the various components of the Million Worker Study, on the available dosimetry results, and on the difficulties that have been encountered. It is expected that the Committee will provide its report in 2016.

4:10 pm **Q&A**

4:25 pm **Break**

## Thirty-Eighth Lauriston S. Taylor Lecture on Radiation Protection and Measurements

5:00 pm

**Introduction of the Lecturer**
Milton J. Guiberteau

**On the Shoulders of Giants: Radiation Protection Over 50 Years**
Fred A. Mettler, Jr.
*New Mexico Federal Regional Medical Center*

There have been remarkable advances in the knowledge of radiation effects and the philosophy of radiation protection over the last half century. No one single person was responsible for this. Most advances have been due to a number of remarkable scientists and physicians (giants) who laid the groundwork, did research, and who mentored and trained us. I have had the good fortune to interact with many of these giants and get to know them on a personal basis. Over the past 50 y we have seen radiobiology progress from single-hit theory to epigenetic effects, watched remarkable growth in medical radiation applications, gone from concern about genetic effects to elucidation of specific tumor risks, seen continued spectacular accidents from various causes, gone from Cold War fallout concerns to issues regarding terrorism and expansion of nuclear weapon countries, seen nuclear power expand then wane and grappled with the legacy issues of nuclear waste. Success in the future will depend upon our current group of "giants" and their ability to identify and train the next generation.

6:00 pm

**Reception in Honor of the Lecturer**
Sponsored by Landauer, Inc.

LANDAUER®

# Tuesday, March 11

8:15 am **NCRP Annual Business Meeting**

9:15 am **Break**

## Radiation Protection in Medicine (PAC 4)

Donald L. Miller, *Session Chair*

9:45 am


**Protection of Patients in Diagnostic and Interventional Medical Imaging**
Kimberly E. Applegate
*Emory University School of Medicine*


The radiology community (radiologists, medical physicists, radiologic technologists, and interventional proceduralists) has led the educational and awareness efforts to reduce radiation dose to our patients through effective collaborations that bridge traditional specialty silos and reach all stakeholders. These successful collaborations have included both vendors and regulators, with the overarching goal of dose reduction. Dose reduction to patients often raises overall safety awareness and lowers occupational doses as well. It is critical that the entire radiology community continue to act as leaders in these efforts in radiation safety for both employees and patients. In order to be successful, we must understand the current state-of-the-science and the growing, worldwide, multimedia resources that are available to us. There is little time or budget for us to recreate training materials or risk communication information that may already exist.

In order to create a strong environment of radiation protection for patients (and for employees), there must also be a strong health system culture of safety. We will discuss multiple elements and training that create a safety culture. Note that safety is necessary but not sufficient to ensure quality healthcare. Radiology departments and healthcare systems focus on safety culture and metrics often based on external requirements or demands such as from the Joint Commission, regulatory agencies, consumer groups, and payers. Increasingly, radiation metrics are included in determining the quality of an imaging department and overall health system.

Together with the increasingly fast-paced and demanding healthcare environment and sharp focus on quality, it has never been more important to understand how to achieve better quality care for radiology departments. That must begin with radiation protection of our patients. We must measure quality for many customers that include patients, referring providers, and many others. How do we show that we are providing, monitoring, and improving quality service in radiology? This presentation will briefly describe the rationale and methods for using collective learning tools that document radiation protection of patients in diagnostic and interventional imaging. These tools include the use of imaging modality registries such as the Computed Tomography Dose Index Registry, peer review of imaging reports, the use of clinical decision support, and guidelines.

Goals and objectives:

- provide the current state-of-the-science regarding cancer risk from medical procedures using ionizing radiation;
- understand the three basic radiation protection principles for patients and for radiation workers;
- recognize key methods to build a safety culture in radiology;
- understand both qualitative and quantitative metrics in a radiology safety program;
- provide examples of quality assurance and improvement projects based on a safety event and that promote a culture of safety; and
- understand the radiation dose reduction goals and educational materials for all stakeholders involved in imaging children (Image Gently®), in imaging adults (Image Wisely®) and in efforts to more appropriately use testing (Clinical Decision Support and the Choosing Wisely® Campaign).

10:10 am

**Protection and Measurement in Radiation Therapy**

Steven G. Sutlief
*University of Washington Medical Center*

From its inception, NCRP has contributed much to the field of radiation therapy. Guidance from NCRP encompasses radiation protection of workers, prenatal exposure, risk of damage to normal tissues, reference dosimetry, neutron contamination in therapeutic beams, and facility shielding. Radiation protection of the patient, staff, and members of the public must be reassessed with the introduction of each new technology into radiation therapy, which in turn underscores the need to improve our basic scientific understanding.

Radiation protection concerns include secondary cancers due to radiation to uninvolved tissues, damage to the fetus, damage to implantable electronic devices (*e.g*., pacemakers and implantable cardioverter defibrillator), and protection of staff and members of the public near radiation therapy equipment.

These concerns must be addressed in ways appropriate to the technology in use. Technological developments in radiation therapy include brachytherapy using either superficial application or temporary or permanent implantation, therapy with radioactive drugs, conventional and conformal external beams (photons or electrons), higher energy beams (≥10 MV) where neutrons contribute, intensity modulated radiation therapy and volumetric arc therapy, small field delivery (*via* stereotactic radiosurgery or stereotactic body radiation therapy), total body irradiation and total skin electron therapy, specialized equipment (such as Tomotherapy®, CyberKnife®, and $^{60}Co$ with onboard magnetic resonance imaging), and particle therapies using protons or heavier ions.

This in turn leads to consideration of the science underlying radiation protection and measurement. Scientific concerns include dose risk, both in terms of prompt effects (normal tissue morbidities such as moist desquamation and impaired salivary function) and delayed effects such as secondary cancers and cardiovascular disease. A second underlying scientific concern is dose calculation, which includes absolute dosimetry, extra-focal and leakage radiation, and neutron contamination in beam therapy. A third concern involves dose measurement, both in the case of brachytherapy sources and external beam. A final concern is the engineering of safety and shielding, which includes equipment design, personal shielding, and facility shielding.

Historical milestones include the formation of several radiation protection organizations in the late 1920s, including the predecessor of NCRP. Through the efforts of these organizations and other professional societies, guidance has been offered to the user community and members of the public on the issues listed above. During the ensuing years, refinements were made both to the quantities used in radiation protection and to the dose limits for workers and members of the public. Most of the primary concerns were identified early in the history of radiation protection and now undergo periodic revision.

Current trends in radiation protection are driven by the rapid commercial development of new radiation therapy technologies, improved science of normal tissue susceptibilities to radiation, and the evolving technology of implantable devices. Foremost among current technological advancements are the use of image guidance and wider availability of proton therapy. Other recent developments include intra-arterial delivery of radioactive microspheres for treating liver lesions, radiolabeled monoclonal antibodies for treating certain lymphomas, and the very recent introduction of therapeutic radiopharmaceuticals incorporating alpha-emitting radionuclides.

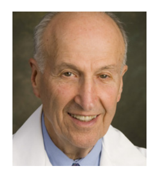
Future developments will likely include increased use of imaging for assessment and treatment positioning and wider clinical use of molecularly-based disease assessment and treatment strategies. While the conformity of radiation dose continues to undergo incremental refinements, greater gains may be made by assessing patient-specific radiation biology for the purpose of patient selection, so that radiation is given only to those patients likely to benefit from it, as well as broader use of monoclonal antibodies or coupling of radiotherapy with immunotherapy.

This presentation will review historical trends in radiation protection and measurement, describe the current status, and suggest future directions likely to be most fruitful.

