FINAL PROGRAM

27th Annual Meeting
of the
Council on Ionizing Radiation Measurements and Standards

"STRENGTHENING THE ECONOMY AND HOMELAND SECURITY WITH RADIATION MEASUREMENTS AND STANDARDS"

April 8 – 10, 2019
National Institute of Standards and Technology
Gaithersburg, Maryland

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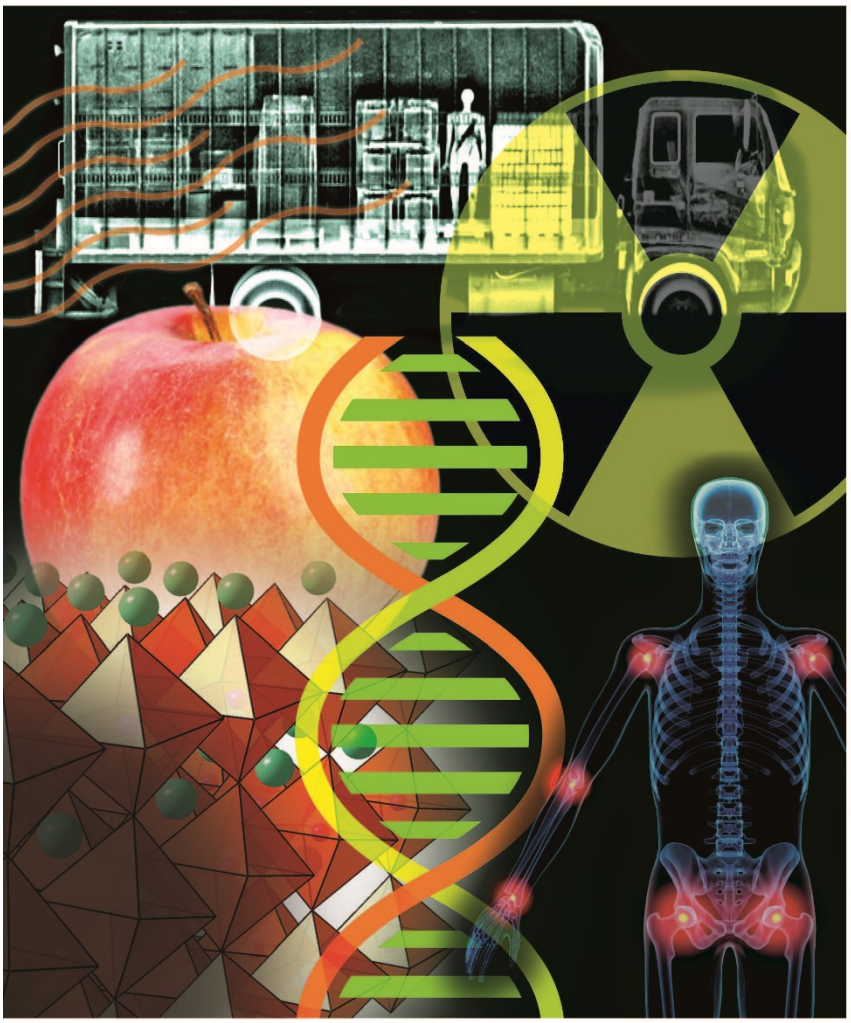
THE COUNCIL ON IONIZING RADIATION MEASUREMENTS AND STANDARDS GRATEFULLY THANKS ITS DISTINGUISHED SPONSORS

CIRMS

COUNCIL ON IONIZING RADIATION MEASUREMENTS AND STANDARDS

Strengthening the Economy and Homeland Security with Radiation Measurements and Standards

27TH ANNUAL MEETING
APRIL 8-10, 2019 • AT NIST, GAITHERSBURG, MD



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* Sponsors of the Junior Investigator Travel Grant Awards and Poster Session Competition

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Radiation Protection & Homeland Security	Stephanie Healey, U.S. Food and Drug Administration
Industrial Applications and Materials Effects	Kim Morehouse, U.S. Food and Drug Administration Roberto Uribe-Rendon, Kent State University
Medical Applications	Ronaldo Minniti, National Institute of Standards and Technology Regina Fulkerson, Varian Medical Systems Wesley Culberson, University of Wisconsin – Madison

MEETING FOCUS

The 27th Annual Meeting of the Council on Ionizing Radiation Measurements and Standards will focus on "Strengthening the Economy and Homeland Security with Radiation Measurements and Standards". For over twenty-five years, CIRMS has played an important role in serving as a public forum for discussion of radiation measurements and standards issues for industry, academia and government. The technical program of the CIRMS meetings consist of oral and poster presentations and three parallel working group sessions that address measurement and standards needs in the following topics:

- Medical Applications: Radiation therapy, dosimetry, radioactivity measurements, diagnostics, imaging, microdosimetry, image guided radiation therapy, radiation biology, phantoms, nuclear medicine, etc.

- Radiation Protection & Homeland Security: advances in detection instrumentation, emergency response, nuclear events, radiochemistry, waste analysis, personnel dosimetry, electronic dosimeters, bioassay and internal dosimetry environmental dosimetry, first responder needs, consequence management, etc.