10:35 am

**Protection of the Developing Embryo and Fetus from Ionizing Radiation Exposure**

Robert L. Brent
*Alfred I. duPont Institute Hospital for Children*



Scientific knowledge has increased and public concerns have changed in the 37 y since NCRP Report No. 54, *Medical Radiation Exposure of Pregnant and Potentially Pregnant Women* (1977) was published. The scope of Report No. 174, *Preconception and Prenatal Radiation Exposure: Health Effects and Protective Guidance* (2013) covers both ionizing radiation and nonionizing sources. The ionizing radiation sources discussed consist predominantly of low linear-energy transfer radiation.

- **Gamete radiation:** There is no convincing direct evidence of germline mutation manifest as heritable disease in the offspring of humans and attributable to ionizing radiation, yet radiation clearly induces mutations in microbes and somatic cells of rodents and humans, and transgenerational effects in irradiated drosophila and mice are established. It would be imprudent to ignore the possibility of human germ-cell mutation, especially since progress in human genetics and genomics promises quantum improvements in being able to address the issue in the future.
- **Pregnancy risks from ionizing radiation:** The background rate for major

congenital malformations is ~3 % (*i.e.*, in the absence of radiation exposure about 3 of every 100 children born have a recognizable major birth defect). Pregnancy loss (spontaneous abortion, miscarriage) in women who know they are pregnant occurs in 15 % of pregnancies with a wide standard deviation. Doses to the embryo estimated to be in the range of 0.15 to 0.2 Gy during the preimplantation and presomite stages may increase the risk of embryonic loss. However, an increased risk of congenital malformations or growth retardation has not been observed in the surviving embryos. These results are primarily derived from mammalian animal studies and are referred to as the "all or none phenomenon." The potential tissue reactions of ionizing radiation (previously referred to as deterministic effects) are congenital malformations, mental retardation, decreased intelligence quotient, microcephaly, neurobehavioral effects, convulsive disorders, growth retardation (height and weight), and embryonic and fetal death (miscarriage, stillbirth). All these effects are consistent with having a threshold dose below which there is no increased risk. Based on animal studies, the no-adverse-effect level (dose to the embryo or fetus) in humans is estimated at 0.2 Gy for anatomical congenital malformations during a very short period during early organogenesis, and is higher for most other tissue reactions. Doses to the embryo or fetus due to radiation exposure to the maternal chest, extremities, neck and head from diagnostic x-ray procedures do not exceed 0.1 Gy and are thus less than the no-adverse-effect level for any of the previously mentioned tissue reactions.

- **Radiation carcinogenesis:** The risk of cancer in offspring that have been exposed to diagnostic x-ray procedures while *in utero* has been debated for 55 y. High doses to the embryo or fetus (*e.g.*, >0.5 Gy) increase the risk of cancer. Most pregnant women exposed to x-ray procedures and other forms of ionizing radiation today received doses to the embryo or fetus <0.1 Gy. The risk of cancer in offspring exposed *in utero* at a low dose such as <0.1 Gy is controversial and has not been fully resolved. Nevertheless, diagnostic imaging procedures utilizing ionizing radiation that are clinically indicated for the pregnant patient should be performed because the clinical benefits outweigh the potential oncogenic risks.
- **Mitigation of ionizing radiation risk for pregnant or potentially-pregnant women:** Prior to any medical ionizing radiation exposure, it is important to assess if the woman is pregnant, or if there is the possibility that she may be pregnant. The conventional methods of pregnancy assessment range from verbal communication to a highly-sensitive biochemical assay of human chorionic gonadotropin produced by the developing placenta. Nevertheless, women should be considered potentially pregnant if she thinks she may be pregnant.
- **Communicating benefits and risks:** Women exposed to radiation during pregnancy and members of their families often seek counseling about the associated radiation exposure and present with various levels of anxiety. In such circumstances it is important that the counselor be well versed in the potential adverse consequences associated with the various levels of radiation exposure.

11:00 am **Q&A**

# Radiation Education, Risk Communication, Outreach, and Policy (PAC 7)

Julie E.K. Timins, *Session Chair*

11:20 am

**Historical Trends in Radiation Protection, Policy and Communications: 1964 to the Present**

Paul A. Locke
*The Johns Hopkins University Bloomberg School of Public Health*

The past 50 y have seen substantial developments in radiation epidemiology, technology, dosimetry, regulations and protection efforts. During the last five decades, radiation communication has also evolved, growing more sophisticated as communication science and practice have advanced and matured. This talk will cover the trends in radiation protection over the past 50 y, illustrated by progress in science and practice of risk communication and changes in societal expectations, and examine challenges that confront radiation risk communication in the future.

Early radiation communication efforts largely adopted a paternalistic approach, featuring experts whose purpose was to educate members of the public about the risks and benefits of radiation. Based on studies in communication and research, this model has been largely replaced by a more collaborative process, structured around discussions among radiation experts, stakeholder groups, and community representatives. Concurrently, communications technology since the mid-20th century has been transformed by, among other things, the explosion in cellular devices and the rise of social media. These have been both a boom and challenge for radiation risk communication efforts.

This talk will examine the ways in which risk communication has transformed since NCRP was chartered by the U.S. Congress. From the mid-20th century focus on mitigating potential nuclear attacks and civil defense to the early 21st century focus on preparedness, medical radiation, and response to the accident at Fukushima, the type, nature and technology of communications has changed greatly. NCRP and its members should be prepared for addressing both emerging issues of radiation protection and new, innovative ways of communicating about radiation benefits, risks and policies.

11:45 am

**U.S. Radiation Protection: Role of National and International Advisory Organizations and Opportunities for Collaboration (Harmony not Dissonance)**

Michael A. Boyd
*U.S. Environmental Protection Agency*

The early history of radiation protection recommendations in the United States is intertwined with similar efforts in Europe. At the second International Congress of Radiology in Stockholm in 1928, Rolf Sievert was chosen to chair the new International X-Ray and Radium Protection Committee, which later became the International Commission on Radiological Protection (ICRP). One of the seven members elected to that first committee was 26 y old Lauriston Taylor. The following year, Dr. Taylor became the first chair of the U.S. Advisory Committee on X-Ray and Radium Protection, which would eventually become the National Council on Radiation Protection and Measurements (NCRP), the organization he led until 1977.

Our knowledge of radiation-related health risk has evolved and improved over time. As indicated by the names of the early organizations, the first recognized threats from radiation exposure came from radium and x rays. Early radiation protection advice concentrated on preventing observed deterministic effects (*e.g.*, skin erythema). In the 1950s, concern had shifted to preventing genetic effects, which were thought to be possible at doses lower than the levels associated with observable tissue damage. Major epidemiological studies, such as the Life Span Study (LSS) of Japanese atomic-bomb survivors, failed to show evidence of genetic effects, but did show excess cancers in people exposed to a few hundred millisieverts. More recent follow-up of the LSS cohort and other large epidemiological studies have shown positive dose response correlations around, and in some cases below, 100 mSv, so that cancer risk is now the limiting factor in setting radiation protection regulations. Both the U.S. National Academy of Sciences (NAS) and the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) recommend using a linear no-threshold model for estimating excess cancers at low doses. More recently, scientists have begun to explore noncancer endpoints, such as circulatory disease, and to suggest that these effects too might result from exposures to moderate doses of radiation. Science continues to be a driving force in the evolution of the system of radiation protection.

The considerable degree to which the system of radiation protection is practiced consistently around the world is largely attributable to the longstanding coordination and collaboration between NCRP and ICRP. There is a familiar organizational flowchart which characterizes, somewhat ideally, how radiation protection science forms the basis of recommendations, and how the recommendations eventually become regulations or guidance. In this scheme, the state-of-the-science is collected and reviewed by organizations of recognized experts, most notably UNSCEAR and, in the United States, NAS. UNSCEAR publications and the NAS Biological Effects of Ionizing Radiation (BEIR) reports are definitive sources of current information on radiation exposures of the public and their associated health risks. These publications alert ICRP and NCRP when there is a need to modify their radiation protection recommendations. New recommendations, in turn, are incorporated by the International Atomic Energy Agency (IAEA) through revisions to the IAEA Basic Safety Standards (BSS). National authorities that receive funding from the IAEA are required to adopt the BSS in their national regulations. Although the United States does not fall in this category, our regulations and guidance remain broadly consistent with the BSS.