- Industrial Applications and Materials Effects: radiation processing, material effects, space applications, food irradiation and sterilization, irradiators, low dose standards, safety at radiation facilities, ASTM standards, accelerator design, etc.

We have an outstanding list of speakers this year on a large diversity of topics which will help stimulate discussion among attendees to the conference and help identify challenges and needs to advance the field of ionizing radiation measurements and standards.

NEEDS REPORT EXECUTIVE SUMMARY

The Council on Ionizing Radiation Measurements and Standards (CIRMS) is an independent, non-profit council that draws together experts involved in all aspects of ionizing radiation to discuss, review and assess developments and needs in this field. Drawing upon expertise from government and national laboratories, agencies and departments, from the academic community and from industry, CIRMS has issued four triennial reports on "Needs in Ionizing Radiation Measurements and Standards." Such needs are delineated in Measurement Program Descriptions (MPDs) that indicate the objective, state background information, define needed action items and resource requirements in terms of personnel and facilities.

Each of the subcommittees of the CIRMS Science and Technology Committee has prepared a series of MPDs pertinent to their area of expertise. These emerge through data sharing and focused discussion at CIRMS meetings and workshops. These three subcommittees are:

- The Medical Applications Subcommittee
- The Radiation Protection Subcommittee
- The Industrial Applications and Materials Effects Subcommittee

The most recent Dynamic Needs Report is available on the CIRMS website at
http://www.cirms.org/w/index.php?title=Executive_Summary

FULL MEETING AGENDA AT A GLANCE

MONDAY, APRIL 8, 2019
MORNING PLENARIES - RED AUDITORIUM

8:30 am Registration/ Breakfast on your own

9:00 am **President's Welcome**
Dr. Regina Fulkerson, President, CIRMS

Welcome to NIST
Dr. James Adams
Chief, Radiation Physics Division, Physical Measurement Laboratory
National Institute of Standards and Technology, MD

9:15 am **Introduction to the NEEDS REPORT**
Dr. Walter E. Voit
University of Texas at Dallas

9:30 am **Keynote Address**
Dr. R. Joel England, SLAC National Accelerator Laboratory
Making a Particle Accelerator on a Chip: Recent Advances and Potential Applications
About the Presentation & Speaker:
https://www.youtube.com/watch?v=kG1TUhYLAeM

10:00 am Discussion

10:10 am **Lightning Talks by Poster Presenters**

10:30 am Coffee Break and Poster Viewing

11:15 am **CIRMS Junior Investigator Award Program Presentations**

11:15 am **Junior Investigator Travel Grant Award – sponsored by Landauer**
Emily J. King – University of Wisconsin – Madison, Medical Radiation Research Center
Design of a medium-energy free-air ionization chamber

11:25 am **Junior Investigator Travel Grant Award - sponsored by Hopewell Designs, Inc.**
Irwin Tendler – Dartmouth College, Thayer School of Engineering
Scintillator –based optical Imaging for use in remote surface dosimetry

11:35 am **Junior Investigator Travel Grant Award- sponsored by IBA Industrial, Inc.**
Xiaoya (Judy) Wang – McGill University, Medical Physics
Quantifying differences between theoretical models in calculations of Compton mass energy-transfer coefficients

11:45 am **Junior Investigator Travel Grant Award - sponsored by Sterigenics**
Alexandra Bourgouin – Carleton University, Medical Physics
Determination of W_{air} in high-energy clinical electron beams using aluminium detectors

11:55 pm **Poster Viewing**

12:15-1:30 pm Lunch

AFTERNOON BREAKOUT SESSIONS

1:45 pm **Working Groups Session I**

Medical Applications
- Lecture Room A -

Radiation Protection
- Lecture Room B -

Industrial Applications
- Lecture Room D -

3:15 pm Coffee Break

3:45 pm **Joint Session for Medical Applications, Radiation Protection & Industrial Applications**
- Red Auditorium -

Session Title: Chemistry and Biology of DNA Damage and its Modification
Session Chair: Dr. Amitava Adhikary, Department of Chemistry, Oakland University

5:15 pm Adjourn Day 1

TUESDAY, APRIL 9, 2019
MORNING PLENARIES - RED AUDITORIUM

8:30 am Registration

9:00 am **President's Welcome**
Dr. Regina Fulkerson, President, CIRMS

9:15 am **Plenary Session I**
Dr. Bert Coursey, National Institute of Standards and Technology
Remembering Randy Caswell

Randall S. Caswell Award for Distinguished Achievement in the Field of Ionizing Radiation Measurements and Standards presented to:
Dr. Roberto Uribe, Kent State University

9:45 am **Plenary Session II**
Kip Kelley, Mirion Technologies
Radiation Mapping for Emergency Situations using Unmanned Vehicles – from Slight Contamination to Nuclear Disaster
About the Presentation & Speaker:
https://www.mirion.com/products/incident-prevention

10:15 am Coffee Break and Poster Viewing

10:30 am **Plenary Session III**
Dr. Niek Schreuder, Provision Solutions, LLC
The Economics of Particle Therapy
About the Presentation & Speaker:
https://provisionhealthcare.com/2013/08/01/niek-schreuder-joins-provision-center-for-proton-therapy-as-vp-chief-medical-physicist/