There are many exceptions to this flowchart and many nations tailor the flow path to their unique needs. In the United States, the path from new science and recommendations to new regulations must follow the process laid out in the Administrative Procedure Act, which provides the public an opportunity to review and comment on proposed regulations before they are adopted. Federal agencies must be given statutory authority to issue regulations, and their regulations will reflect the requirements of the particular statute they are using. For that reason, there is a certain degree of dissonance across the many U.S. federal and state radiation protection regulations. Both the U.S. Environmental Protection Agency and the U.S. Nuclear Regulatory Commission have announced plans to revise key radiation protection regulations in the coming years. These rulemakings may provide an opportunity for incorporating many of the latest recommendations of ICRP and NCRP into U.S. regulations. A result of achieving this desirable goal would be more harmony in the practice of radiation protection, both nationally and internationally.

12:10 pm **Q&A**

# Summary: NCRP for the Future

John D. Boice, Jr., *Session Chair*

12:25 pm

**Capturing Opportunities and Meeting Challenges in Radiation Protection**

Kenneth R. Kase
*Honorary Vice President, NCRP*

This summary of the 2014 Annual Meeting captures the opportunities presented during the Warren K. Sinclair Keynote Address and the six scientific sessions including the subsequent questions and answers. It captures the important issues that emerge in these opportunities and discusses the challenges that they bring to radiation protection. These opportunities arise in the basic sciences; in operational areas such as emerging technologies, preparing for the improbable but possible event, industry and medicine; and in education, communication and policy. The challenges include identifying the most important aspects of radiation protection and measurement, prioritizing them in accordance with the NCRP mission and gaining support for the activities of the NCRP to address these issues in the fulfillment of its charter.

12:50 pm

**Closing Remarks**

John D. Boice, Jr.
*President, NCRP*

1:00 pm **Adjourn**

# Program Committee

**Kenneth R. Kase**, *Chair*
*Honorary Vice President, National Council on Radiation Protection & Measurements*

**John D. Boice, Jr.**, *Co-Chair*
*President, National Council on Radiation Protection & Measurements*

**Jerrold T. Bushberg**, *Co-Chair*
*University of California, Davis*
*Senior Vice President & Chairman of the Board, National Council on Radiation Protection & Measurements*

**James A. Brink**
*Massachusetts General Hospital*

**S.Y. Chen**
*Illinois Institute of Technology*

**Raymond A. Guilmette**
*Lovelace Respiratory Research Institute*

**Kathryn D. Held**
*Massachusetts General Hospital*

**Paul A. Locke**
*Johns Hopkins University*

**Donald L. Miller**
*U.S. Food & Drug Administration*

**John W. Poston, Sr.**
*Texas A&M University*

**Kathryn H. Pryor**
*Pacific Northwest National Laboratory*

**Richard E. Toohey**
*M.H. Chew & Associates*

## Registration

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|---|---|
| Monday, March 10, 2014 | 7:00 am – 5:00 pm |
| Tuesday, March 11, 2014 | 7:00 am – 11:00 am |

**Register online: http://registration.ncrponline.org/**

## 2015 Annual Meeting

*Changing Regulations and Radiation Guidance: What Does the Future Hold?*

*Donald A. Cool, Chair*
*Ruth E. McBurney & Kathy H. Pryor, Co-Chairs*

March 16–17, 2015
Bethesda, Maryland

# Biographs

**David J. Allard** is the Director of Pennsylvania's Department of Environment Protection (DEP) Bureau of Radiation Protection; responsible for the accelerator, x ray, environmental surveillance, nuclear safety, radiological emergency response, radioactive materials, decommissioning/site cleanup, low-level waste and radon programs within the Commonwealth. He is the Governor's official liaison to the U.S. Nuclear Regulatory Commission, and a Commissioner for the Appalachian States Low-Level Radioactive Waste Compact Commission.

Mr. Allard received a BS in Environmental Sciences from the State University of New York - Albany and an MS in Radiological Sciences and Protection from the University of Massachusetts - Lowell. He is certified by the American Board of Health Physics, a Fellow of the Health Physics Society, and the Conference of Radiation Control Program Directors' official liaison to NCRP.

Prior to joining DEP in February 1999, he was a consultant to the U.S. Department of Energy on environmental and occupational radiation protection for 8 y. Mr. Allard has been involved in the various aspects of governmental, industrial, reactor, medical and academic radiation protection for 36 y. He serves as a member or advisor on several national radiation protection committees, has authored numerous professional papers and reports, and lectures frequently on a wide variety of radiation protection topics and concerns.

**Kimberly E. Applegate** is a professor of radiology and pediatrics and director of practice quality improvement in radiology at Emory University in Atlanta. At Emory University, she chairs the Radiation Control Council which reviews policy, clinical and research activities involving the use of ionizing radiation. Kimberly is dedicated to service in organized radiology-she is the President of the Association for University Radiologists (AUR) Research and Education Foundation, Past President of AUR, and served on multiple medical boards and editorial boards. Dr. Applegate has published over 140 peer-reviewed papers and book chapters, and presented scientific papers and lectures at medical and scientific assemblies around the world. In 2007, Dr. Applegate was elected to both the NCRP and the Steering Committee of the American College of Radiology (ACR), and began work on the initial Steering Committee for the Image Gently® Campaign to reduce radiation exposure in children. The Campaign has received a number of awards and collaborates internationally to change imaging practice. She is the national and international outreach chair for this campaign. In 2010, she co-edited the book, *Evidence-Based Imaging in Pediatrics*, to promote appropriate use of medical imaging in infants and children. Most recently, she co-authored the ICRP Publication 121, *Radiological Protection of Paediatric Diagnostic and Interventional Radiology*. She has long had an interest in the development of imaging guidelines, chairing this process for ACR, and collaborating with the World Health Organization and the International Atomic Energy Agency on international guideline development.
Dr. Applegate is the ACR Vice Speaker and member of its Executive Committee.

**Carol D. Berger** is Certified by the American Board of Health Physics, a Fellow member of the Health Physics Society, and has over 35 y experience in nuclear activities with emphasis in strategic planning, radiation dosimetry, instrumentation, and applied health physics. She is Past-President of the American Academy of Health Physics (AAHP), a past member of the Panel of Examiners for the American Board of Health Physics, Past President and Past Secretary of the East Tennessee Chapter of the Health Physics Society, and Past Director and Treasurer of the Baltimore-Washington Chapter of the Health Physics Society. She is a recognized expert in the fields of external and internal dosimetry, having participated on several American National Standards Institute, American Society for Testing and Materials, and NCRP committees for establishing dosimetry and radiation safety standards. Prior to her current position as President of Integrated Environmental Management, Inc., an Small Business Administration -registered woman-owned business with offices in Maryland and Ohio, she served as a senior technical consultant for

IT Corporation, head of the Radiation Dosimetry Group at Oak Ridge National Laboratory, adjunct teaching staff at Oak Ridge Associated Universities, and was a member of the Health Physics and Dosimetry Task Group for the President's Commission on the Accident at Three Mile Island. Dr. Berger is the third recipient of the Joyce B. Davis Memorial Award for professional achievement and ethical behavior in the practice of health physics, given by AAHP.

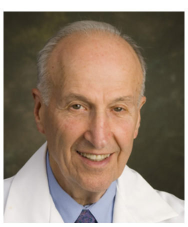
**John D. Boice, Jr.** is the President of NCRP, Bethesda, Maryland, and Professor of Medicine at Vanderbilt University School of Medicine, Nashville, Tennessee. He is an international authority on radiation effects and currently serves on the Main Commission of the International Commission on Radiological Protection and as a U.S. advisor to the United Nations Scientific Committee on the Effects of Atomic Radiation. During 27 y of service in the U.S. Public Health Service, Dr. Boice developed and became the first chief of the Radiation Epidemiology Branch at the National Cancer Institute. Dr. Boice has established programs of research in all major areas of radiation epidemiology, with major projects dealing with populations exposed to medical, occupational, military and environmental radiation. These research efforts have aimed at clarifying cancer and other health risks associated with exposure to ionizing radiation, especially at low-dose levels. Boice's seminal discoveries and over 460 publications have been used to formulate public health measures to reduce population exposure to radiation and prevent radiation-associated diseases. He has delivered the Lauriston S. Taylor Lecture at the NCRP and the Fessinger-Springer Lecture at the University of Texas at El Paso. In 2008, Dr. Boice received the Harvard School of Public Health Alumni Award of Merit. He has also received the E.O. Lawrence Award from the Department of Energy - an honor bestowed on Richard Feynman and Murray Gell-Mann among others - and the Gorgas Medal from the Association of Military Surgeons of the United States. In 1999 he received the outstanding alumnus award from the University of Texas at El Paso (formerly Texas Western College). Dr. Boice recently launched the Million U.S. Radiation Workers and Veterans Study to examine the lifetime risk of cancer following relatively low-dose exposures received gradually over time.

**Wesley E. Bolch** is Professor of Biomedical Engineering and Medical Physics in the J. Crayton Pruitt Family Department of Biomedical Engineering at the University of Florida (UF). He serves as Director of the Advanced Laboratory for Radiation Dosimetry Studies at UF. Dr. Bolch earned his BSE degree in environmental engineering in 1984, his ME and PhD degrees in radiological physics in 1986 and 1998, respectively, from the University of Florida. He has been certified by the American Board of Health Physics since 1994 and licensed in Radiological Health Engineering by the Texas Board of Professional Engineers since 1992. In 2011, Dr. Bolch was elected Fellow of both the Health Physics Society and the American Association of Physicists in Medicine. He has been a member of the Society of Nuclear Medicine's Medical Internal Radiation Dose (MIRD) Committee since 1993, a member of NCRP since 2005, and a member of Committee 2 of the International Commission on Radiological Protection (ICRP) since 2005. Within the latter, he serves as C2 Secretary and Leader of the ICRP Task Group on Dose Calculations. He has published over 160 peer-reviewed journal articles, coauthored/edited 14 books/book chapters, and served as coauthor on two NCRP reports, two ICRP publications, and two MIRD monographs. Dr. Bolch has managed a broad research program including (1) National Cancer Institute and U.S. Department of Energy funded projects to construct high-resolution models of the skeleton to support dose-response studies in radionuclide therapy and radiation epidemiology, (2) National Institute of Biomedical Imaging and Bioengineering funded projects to develop scalable nonuniform rational B-spline-based and voxel-based computational phantoms of adult and pediatric patients and associated software for organ dose assessment in nuclear medicine, computed tomography, interventional fluoroscopy, and radiotherapy, (3) private company funded projects to develop stereotactic kilovoltage x-ray treatments for age-related macular degeneration and glaucoma, and (4) Centers for Disease Control and Prevention funded projects in stochastic modeling of worker inhalation and gamma-ray exposures following radiological accidents and potential terrorist events.

# Biographs

**Andre Bouville** was born and educated in France. He came to the United States in 1984 to work for the National Cancer Institute (NCI). His initial assignment was to estimate the thyroid doses received by the American people from $^{131}$I released by the nuclear weapons tests that were conducted at the Nevada Test Site in the 1950s. This study led to the assessment of doses from nuclear weapons tests conducted at other sites all over the world, as well as to a large number of dosimetry studies related to the Chernobyl nuclear reactor accident. He was the head of the Dosimetry Unit of the Radiation Epidemiology Branch at NCI until he retired at the end of 2010. Throughout his career, Dr. Bouville actively participated in the preparation of scientific reports under the umbrella of international organizations, notably the United Nations Scientific Committee on the Effects of Atomic Radiation, the International Commission on Radiological Protection, the International Commission on Radiation Units and Measurements, the World Health Organization, the International Atomic Energy Agency, and the Nuclear Energy Agency. Regarding U.S. organizations, Dr. Bouville was a member of NCRP for 12 y, became a Distinguished Emeritus Member in 2011, and is currently Chair of Scientific Committee 6-9 on the dosimetry for the Million Worker Study. He has served on numerous National Academy of Science committees, is a Lifetime Associate of the National Academies, and is currently a member of the Committee on the analysis of cancer risks in populations near nuclear facilities. For all his achievements, Dr. Bouville was a recipient of the Presidential Rank Meritorial Award in 2003.

**Michael A. Boyd** is a senior health physicist in the U.S. Environmental Protection Agency (EPA) Office of Radiation and Indoor Air/Radiation Protection Division (RPD) and has been with EPA since 1988. As a member of RPD's Center for Science and Technology, Mr. Boyd manages the development of new federal guidance documents. He is also the co-chair of the Federal Guidance Subcommittee of the Interagency Steering Committee on Radiation Standards (ISCORS). Mr. Boyd is a recently elected member of the International Commission on Radiological Protection Committee 4. He chairs the Health Physics Society's International Collaboration Committee and is on the Bureau of the Organisation for Economic Co-operation and Development/Nuclear Energy Agency's Committee on Radiation Protection and Public Health. He has a BS in Biology and MS in Public Health from the University of North Carolina at Chapel Hill.



**Robert L. Brent** is the Distinguished Professor, Louis and Bess Stein Professor of Pediatrics, Radiology and Pathology at the Jefferson Medical College, Director of the Clinical and Environmental Teratology Laboratories at the Alfred I. duPont Hospital for Children in Wilmington, Delaware. Robert Brent was born in Rochester, New York in 1927, received his AB (1949); MD with honor (1953), a PhD (1955) in radiation biology and embryology and Honorary DSc degrees from the University of Rochester and the Jefferson Medical College. From 1944 to 1954 he worked in the cosmic ray research laboratories of the physics department and as a research associate in the genetics and embryology divisions of the Manhattan Project of the University of Rochester, where he began his studies on the teratogenic effects of ionizing radiation. As a graduate student he was appointed the Head of the embryology section of the medical school's atomic energy facility. He was the first research (1953) and clinical fellow (1954) of the March of Dimes involved in congenital malformations research. He spent his army tour at the Walter Reed Army Institute of Research as Chief of Radiation Biology (1955 to 1957).

He came to Jefferson in 1957 and has received every award that Jefferson can offer a faculty member, and for having received continuous federal research funding as a principal investigator for his entire research career. In 1989, he was named the third Distinguished Professor in Jefferson's 188 year history.

He was elected to NCRP in 1973. In 2006 he delivered the L.S. Taylor Lecture, having already received the highest honor of the Teratology Society and the Health Physics Society. He was elected to the Institute of Medicine of the National Academy of Sciences in 1996. He was the editor of "Teratology" for 17 y, and has been invited to China five times and to Japan seven times as a Visiting Lecturer and has had invited lectureships in 27 countries. In 1994 he was selected by the Chinese government as the President of the first International Congress on Birth Defects in China. Dr. Brent will receive the John Scott Award of the American Philosophical Society on November 22, 2013 for his research pertaining to the environmental causes of birth defects but especially for his early research that indicated that the embryo was less vulnerable to the carcinogenic effect of ionizing radiation than the child or adult.

Dr. Brent's greatest recognition has come from his research, publications and lecturing. He is the most frequently consulted authority on the effects of radiation on the embryo and is frequently consulted about other possible teratogenic exposures. His research on the effects of radiation on the embryo demonstrated the no-effect dose for congenital malformations, established that radiation effects on the embryo were due to the direct effects of the radiation, and demonstrated some of the characteristics of the "all-or-none period" of embryonic development.