11:00 am **Plenary Session IV**
Dr. Antonio Damato, Memorial Sloan Kettering
Recoil-Based Short-Lived Alpha Emitting Devices: A Novel Brachytherapy Concept
About the Presentation & Speaker:
https://www.mskcc.org/profile/antonio-damato

11:30 am **CIRMS PHOTO** –
Meeting Group Photo for all attendees to the Conference. Don't miss it!
Location: Right outside of the glass doors that exit the building (door steps next to the Red Auditorium)

12:00-1:30 pm Lunch

AFTERNOON BREAKOUT SESSIONS

1:45 pm **Working Groups Session I**

Medical Applications
- Lecture Room A -

Joint Session for Radiation Protection & Industrial Applications
- Lecture Room B -

Session Title: Cesium-137 Irradiators
Session Chair: Dr. Spencer Mickum, Hopewell Designs Inc.

3:15 pm Coffee Break

3:45 pm **Working Groups Session II**

Medical Applications
- Lecture Room A -

Radiation Protection
- Lecture Room B -

Industrial Applications
- Lecture Room D -

5:15 pm Adjourn Day 2

6:45 pm **Dinner at Coastal Flats**
Address:
135 CROWN PARK AVENUE
Gaithersburg, MD 20878

Phone: (301) 869-8800

(approximately 2 miles from NIST)

WEDNESDAY, APRIL 10, 2019
MORNING PLENARIES - RED AUDITORIUM

8:30 am Registration

9:00 am **Welcome Back**
Dr. Regina Fulkerson, President, CIRMS

9:15 am **Plenary Panelists**

Panel Topic: Radiobiology and Blood Irradiators: Transitioning from Cs-137 to X-rays

Dan Aitkenhead, Best Theratronics Ltd.
Challenges of both Gamma and X-ray Blood Irradiators

Keith A. Kunugi, University of Wisconsin - Madison
Considerations for Replacing Isotope-based Irradiators with X-Irradiators at the UW-Madison

Dr. Kei Iwamoto, University of California at Los Angeles
Gamma-irradiators, X-irradiators, and Radiobiology

10:00 am **Panel Discussion** with three panelists

10:15 am Coffee Break

10:30 am **Capstone Speaker**
Dr. Jeffrey Chapman, US Department of Energy
Radiation Protection in the 21st Century – a Look at the Turning Points in the Practice of Radiation Protection to Envision the Future
About the Presentation & Speaker:
https://www.linkedin.com/in/jeff-chapman-8b129b18/

11:00 am **Report on Needs in Ionizing Radiation**
Dr. Walter E. Voit, University of Texas at Dallas
Summaries of the topics discussed in the afternoon sessions with session chairs

Dr. Walter E. Voit, University of Texas at Dallas
Current/Future Work

12:15 pm **Closing Address/ New Officers**
Dr. Regina Fulkerson, President, CIRMS

12:30 pm Lunch

1:30 **CIRMS Executive Committee Meeting**
Meeting from 1:30 PM - 3:30 PM

3:00 pm Adjourn Day 3

MEDICAL APPLICATIONS
MONDAY APRIL 8, 2019 (AFTERNOON)

1:45 PM – 3:15 PM
LECTURE ROOM A

Session Title: Measurement Needs for Validating Dosimetry Methods for Epidemiological Studies of Health Risks Following Radiotherapy
Session Chair: Dr. Matthew Mille, National Cancer Institute, National Institutes of Health

Dr. Jeremy Polf, University of Maryland
Calibrating CT scanners for Patient Dose Calculations in Proton Beam Radiotherapy

Dr. Matthew Mille, National Cancer Institute, National Institutes of Health
Out-of-Field Dose Reconstruction for Studies of Health Risks Following Photon Radiotherapy When DICOM-RT Files Are Available

Dr. David Borrego, National Cancer Institute, National Institutes of Health
Out-of-Field Dose Reconstruction for Studies of Health Risks Following Photon Radiotherapy When DICOM-RT Files Are Not Available

Dr. Choonsik Lee, National Cancer Institute, National Institutes of Health
Overview of the National Cancer Institute's Radiation Epidemiology Branch and Key Challenges Faced when Reconstructing Patient Dose for Epidemiological Applications

Dr. Yeon Soo Yeom, National Cancer Institute, National Institutes of Health
Out-of-field Dose Reconstruction for Proton Therapy and Measurement of Secondary Neutron Dose

3:15 PM – 3:45 PM
Coffee Break

3:45 PM – 5:15 PM
RED AUDITORIUM

Joint Session for Medical Applications, Radiation Protection & Industrial Applications
Session Title: Chemistry and Biology of DNA Damage and its Modification
Session Chair: Dr. Amitava Adhikary, Department of Chemistry, Oakland University

Dr. Michael Dingfelder, East Carolina University
Track Structure: Simulating the Physics and Chemistry Basis of Radiation Damage

Dr. David Becker, Oakland University
A Radiation Chemistry Track Structure Model in 3D for Ion-beam Irradiated DNA