His writings in the field of litigation concerning the proper role of an expert witness were important. As one of the defense experts in the Bendectin litigation, his testimony contributed to the famous Daubert decision that allowed judges to reject the testimony of junk scientists. His publications include six books and monographs, five movies, 458 publications, and over 400 abstracts.

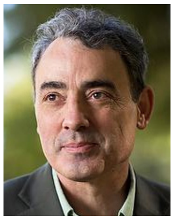
**James A. Brink** is Radiologist-in-Chief at Massachusetts General Hospital (MGH). He earned a BS degree in Electrical Engineering at Purdue University and an MD at Indiana University before completing his residency and fellowship at Massachusetts General Hospital. He joined the faculty at the Mallinckrodt Institute of Radiology at Washington University School of Medicine where he rose to the rank of Associate Professor prior to joining the faculty at Yale University in 1997. Promoted to Professor in 2001, Dr. Brink was appointed Interim Chair in 2003 and Chair of the Yale Department of Diagnostic Radiology in 2006. On February 1, 2013, Dr. Brink left Yale to serve as Radiologist-in-Chief at MGH. While he has broad experience in medical imaging, including utilization and management of imaging resources, he has particular interest and expertise in issues related to the monitoring and control of medical radiation exposure. Dr. Brink is a fellow of the Society for Computed Body Tomography/Magnetic Resonance and a fellow of the American College of Radiology (ACR). For ACR, he serves on the Executive Committee and Board of Chancellors as Chair of the Body Imaging Commission, Chair of the Imaging Communication Network, and Co-Chair of the Global Summit on Radiology Quality and Safety. For the American Roentgen Ray Society, Dr. Brink is a member of the Executive Council and immediate Past President. For NCRP, Dr. Brink is the Scientific Vice President for Radiation Protection in Medicine, and chaired the NCRP scientific committee that defined diagnostic reference levels for medical imaging in the United States (NCRP Report No. 172, 2012). For the International Society of Radiology, Dr. Brink serves as Chair of the International Commission for Radiology Education, and for the Radiological Society of North America, he serves as Co-Chair of the Image Wisely® initiative, a social marketing campaign to increase awareness about adult radiation protection in medicine.

**Jerrold T. Bushberg** is the is the Senior Vice President of NCRP, and Clinical Professor of Radiology and Radiation Oncology, University of California (UC) Davis School of Medicine. He is an expert on the biological effects, safety, and interactions of ionizing and nonionizing radiation and holds multiple radiation detection technology patents. Dr. Bushberg is a fellow of the American Association of Physicist in Medicine and is certified by several national professional boards with specific subspecialty certification in radiation protection and medical physics. Prior to coming to the UC Davis Health System as technical director of nuclear medicine, Dr. Bushberg was on the faculty of Yale University School of Medicine where his research was focused on radiopharmaceutical development. Dr. Bushberg has served as an advisor to government agencies and institutions throughout the nation and around the world on the biological effects and safety of ionizing and nonionizing radiation exposure. He has worked for the U.S. Department of Homeland Security, the World Health Organization, and the International Atomic Energy Agency as a subject matter expert in radiation protection and radiological emergency medical management. Dr. Bushberg has responsibility for medical postgraduate education in medical physics, radiation (ionizing and nonionizing) protection, and radiation biology. The third edition of the textbook, *The Essential Physics of Medical Imaging*, authored by Bushberg, Seibert, Leidholdt, and Boone, is used extensively by radiology residency programs throughout the United States.

**S.Y. Chen** is currently Director of Professional Master of Health Physic Program at the Illinois Institute of Technology (IIT), Chicago. Prior to joining IIT, he was Senior Environmental Systems Engineer and also served as the Strategic Area Manager in Risk and Waste Management in the Environmental Science Division at Argonne National Laboratory, Argonne, Illinois. He received his BS in nuclear engineering from National Tsing Hua University in Taiwan and obtained his MS and PhD in nuclear engineering from the University of Illinois at Champaign-Urbana. Dr. Chen's professional interests include radiation protection, human and environmental health risk, and nuclear accident analysis; with special expertise in environmental cleanup, radioactive material disposition management, and nuclear waste transportation. Dr. Chen has been a NCRP Council member since 1999, and served on its Board (2004 to 2011). He currently serves as NCRP Scientific Vice President on Environmental Radiation and Waste Issues (since 2004). Dr. Chen has served on the U.S. Environmental Protection Agency's Science Advisory Board/Radiation Advisory Committee since 2009. He is a long-time member of the Health Physics Society and of the American Nuclear Society. He was elected to Fellow by the Health Physics Society in 2013, and is a Certified Health Physicist by the American Board of Health Physics. While at Argonne, Dr. Chen developed an integrated risk assessment program that addresses the broad-based issues to support federal risk-based policies. Dr. Chen had served on numerous capacities at NCRP, including chairing Scientific Committee (SC) 87-4 which led to the publication of Report No. 141, *Managing Potentially Radioactive Scarp Metal*, and also chairing SC 5-1, *Decision Making for Late-Late Phase Recovery from Nuclear or Radiological Incidents*. He served as Chair of NCRP 2005 Annual Meeting Program Committee, *Managing the Disposition of Low-Activity Radioactive Materials*, and as Co-Chair of NCRP 2013 Annual Meeting Program Committee, *Radiation Dose and the Impacts on Exposed Populations*.

**C. Norman Coleman** received his BA in mathematics, *summa cum laude*, from the University of Vermont in 1966 and his MD from Yale University in 1970. He is board certified in three specialties - internal medicine from the University of California San Francisco, medical oncology from the National Cancer Institute (NCI), and radiation oncology from Stanford University. He served in the U.S. Public Health Service at the National Institutes of Health [O-4 (retired)]. He was Assistant and tenured Associate Professor of Radiation and Medical Oncology at Stanford and from 1985-1999 and he was Professor and Chairman of the Harvard Medical School Joint Center for Radiation Therapy. Since 1999, he has been Associate Director, Radiation Research Program and Senior Investigator, with a molecular radiation therapeutics laboratory in the Radiation Oncology Branch of NCI. Since 2004 he has also been a Senior Medical Advisor in the Office of the Assistant Secretary for Preparedness and Response in the U.S. Department of Health and Human Services. His focus is on radiological and nuclear preparedness and planning but the programs apply to all hazards. This includes the Scarce Resources for a Nuclear Detonation project and participation at the U.S. Embassy in Tokyo during the Japan disaster in March 2011. Among his honors are the Gold Medal from the American Society for Radiation Oncology and the 2011 Samuel J. Heyman, Service to America Homeland Security Medal.

# Biographs



**Francis A. Cucinotta** is a Professor of Health Physics at the University of Nevada, Las Vegas. Dr. Cucinotta received his PhD in nuclear physics from Old Dominion University. He worked at the National Aeronautics and Space Administration (NASA) Johnson Space Center from 1997 to 2013 as the Radiological Health Officer, Space Radiation Project Manager and Chief Scientist. Dr. Cucinotta developed the astronaut exposure data base of organ doses and cancer risk estimates for all human missions from Mercury to the International Space Station (ISS), and developed risk models for acute, cancer and circulatory diseases. He was NASA's manager for the construction of the NASA Space Radiation Laboratory (NSRL), and NSRL Operations from 2003 to 2012. Dr. Cucinotta worked on radiation safety in NASA's mission control for the Space Shuttle and ISS programs in 1989 and 1990, including during the October of 1989 solar event, and from 2000 to 2006. Dr. Cucinotta has published over 300 journal articles, numerous book chapters, and over 100 NASA technical reports on nuclear and space physics, radiation shielding, DNA damage and repair, biodosimetry, systems biology, and risk assessment models. He has won numerous NASA awards for his efforts in research, mission safety, and research management. Dr. Cucinotta is currently the President of the Radiation Research Society, and a Council Member of NCRP.