Dr. Shubhankar Suman, Georgetown University
Role of Persistent DNA Damage Response in Heavy-Ion Space Radiation-Induced Carcinogenesis

Dr. Sudipta Seal, University of Central Florida
Understanding the Rare Earth Nanomaterials in Mitigation Radiation in Biological Environment

Dr. Jeffrey Buchsbaum, Radiation Research Program, National Institute of Health
DNA Damage and High LET Radiation and the Clinic – Biologic Dosimetry is the Goal

MEDICAL APPLICATIONS
TUESDAY APRIL 9, 2019 (AFTERNOON)

1:45 PM – 3:15 PM
LECTURE ROOM A

Session Title: Targeted Radionuclide Therapies (TRT)
Session Chair: Dr. Jacek Capala, National Cancer Institute, National Institutes of Health

Dr. Robert Hobbs, Johns Hopkins University
Radiation Dosimetry as a Biomarker

Dr. Sara St. James, University of California San Francisco
Radiation Dose: External Beam Radiation Therapy Conventions and the Evolving Field of Radiopharmaceutical Therapy

Dr. Yuni Dewaraja, University of Michigan
Patient Specific Dosimetry: To What Extent Can It be Simplified to Move from Research to The Clinic

Dr. Bryan Bednarz, University of Wisconsin
Implications of Heterogenous Dose Distributions for Radiopharmaceutical Therapy Revisited

Dr. Richard Wahl, Washington University
Patient-Specific Dosimetry: A Nuclear Medicine Physician Perspective

3:15 PM – 3:45 PM
Coffee Break

3:45 PM – 5:15 PM
LECTURE ROOM A

Session Title: Radionuclide Therapy and Standards
Session Chair: Dr. Wesley Culberson, University of Wisconsin

Elisa Napoli, Oncoinvent
Radium Isotopes as a Weapon Against Cancer

Dr. John Keightley, National Physical Laboratory, United Kingdom.
Recent Progress in Primary Activity Standards and Nuclear Data for Targeted Alpha Therapy

Dr. Brian Zimmerman, National Institute of Standards and Technology
Radioactivity Standards for Image-based, Patient-specific Nuclear Medicine Treatment Planning

RADIATION PROTECTION & CONSEQUENCE MANAGEMENT
MONDAY APRIL8, 2019 (AFTERNOON)

1:45 PM – 3:15 PM
LECTURE ROOM B

Session Title: Radiological Reference Materials for Consequence Management of Nuclear Emergencies
Session Chair: Dr. Stephanie Healey, Food and Drug Administration

Dr. Robert Jones, Center for Disease Control
CDC'S Rapid Radionuclide Bioassay Screen – Updates, New Methods, and Plans for the Future

Dr. Evgeny Taskaev, Eckert & Ziegler Analytics
What is Reference Material for Radioactivity Measurements in Consequence Management

Dr. Bill Cunningham, Food and Drug Administration
The Role of Reference Materials in Risk Analysis for Radionuclides in Food

Dr. Stephanie Healey, Food and Drug Administration
Development of Radiological Performance Testing Program for Food Emergency Response Network (FERN) Method Development and Laboratory Competence Evaluation

Zhichao Lin, Food and Drug Administration
Considerations and Approaches in Development of Food-Based Reference Materials

3:15 PM – 3:45 PM
Coffee Break

3:45 PM – 5:15 PM
RED AUDITORIUM

Joint Session for Medical Applications, Radiation Protection & Industrial Applications
Session Title: Chemistry and Biology of DNA Damage and its Modification
Session Chair: Dr. Amitava Adhikary, Department of Chemistry, Oakland University

Dr. Michael Dingfelder, East Carolina University
Track Structure: Simulating the Physics and Chemistry Basis of Radiation Damage

Dr. David Becker, Oakland University
A Radiation Chemistry Track Structure Model in 3D for Ion-beam Irradiated DNA

Dr. Shubhankar Suman, Georgetown University
Role of Persistent DNA Damage Response in Heavy-Ion Space Radiation-Induced Carcinogenesis

Dr. Sudipta Seal, University of Central Florida
Understanding the Rare Earth Nanomaterials in Mitigation Radiation in Biological Environment

Dr. Jeffrey Buchsbaum, Radiation Research Program, National Institute of Health
DNA Damage and High LET Radiation and the Clinic – Biologic Dosimetry is the Goal

RADIATION PROTECTION & CONSEQUENCE MANAGEMENT
TUESDAY APRIL 9, 2019 (AFTERNOON)
LECTURE ROOM B

1:45 PM – 3:15 PM
LECTURE ROOM B

Joint Session for Industrial Applications & Radiation Protection
Session Title: Cesium-137 Irradiators
Session Chair: Dr. Spencer Mickum, Hopewell Designs Inc.

Dr. Spencer Mickum – Hopewell Designs Inc.
Impact from the Potential Shortage of Cs-137 Supply

Dr. Jacob Kamen - Mount Sinai Hospital
Successful Migration from Radioactive Irradiators to X-Ray Irradiators in One of the Largest Medical Centers in the U.S.A.

Lance Garrison, National Nuclear Security Administration
Development and Certification of Type B Containers for self-shielded irradiators

Dr. Ronnie Minniti, National Institute of Standards and Technology
Air Kerma Calibrations at NIST using Cesium-137

Dan Aitkenhead, Best Medical
Challenges Selling both Gamma and X-ray Blood Irradiators

3:15 PM – 3:45 PM
Coffee Break

3:45 PM – 5:15 PM
LECTURE ROOM B

Session Name: Homeland Security and Radiation Protection
Session Chair: Dr. Stephanie Healey, Food and Drug Administration

Dr. Jack Glover, National Institute of Standards and Technology
Proposals to Improve the Accuracy of Calculating Reference Effective Dose in ANSI N43.17 (Security Screening of Persons)

Robert B. Hayes, North Carolina State University
Novel Nuclear Forensics and Emergency Response Technologies

INDUSTRIAL APPLICATIONS AND MATERIAL EFFECTS
MONDAY APRIL 8, 2019 (AFTERNOON)

1:45 PM – 3:15 PM
LECTURE ROOM D

Session Title: A Consortium for Radiation Science: Development of a Network of Facilities for Industrial Applications with Electron, Gamma-Ray and X-Ray Beam Capabilities
Session Chair: Dr. Mark S. Driscoll, The State University of New York, College of Environmental Science and Forestry

Presentation Titles: The speakers listed below will be giving an introduction and overview to stimulate discussions on this topic with members of the audience.

Dr. Mark S. Driscoll, State University of New York College of Environmental Science and Forestry

Dr. Walter E. Voit, University of Texas, Dallas

Dr. James Adams, NIST

Dr. Mohamad Al-Sheikhly, University of Maryland

* Representative from the International Irradiation Association

3:15 PM – 3:45 pm
Coffee Break

3:45 PM – 5:15 PM
RED AUDITORIUM

Joint Session for Medical Applications, Radiation Protection & Industrial Applications
Session Title: Chemistry and Biology of DNA Damage and its Modification
Session Chair: Dr. Amitava Adhikary, Department of Chemistry, Oakland University

Dr. Michael Dingfelder, East Carolina University
Track Structure: Simulating the Physics and Chemistry Basis of Radiation Damage

Dr. David Becker, Oakland University
A Radiation Chemistry Track Structure Model in 3D for Ion-beam Irradiated DNA

Dr. Shubhankar Suman, Georgetown University
Role of Persistent DNA Damage Response in Heavy-Ion Space Radiation-Induced Carcinogenesis

Dr. Sudipta Seal, University of Central Florida
Understanding the Rare Earth Nanomaterials in Mitigation Radiation in Biological Environment

Dr. Jeffrey Buchsbaum, Radiation Research Program, National Institute of Health
DNA Damage and High LET Radiation and the Clinic – Biologic Dosimetry is the Goal

INDUSTRIAL APPLICATIONS AND MATERIAL EFFECTS
TUESDAY APRIL 9, 2019 (AFTERNOON)

1:45 PM – 3:15 PM
LECTURE ROOM B

Joint Session for Industrial Applications & Radiation Protection
Session Title: Cesium-137 Irradiators
Session Chair: Dr. Spencer Mickum, Hopewell Designs Inc.

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Successful Migration from Radioactive Irradiators to X-Ray Irradiators in One of the Largest Medical Centers in the U.S.A.

Dr. Lance Garrison, National Nuclear Security Administration
Development and Certification of Type B Containers for Self-shielded Irradiators

Dr. Ronnie Minniti, National Institute of Standards and Technology
Air Kerma Calibrations at NIST using Cesium-137

Dan Aitkenhead, Best Medical
Challenges Selling both Gamma and X-ray Blood Irradiators

3:15 PM – 3:45 PM
Coffee Break

3:45 PM – 5:15 PM
LECTURE ROOM C

Session Name: Low Energy Electron Beam Standards and Applications for Industry
Session Chair: Dr. Mark S. Driscoll, The State University of New York, College of Environmental Science and Forestry

Fred Bateman, National Institute of Standards and Technology (NIST)
Low Energy Laboratory Electron Beam Unit

Karl E. Swanson, President, PCT Ebeam and Integration
Current and Developing Applications for Low Voltage Electron Beam Systems

Fred Bateman, Karl Swanson and Ileana Pazos
Panel Discussion on Possible Research using NIST's New Low Energy Electron Beam System

CONFERENCE ABSTRACTS

MONDAY APRIL 8, 2019 - MORNING PLENARIES

KEYNOTE ADDRESS

Making a Particle Accelerator on a Chip: Recent Advances and Potential Applications

R. Joel England[1], Peter Hommelhoff[2], and Robert L. Byer[3]
[1]SLAC National Accelerator Laboratory, Menlo Park, CA, 94025
[2]Department of Physics, Friedrich-Alexander University Erlangen-Nuremberg, Germany, 91058
[3]Department of Applied Physics, Stanford University, Stanford, CA, 94305