**Raymond A. Guilmette** received a BS in nuclear engineering from Rensselaer Polytechnic Institute and an MS in environmental health sciences and a PhD in radiological health from New York University. For almost 40 y, he has been studying the metabolism, biokinetics, dosimetry, biological effects of internally-deposited radionuclides, developing methods for removing radionuclides from the body (decorporation), and studying the mechanisms of deposition, clearance and retention of inhaled materials. Most of this research was performed at the Lovelace Respiratory Research Institute (LRRI) (formerly the Inhalation Toxicology Research Institute), where he worked for 23 y. From 2000 through 2007, he was team leader for internal dosimetry at the Los Alamos National Laboratory, assessing radiation doses for workers who were exposed to radionuclides associated with the nuclear weapons industry. In 2007, he returned to LRRI as director of the Center for Countermeasures Against Radiation where he is evaluating the efficacy of chemical compounds designed to decorporate radionuclides as well as drugs designed to ameliorate the effects of acute radiation syndrome from large external radiation doses. He is a past president of the Health Physics Society, received its Distinguished Scientific Achievement Award in 2002, and has given several honorary lectures (Newell Stannard Memorial Lecture, 2006; G. William Morgan Lecture, HPS, 2009; inaugural Patricia W. Durbin Memorial Lecture, Lawrence Berkeley National Laboratory, 2010). He is a member of scientific committees of the International Commission on Radiological Protection, NCRP (also a board member), the International Agency for Research on Cancer, U.S. Environmental Protection Agency, and the U.S. National Academies of Science.

**Kathryn D. Held** is an Associate Radiation Biologist in the Department of Radiation Oncology, Massachusetts General Hospital (MGH) and Associate Professor of Radiation Oncology (Radiation Biology) at Harvard Medical School (HMS). At MGH, Dr. Held leads a team that is involved in research on molecular mechanisms for the induction of bystander effects by high energy particles in cells and tissues, characterization of proton beam induced DNA damage responses, development of a cancer screening platform for personalized radiation medicine, mechanisms for regulation of DNA damage response by cell-cell communication, and development of novel agents for mitigation of radiation-induced pulmonary injury. Dr. Held also teaches radiation biology to radiation oncology medical and physics residents and graduate students at MGH/HMS and the Massachusetts Institute of Technology. Dr. Held earned her PhD in biology from the University of Texas, Austin. She has served on review panels for numerous federal agencies including the National Institutes of Health, the National Aeronautics and Space Administration (NASA), and the U.S. Army Medical Research and Material Command programs and other organizations such as the Radiological Society of North America, is on the Editorial Boards of Radiation Research and the International Journal of Radiation Biology, and has served on committees for the National Academy of Science/National Research Council, NASA, and the American Society of Radiation Oncology. She has been a President of the Radiation Research Society and is currently on the Board of Directors and Vice President of Program Area Committee 1 of NCRP, having served as Chair of the Program Committee for the 2011 NCRP Annual Meeting on Scientific and Policy Challenges of Particle Radiations in Medical Therapy and Space Missions.

**Mark D. Hoover** is a senior research scientist in the Division of Respiratory Disease Studies at the Centers for Disease Control and Prevention (CDC), National Institute for Occupational Safety and Health (NIOSH), in Morgantown, West Virginia. Dr. Hoover is coordinator of the NIOSH Exposure Assessment Cross-Sector Research Program, as well as a critical area leader in the NIOSH Nanotechnology Research Center. NIOSH is the leading U.S. federal agency conducting research and making recommendations to prevent work-related illness, injury, disability and death. Prior to joining NIOSH in 2000, Dr. Hoover was an aerosol scientist for 25 y at the U.S. Department of Energy's Lovelace Respiratory Research Institute in Albuquerque, New Mexico, where his activities included the design and operation of the U.S. test facility for radiation instrumentation for air sampling and monitoring. He earned a BS in mathematics and English in 1970 from Carnegie Mellon University and an MS and PhD in nuclear engineering in 1975 and 1980 from the University of New Mexico. He is board certified in the comprehensive practice of health physics and in the comprehensive practice of industrial hygiene. Dr. Hoover has served as chairman or contributor to the development of many national and international standards; is the cofounder of the U.S. Air Monitoring Users Group; is a past chairman of the American International Health Alliance Nanotechnology Working Group; and is author or co-author of more than 190 open literature publications. He is co-editor of the 2011 CRC Press handbook on *Radioactive Air Sampling Methods*; chair of NCRP Scientific Committee 2-6 on Radiation Safety Aspects of Nanotechnology; project leader for preparation of the International Electrotechnical Commission technical report on *Radiation Instrumentation Issues for Airborne Materials Including Nanoparticles*; and the co-lead editor for preparation of a new monograph on *Nanoinformatics Principles and Practices*. Special emphasis areas for Dr. Hoover's work include a graded approach to exposure assessment and characterization of nanoparticles in the workplace, development of a prototype *Nanoparticle Information Library*, and promotion of opportunities to apply performance-based occupational exposure limits or control banding approaches to nanotechnology. Detailed information about the NIOSH exposure assessment research program and the NIOSH nanotechnology health and safety research program can be found at http://www.cdc.gov/niosh/programs/expa/ and http://www.cdc.gov/niosh/topics/nanotech.

**Kenneth R. Kase** is Honorary Vice-President of NCRP. He was a member of the Council for 24 y, served as Senior Vice President for 9 y, and for 12 y as Scientific Vice President and Chair of Scientific Committee 46 for Operational Radiation Safety. He also was a member of Committee 4 of the International Commission on Radiation Protection from 1997 to 2001. Dr. Kase completed his term as President of the International Radiation Protection Association (IRPA) in May 2012. He served as Vice-President from 2004 to 2008, and chaired the International Congress Program Committee for the 2000 International Congress on Radiation Protection (IRPA 10) in Hiroshima, Japan.

Kenneth Kase began his career in Health Physics at Lawrence Livermore National Laboratory, California, in 1963 and moved to Stanford Linear Accelerator Center (SLAC) in 1969. In 1975 he received a PhD from Stanford University and was appointed to the faculty of Radiation Oncology at the Harvard Medical School. He was appointed Professor of Radiation Oncology at the University of Massachusetts Medical School in 1985. In 1992 he returned to Stanford and was appointed Associate Director of SLAC and Director of the Environment, Safety and Health Division in 1995. He retired from that post in 2001 and from SLAC in 2005. Currently he is associated with Lyncean Technologies, Inc., a research and development firm in Palo Alto, California. He is married to Grady and has two daughters and 6 grandchildren.

Throughout his career Dr. Kase has been active in research activities related to radiation physics and radiation protection, particularly in radiation measurements and the operation of particle accelerators. He has published over 75 papers in peer reviewed journals, co-authored one book, and edited three others on radiation dosimetry.

Dr. Kase served on the Board of Directors of the Health Physics Society (HPS) from 1989 to1992 and 2002 to 2005 and as President of the HPS in 2003 to 2004. He served on the Board of Directors of the American Association of Physicists in Medicine (AAPM) from 1984 to 1991, and as AAPM Treasurer from 1986 to 1991. Dr. Kase also has been an associate editor of *Health Physics, Medical Physics*, and *Radiation Research*.