Particle acceleration in dielectric microstructures powered by infrared lasers, termed *dielectric laser acceleration* (DLA), is a new and promising area of advanced accelerator research. The idea of using lasers to accelerate subatomic particles dates back even before the coinage of the word “laser.” However, the technology to make such accelerators did not exist until more recently. With the advent of efficient solid-state lasers and a rich variety of nanofabrication techniques developed by the semiconductor industry, scientific research in photonic devices, optical waveguides, and metamaterials for myriad uses (including particle acceleration) has garnered much interest in recent years. An active international community has developed working on photonic structure-based particle acceleration, including government laboratories in both the United States and in Europe, as well as university groups in Israel, US, Germany, Japan, and Taiwan. Applications for a compact accelerator with target energies in the 1-20 MeV range, such as medical radiation oncology or ultrafast electron diffraction (UED), could provide compelling near term uses for a DLA based system. The operating principles are similar in some ways to conventional radio-frequency accelerators but scaled down in operating wavelength and size by 5 orders of magnitude. This change of scale opens up a plethora of new areas of investigation and incorporates fields of study (material science, advanced photonics, laser science, nanofabrication) that are outside the usual framework for conventional accelerators. This may lead to very different operating regimes for light sources based on DLA and to attosecond science developments for understanding atomic and molecular processes on short time scales. We will provide an update on new developments in this area of research and present results from a recent workshop held at SLAC to explore the variety of applications for this technology.

Unmanned Aerial Vehicles (UAVs) Based Radiation Detectors

Kip Kelley
Mirion Technologies

I will provide a brief introduction about the types of unmanned vehicles and regulations. Also, an introduction to SpirMobile Mapping Software to include Dose Equivalent Rate, Nuclide Identification, GPS, Height to Ground Measurements.

The Economics of Particle Therapy

Niek Schreuder
Provision Solutions, LLC

Proton therapy is a technologically advanced form of radiation therapy that is in use since 1952. It is safe and beneficial to many cancer cases since the integral dose is significantly reduced. There are many factors to consider when weighing the costs of any form of therapy. For many patients, the benefits of proton therapy are greater than the costs and this is a driving factor for the increased prevalence of proton therapy in the world. The basics of proton therapy will be discussed and the many factors that go into making a therapy center successful, not only for patients but for the business will be discussed.

Recoil-based Short-lived Alpha Emitting Devices: A Novel Brachytherapy Concept

Antonio L. Damato, PhD, DABR
Memorial Sloan Kettering Cancer Center, New York, New York

A novel brachytherapy approach had recently been proposed permitting the local delivery of alpha radiation at distances multiple millimeters away from the implanted device. The device releases short-lived alpha emitting sources from its surface; these alpha-emitters travel in tissue through diffusion and convection, enabling the irradiation of areas proximal to the implantation site. Based on preliminary results on human subjects and on animals, this approach may permit the use of interstitial devices locally delivering high-LET alpha radiation for the treatment of solid tumors.
Recently, a device of this kind has become available for use in clinical trials in the US, and has been used abroad in animal studies and in humans. DaRT (diffusing alpha-emitters radiation therapy), developed by Alpha Tau Medical (Tel Aviv, Israel) consists of wire containing ^{224}Ra atoms implanted in tissue, emitting by recoil daughter elements ^{220}Rn and ^{216}Po, alpha emitters with < 1 min half life, and ^{212}Pb, with a 10.6 hours half life and whose beta decay products ^{212}Bi and ^{212}Po are alpha emitting. Given the short range of the alpha particles, dose distribution in tissue is regulated by the distribution over time of the emitting atoms, which will depend on their half life, chemical properties and biological interactions, on the density and properties of the tissues through which they diffuse, and on the presence of convection mechanisms such as vasculature. The current understanding of the dose distribution is based on simplified diffusion models of ^{220}Rn and ^{212}Pb. In-vivo experiments in animals have demonstrated that a therapeutic range of ~3mm from the wire can be expected. Variabilities depending on tissue type and vasculature have also been observed.

Plenary Panel on Radiobiology and Blood Irradiators: Transitioning from ^{137}Cs to X-rays

Session Abstract

Cesium-137 and Cobalt-60 irradiators have been used for the past decades for many types of applications including, to name a few, radiation biology research, irradiation of cells, blood irradiation performed at hospitals to prevent the transfer of graft-versus-host disease during blood transfusions, calibration of instruments, radiation dose primary standards, etc. A vast amount of research exists using these radionuclide sources which has served as the backbone for these applications to ensure for example the successful treatment of blood during irradiation as well as helping advance the field of radiation therapy through radiobiology research. Due to the fear that radionuclide irradiators can be stolen for malicious use (e.g. construction of radiation dispersive devices), there has been a need to consider the use of alternative (non-radionuclide) radiation sources such as x-rays and electron beams for these applications. The panel will share their experience of switching to these alternative irradiator sources. We aim to discuss in an open forum how the different characteristics introduced by these new devices such as the different energy spectrum, beam uniformity, depth of penetration, dose values, shelf life of irradiated products, etc.…, may affect some of these applications. The plenary panel session will focus exclusively on radiobiology applications and blood irradiation and aim to identify any needs to be addressed by the community in switching from radionuclide to x-ray and e-beam irradiators.

Challenges of both Gamma and X-ray Blood Irradiators

Dan Aitkenhead

Best Theratronics Ltd

Considerations for Replacing Isotope-based Irradiators for X-Irradiators at the UW-Madison

Keith A. Kunugi

University of Wisconsin

Gamma-irradiators, X-irradiators, and Radiobiology

Kei Iwamoto

University of California Los Angeles

CAPSTONE PLENARY ADDRESS

Radiation Protection in the 21st Century – a Look at the Turning Points in the Practice of Radiation Protection to Envision the Future

Jeffrey Chapman

Oak Ridge National Laboratory

This presentation will cover advances in instrumentation, methods, and information management that will continue to assure the safe handling and use of radioactive and nuclear materials, and radiation generating machines in industry, power, and medicine. I will also discuss the convergence, at least by the IAEA, in the 3S concept which combines holistically, the concepts of Safety-Security-Safeguards into an overall integrated approach to safety and security.

ABSTRACTS OF JOINT SESSION ON CHEMISTRY AND BIOLOGY OF DNA DAMAGE AND ITS MODIFICATION

Session Chair: Dr. Amitava Adhikary, Department of Chemistry, Oakland University

Track Structure: Simulating the Physics and Chemistry Basis of Radiation Damage

Michael Dingfelder
Department of Physics, East Carolina University

Track structure simulations follow the primary charged particle (electrons, protons, alpha particles, light and heavy ions) as well as all produced secondary particles (electrons) from starting or ejection energy down to total stopping, in an event-by-event manner. They therefore provide detailed information on the spatial distribution of energy depositions, ionization or excitation types, or radical species produced in the early physical and chemical stages of radiation action with matter. These Monte Carlo (MC) codes require reliable interaction cross sections for all considered elastic and inelastic interactions with all considered materials. In addition, they also require consistent radiation transport models, as well as realistic geometrical models of the target. Typically, these codes simulate infinite transport in a homogeneous 3-dim medium to determine the initial physical energy depositions and locations of created chemical radicals. Then, the initial damage patterns are overlaid with geometrical models to simulate and determine biological outcomes such as initial DNA damage, etc. In this talk we will review the state of the art of charged particle track structure simulations and present a selection of typical biological endpoints.

A Radiation Chemistry Track Structure Model in Three Dimensions for Ion-beam Irradiated DNA

David Becker[1], Amitava Adhikary[1], Thomas Baumann[2], Keaton Curran[1], Cameron G. Hanson[1], Kari Macfarlane[1], Samuel Ward[1], and Michael D. Sevilla[1]
[1]Department of Chemistry, 146 Library Drive, Oakland University, Rochester, MI 48309. [2]National Superconducting Cyclotron Laboratory, Michigan State University, 640 S. Shaw Lane, East Lansing, MI 48824

As ion-beam clinical applications become more prevalent and long-distance space missions are contemplated, an increased understanding of the effects of high energy ions on DNA becomes desirable. A double strand break embedded in a clustered damage site is difficult for cellular repair and may result in cell death or mutagenesis. Multiple damage sites within *ca.* 10 base pairs generally qualify as a damage cluster, and it has been estimated that up to 90% of the energy deposited with densely ionizing radiation results in clustered damage sites. Thus, the spatial locations and proximity of damage sites are relevant to the cellular effect of the damage. Our research has focused on characterization of the location, in three dimensions, of the various types of damage (i.e., strand breaks, base damage) that occur in ion-beam irradiated DNA and the radiation chemical processes that lead to them.

Experiments are performed on hydrated DNA samples which are not in a bulk aqueous environment, so that the effect of •OH is minimized and direct-type effects predominate. In the experiment, approximately 12 small (*ca.* 10 mm x 4 mm x 1 mm) samples are stacked in a sample packet and ion-beam irradiated at 77 K. The beam traverses the samples, with the Bragg peak positioned such that the last three or four samples remain unirradiated. Each small sample is analyzed, using ESR, for trapped radicals at 77 K, and, after warming to room temperature, for unaltered base release using HPLC. Unaltered base release is assumed to be a good measure of strand break formation.

At 77 K, nine different radicals have been identified in ion-beam irradiated samples to date, three base radicals, four sugar radicals, and two phosphorus-centered radicals. In Kr-86 irradiated samples, the yield of unaltered bases is the same as the total yield of trapped sugar radicals at 77 K, indicating, as has been hypothesized earlier, that, in ion-beam irradiated DNA, sugar radicals are the precursors to strand breaks. (Curiously, in γ-irradiated DNA, the unaltered base release yield exceeds the yield of sugar radicals, indicating that a fraction of the strand breaks formed do not originate with preformed sugar radicals.)