**Jill A. Lipoti** was the Director of Water Monitoring and Standards at the New Jersey Department of Environmental Protection until her retirement in 2013. From 1989 to 2010, she directed the activities of the Radiation Protection Programs for New Jersey, with responsibility for the x ray, radioactive materials, nuclear emergency response, environmental monitoring, radon, and nonionizing programs, involving regulation and licensure of professionals. She received the Edward J. Ill Excellence in Medicine Award in 2009 for her work in reducing patient radiation dose from x rays. Dr. Lipoti served as the New Jersey Commissioner to the Atlantic Interstate Low-Level Radioactive Waste Compact. Dr. Lipoti was elected to the Board of Directors and as Chairperson for the Conference of Radiation Control Program Directors (CRCPD), a nonprofit organization representing all 50 states. In 2000, she received the Gerald S. Parker Award of Merit, the CRCPD's highest award. Dr. Lipoti was elected to NCRP in 2001 and has served on the Board of Directors, Program Area Committee 5 on Environmental Radiation and Radioactive Waste Issues, and on Scientific Committee 5-1, Approach to Optimizing Decision Making for Late-Phase Recovery From Nuclear or Radiological Terrorism Incidents. She served as a member and chair of the Radiation Advisory Committee of the Environmental Protection Agency's Science Advisory Board (SAB) and also served on the SAB's Committee on Science Integration for Decision Making. She served on the Food and Drug Administration's Technical Electronic Product Radiation Safety Standards Committee. Dr. Lipoti served on the National Academies committee to write a report on Uranium Mining in Virginia under the Board on Earth Sciences and Resources. Dr. Lipoti received the Distinguished Alumni George H. Cook Award, Cook College, Rutgers University. She received her PhD in Environmental Science from Rutgers University in 1985. She has traveled to Uganda and Ethiopia on missions for the International Atomic Energy Agency.

**Paul A. Locke**, a public health scientist and attorney, is an Associate Professor at the Johns Hopkins University Bloomberg School of Public Health in the Department of Environmental Health Sciences, Division of Molecular and Translational Toxicology. He holds an MPH from Yale University School of Medicine, a DrPH from the Johns Hopkins University Bloomberg School of Public Health, and a JD degree from Vanderbilt University School of Law.

Dr. Locke's research and practice focus on how decision makers use environmental health science (toxicology, radiobiology, epidemiology) in regulation and policy making and how environmental health sciences influence the policy-making process. His areas of study include radiation risk communication, designing and evaluating radiation protection initiatives and radiation policies, radon risk reduction, safe disposal of high level radioactive waste, and use of computed tomography as a diagnostic screening tool. Dr. Locke directs the School's Doctor of Public Health program in Environmental Health Sciences.

Dr. Locke was a member of the National Academy of Sciences (NAS) Nuclear and Radiation Studies Board from 2003 to 2009. He has served on seven National Academy committees, and is currently a member of an NAS committee that is tasked with providing an assessment of lessons learned from the Fukushima nuclear accident for improving the safety and security of nuclear plants in the United States. He is also a member of the Board of Directors of NCRP. He was program committee chair of the NCRP's 2010 annual meeting entitled "Communication of Radiation Benefits and Risks in Decision Making." Dr. Locke is admitted to practice law in the State of New York, the District of Columbia, the Southern District Court of New York, and the United States Supreme Court.

**Ruth E. McBurney** is the Executive Director of the Conference of Radiation Control Program Directors. In that position, she manages and directs the administrative office for the organization. Prior to taking that position in January 2007, she was the Manager of the Radiation Safety Licensing Branch at the Texas Department of State Health Services, culminating 25 y of service in the Texas Radiation Control Program, most of which involved licensing and standards development. Ms. McBurney has served on the U.S. Nuclear Regulatory Commission's Advisory Committee on the Medical Use of Isotopes and the U.S. Food and Drug Administration's National Mammography Quality Assurance Advisory Committee. She is currently serving as a Member of NCRP, and is also on the Board of Directors. She served as a consultant to the International Atomic Energy Agency in the categorization of radiation sources and recently served on a committee of the National Academy of Science regarding replacement technologies for high-risk radiation sources. She has also been a U.S. delegate to the International Radiation Protection Association's 10th, 11th, 12th, and 13th Congresses.

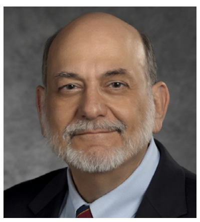
Ms. McBurney holds a BS in Biology from Henderson State University in Arkansas and an MS in Radiation Sciences from the University of Arkansas for Medical Sciences. She is also certified in comprehensive health physics by the American Board of Health Physics.

**Fred A. Mettler, Jr.** is currently Professor Emeritus and Clinical Professor at the Department of Radiology at the University of New Mexico School of Medicine. He was chairman of the department for 18 y from 1994 to 2003. He is currently in the Radiology and Nuclear Medicine Service at the New Mexico Federal Regional Medical Center.

He graduated with a BA in Mathematics from Columbia University and in 1970 he received his MD from Thomas Jefferson University. He performed a rotating internship at the University of Chicago and subsequently completed a Radiology and Nuclear Medicine Residency at Massachusetts General Hospital. He received an MS in Public Health from Harvard University in 1975. He is a fellow of both the American College of Radiology and the American College of Nuclear Physicians. He is board certified in both radiology and nuclear medicine.

Dr. Mettler has authored over 360 scientific publications including 20 textbooks, and holds four patents. The books are on *Medical Management of Radiation Accidents*, *Medical Effects of Ionizing Radiation and Radiology* and *Nuclear Medicine*. He was a Scientific Vice President of NCRP and remains a member. He has chaired several committees for the Institute of Medicine/National Research Council and is a member of the Nuclear and Radiation Studies Board of the National Academies. He is also an academician of the Russian Academy of Medical Sciences. Dr. Mettler has been listed in "The Best Doctors in America" since 1994 as an expert in both nuclear medicine and radiation injury. He has been a certifying examiner for the American Board of Radiology for 30 y.

He was the United States Representative to the United Nations Scientific Committee on the Effects of Atomic Radiation 28 y. He is an Emeritus Commissioner of the International Commission on Radiation Protection (ICRP). He was the Health Effects Team Leader of the International Chernobyl Project. He has served as an expert on radiation effects and accidents for the Centers for Disease Control and Prevention, the World Health Organization, the International Atomic Energy Agency, the International Agency on Research on Cancer, and for the Costa Rican, Peruvian, Panamanian, Polish governments. He was a co-author of the NCRP and ICRP reports on radiation protection during radiological terrorism and has been a member of multiple subgroups on radiological terrorism for the U.S. Department of Homeland Security. He is currently a health advisor to the Japanese Cabinet for the Fukushima nuclear disaster.



**Donald L. Miller** is the Chief Medical Officer for Radiological Health in the Office of In Vitro Diagnostics and Radiological Health of the Center for Devices and Radiological Health at the U.S. Food and Drug Administration (FDA). He received a BA in molecular biophysics and biochemistry from Yale University and an MD from the New York University School of Medicine. He completed his residency and fellowship at the New York University Medical Center. Dr. Miller, an interventional radiologist, is a Fellow of the Society of Interventional Radiology and of the American College of Radiology and an Honorary Member of the American Association of Physicists in Medicine. He is Vice-Chair of Committee 3 of the International Commission on Radiological Protection and serves as a consultant to the International Atomic Energy Agency and the World Health Organization. He served as Vice-Chair for NCRP Report No. 168 and Consultant for NCRP Report No. 172. He currently serves as Co-Chair of NCRP Program Area Committee 4 and a member of the Nominating Committee. Prior to joining FDA, Dr. Miller was a Professor of Radiology and Radiological Sciences at the Uniformed Services University of the Health Sciences and an adjunct investigator at the National Cancer Institute. His research interests have centered on radiation protection in medicine.

**John W. Poston, Sr.** is a Professor in the Department of Nuclear Engineering and Associate Director of the Nuclear Power Institute. He has been at Texas A&M University since 1985 and served for 10 y as the Department Head. Prior to coming to Texas A&M, he was on the faculty at the Georgia Institute of Technology and, earlier, at the Oak Ridge National Laboratory and the Babcock & Wilcox Company in Lynchburg, Virginia. He is a Fellow of the American Nuclear Society, the Health Physics Society, the American Association for the Advancement of Science, and a Distinguished Emeritus Member of NCRP. Currently, he serves as the NCRP Vice President for Program Area Committee 3, Nuclear and Radiological Security and Safety.

**R. Julian Preston** recently retired as the Associate Director for Health for the National Health and Environmental Effects Research Laboratory of the U.S. Environmental Protection Agency (EPA). He also served as Director of the Environmental Carcinogenesis Division at EPA and as senior science adviser at the Chemical Industry Institute of Toxicology. He has been employed at the Biology Division of the Oak Ridge National Laboratory and has served as associate director for the Oak Ridge-University of Tennessee Graduate School for Biomedical Sciences. Dr. Preston's research and current activities have focused on the mechanisms of radiation and chemical carcinogenesis and the approaches for incorporating these types of data into cancer risk assessments. Dr. Preston was chair of Committee 1 of the International Commission on Radiological Protection (ICRP), a member of the ICRP Main Commission, and a member of the U.S. delegation to the United Nations Scientific Committee on the Effects of Atomic Radiation. He is an associate editor of *Environmental and Molecular Mutagenesis*, *Mutation Research*, *Chemico-Biological Interactions*, and *Health Physics*. Dr. Preston has had more than 200 peer-reviewed papers and chapters published. He received his BA and MA from Peterhouse, Cambridge University, England, in genetics and his PhD from Reading University, England, in radiation genetics. He has served on the National Research Council's Committee to Assess the Scientific Information for the Radiation Exposure Screening and Education Program and the Task Group on the Biological Effects of Space Radiation.

# Biographs

**Kathryn H. Pryor** has been a member of Program Area Committee (PAC) 2 since 2007 and a member of NCRP since 2010. She has served on Scientific Committees 2-4, 2-5, 2-7, 1-19, and 6-9. Ms. Pryor is currently on the NCRP Board of Directors and is Scientific Vice President of PAC 2. She received her BS in Biology in 1979 and MS in Radiological Sciences in 1981, both from the University of Washington.

Ms. Pryor currently holds the position of Chief Health Physicist at the Pacific Northwest National Laboratory (PNNL) in Richland, Washington, and has provided management and technical support to the PNNL Radiation Protection Division since 1992. She also served as the Chief Radiological Engineer for the design of the Pit Disassembly and Conversion Project. Ms. Pryor has previously held radiation protection technical support positions at the San Onofre Nuclear Generating Station and the Trojan Nuclear Plant, and was the Radiation Safety Officer at the University of Southern California Health Sciences Campus.

Ms. Pryor is a Fellow member of the Health Physics Society (HPS) and served as President-Elect, President, and Past President from 2010 to 2013. She is certified in comprehensive practice by the American Board of Health Physics (ABHP), and served on the ABHP both as a member and Chair from 1998 to 2002. Ms. Pryor was awarded the William McAdams Outstanding Service Award by ABHP in 2007 and the John P. Corley Meritorious Service Award by the Columbia Chapter of HPS in 2003.

**Steven L. Simon** received a BS in Physics from the University of Texas, an MS in Radiological Physics from the University of Texas Health Sciences Center in Dallas, and a PhD in Radiological Health Sciences from Colorado State University. Early in his career, he worked in medical physics and was the first treatment planner for clinical trials of treatments of solid tumors with negative pi-mesons at the Los Alamos Physics Meson Facility. Later specializing in environmental radioactivity, he directed the first nationwide monitoring program of the Marshall Islands for residual contamination from nuclear testing. He also participated in the radiological monitoring of numerous other nuclear test sites worldwide including Johnston Island, French Polynesia, and Algeria and has lead, or participated in, health risk studies of fallout exposures in Utah, the Marshall Islands, and Kazakhstan. In 2000, Dr. Simon joined the National Cancer Institute's Radiation Epidemiology Branch as an expert in dose reconstruction and presently heads the Dosimetry Unit in that group. Steve is a member of NCRP and has been an Associate Editor of *Health Physics* for 20 y. In 2011 during the Fukushima crisis, Steve was deployed by the U.S. Department of Health and Human Services to the U.S. Embassy in Japan to assist with the protection of American citizens.

**Steven G. Sutlief** received his PhD in experimental particle physics from the University of Washington and subsequently completed a post-doctoral fellowship in radiation therapy medical physics at the University of Washington with research in intensity modulated radiation therapy. Since then he has been chief medical physicist at the Veterans Affairs (VA) Puget Sound Health Care System in Seattle and an affiliate faculty member in the University of Washington School of Medicine. He actively participates in the American Association of Physicists in Medicine, where he has served on many committees and on several task group reports. Dr. Sutlief has worked to advance radiation therapy within the VA, including agency-wide radiotherapy equipment modernization, radiotherapy device interconnectivity, consultation for the VA National Health Physics Program, participation in several investigations, and development of qualification standards for therapeutic medical physicists. He has coauthored 45 articles and book chapters related to therapeutic medical physics. Dr. Sutlief developed and taught the physics curriculum for the Bellevue College Medical Dosimetry program. He has served as a consultant to the International Atomic Energy Agency and as a member of the Radiation Oncology planning group for the Integrating the Healthcare Enterprise. Recently Dr. Sutlief was a Co-organizer for the AAPM Summer School on Quality and Safety in Radiation Therapy and was a faculty member for the Veterans Health Administration Biennial Conference on Radiation Oncology. He is currently an NCRP Council member.

**Julie E.K. Timins** is a Diagnostic Radiologist, board certified in General Radiology and in Nuclear Medicine. Her medical practice has been varied, including Chair of Nuclear Medicine at the Veterans Administration Hospital in Lyons, New Jersey; 10 y as Staff Radiologist at Robert Wood Johnson University Hospital, New Brunswick, New Jersey; 11 y in an inner-city hospital in Jersey City; and over 4 y in a suburban outpatient imaging facility specializing in Mammography and Women's Imaging in Morristown, New Jersey. Dr. Timins is Chair of the New Jersey Commission on Radiation Protection, and sits on the New Jersey Radiologic Technology Board of Examiners. She served on the NCRP Board of Directors, and received a Commendation for Outstanding Service on the 2010 Annual Meeting Program Committee - "Communication of Radiation Benefits and Risks in Decision Making." She is past president of the Radiological Society of New Jersey and recipient of that organization's Gold Medal Award. Active in the American College of Radiology, of which she is a Fellow and former member of the Council Steering Committee, Dr. Timins currently sits on the Commission on Quality and Safety as Vice-Chair for Practice Guidelines and Technical Standards. She is a recipient of the Advisory Committee Service Award of the U.S. Food and Drug Administration, in recognition of distinguished service on the National Mammography Quality Assurance Advisory Committee. The American Association for Women Radiologists has honored Dr. Timins with the Professional Leadership Award for Mid Career/Senior Faculty and the President's Award. In appreciation of service as an Affiliate Member of the Conference of Radiation Control Program Directors, she was presented with the Board of Directors Award for Outstanding Achievement in the Field of Radiation Protection, for participation on the H-30 Task Force and development of the White Paper on Bone Densitometry.

**Richard E. Toohey** received his PhD in physics from the University of Cincinnati in 1973. He spent the first part of his career at Argonne National Laboratory in both research and operational health physics. He recently retired from Oak Ridge Associated Universities, where he served as director of the Radiation Internal Dose Information Center, as Senior Health Physicist for the Radiation Emergency Assistance Center/Training Site, Director of Dose Reconstruction Programs, and Associate Director of the Independent Environmental Assessment and Verification Program. He is currently employed by M.H. Chew and Associates. He is certified in comprehensive practice by the American Board of Health Physics, was the 2008 to 2009 President of the Health Physics Society, is a member and director of NCRP, Treasurer of the International Radiation Protection Association, and Chair of the Scientific Advisory Committee for the U.S. Transuranium and Uranium Registries. His specialties are internal radiation dosimetry, dose reconstruction, and radiological emergency response. Dr. Toohey has 125 publications in the open literature, and is a retired Lt. Colonel, U.S. Army Reserve.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# Notes

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