The Radiation Chemical Track Structure Model that results proposes that the high energy density in the beam core results in a high concentration of radicals in the core, and that, even at 77 K, rapid recombination between oppositely charged free radicals due to Coulomb attractions depletes the concentration of charged radicals in the core. However, neutral sugar radicals, formed by early rapid deprotonation of sugar cation radicals, survive and are trapped in the core. Very early excited state reactions of the guanine and adenine cation radicals in the core, before recombination can occur, results in excess guanine and adenine base release, relative to γ-irradiated samples. The model also postulates that γ-irradiation-like spurs are formed in the ion-beam penumbra, and that the trapping of radicals in the penumbra mimics that which would be found in γ-irradiated DNA. Because of the theoretically proposed $1/r^2$ fall off of dose with radial distance in the penumbra, a good deal of base damage should occur in the vicinity of the core, resulting in difficult-to-repair damage clusters. In addition, relative to γ-irradiated DNA samples, there is a higher concentration of the immediate strand break radicals C3´•$_{dephos}$ and $ROPO_2^{\bullet -}$, formed from low energy electrons, observed. Their presence suggests that there are mechanisms for strand breaks in the core which are not significant in the penumbra, likely resulting in an increased clustered damage in the core. With the proposition that the penumbra is □-radiation like with regard to radical trapping, the energy

partition between the beam core and beam penumbra is determined, and matches well that calculated from track structure models.

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Role of Persistent DNA Damage Response in Heavy-ion Space Radiation-induced Carcinogenesis

Shubhankar Suman[1], Kamal Datta[1], Santosh Kumar[1], Albert J Fornace Jr[1].
[1]Department of Oncology, Lombardi Comprehensive Cancer Center, Georgetown University Medical Center, Washington DC

Ionizing radiation (IR) exposure to astronauts during deep space exploration such as a mission to Mars remains a major health concern due in part to chronic exposures to galactic cosmic radiation (GCR). The main components of GCR are subatomic particles (protons, neutrons and alpha particles) and only less than 1% are heavy, high energy particles (HZE), however due to their high linear energy transfer (high-LET) characteristics, HZE contribute significantly to a total dose received by an astronaut. It is expected that a return trip from Mars will result in a cumulative radiation dose of about 20 cGy from a daily dose of about 481 μGy to astronauts from GCR. A three-year Mars mission is expected to expose astronauts to 1200 mSv of total radiation dose, which is significantly higher than background radiation on the Earth surface.

Cancer is a known long-term health risk for astronauts undertaking deep space missions and considered a potential "show-stopper" for Mars mission. The overarching goal of our research is to understand gastrointestinal (GI) cancer risk by providing biological insight on radiation quality effects, deciphering molecular events involved in GI-carcinogenesis, and to identify plausible targets for chemoprevention. To bridge knowledge gaps in radiation quality effects on GI carcinogenesis and associated signaling pathway perturbations, we exposed wild-type and genetically-engineered mouse models to simulated space radiation at NASA space radiation laboratory (NSRL) and compared results with low-LET γ-rays data up to 12 months after exposure.

HZE radiation-induced higher levels of persistent oxidative stress marked by increased accumulation of intracellular reactive oxygen species (ROS) in mouse intestine compared to γ radiation. The oxidative DNA damage was higher, while cell death was unchanged, and mitotic activity was increased after HZE radiation. Space radiation exposure also triggered a time-dependent progressive increase in DNA double strand breaks (DSBs) marked by γH2AX and 53BP1 foci accumulation along with alterations in DNA damage and repair signaling. A subset of proliferative GI stem cells showed permanent exit from cell cycle and become senescent. Also, a sub-population of the senescent cells acquired the senescence-associated secretory phenotype (SASP), and this was accompanied by increased cell proliferation, implying a role for pro-growth inflammatory factors. We also found a plausible correlation in persistent DNA damage, alterations in DNA repair response, and cellular senescence with GI carcinogenesis. Further, when we knocked out Wip1 phosphatase, a negative regulator of DNA damage-signaling pathway, we found that HZE-induced tumorigenesis was completely abrogated, which further affirms the role of DNA damage response in space radiation-induced tumorigenesis. Overall, this study is important in understanding heavy ion radiation-induced DNA damage response and GI cancer risk and has implications for developing preventive strategies against the tumorigenic potential of space radiation.

Understanding the Rare Earth Nanomaterials in Mitigation Radiation in Biological Environment

Sudipta Seal
Materials Science Eng, AMPAC, Nanoscience Technology Center, College of Medicine

Radiation exposure leads to the generation of oxidative stress inducing reactive oxygen species (ROS) and reactive nitrogen species (RNS) which possess significant threat to the normal functioning of cellular DNA, proteins and lipids. Irradiation effects include changes in the cellular oxidation state, which affects the mitochondrial function, inducing/inhibiting numerous pathways and finally leading to cellular apoptotic processes. Primary effects of irradiation include damage to the cellular environment via direct-type and indirect pathways. However, the chemical events involve free radical processes that lead to secondary radicals; reactions of these radicals result in the generation of plethora of ROS/RNS and further oxidative damages to DNA/RNA leading to cascade of unwanted genetic and molecular reactions. We have developed and engineered rare earth-based cerium oxide nanomaterial (CNP) which leads to reduce the oxidative stress and successive DNA/RNA damages. Work in our laboratory and our collaborative efforts have established that CNP possess unique auto regenerative antioxidative property. This unique property of CNP makes it a promising therapeutic reagent with protective effects on biological tissues against radiation, preventing laser-induced retinal damage and gastrointestinal epithelium from radiation-induced damages by reducing ROS and RNS levels and upregulating antioxidative properties, apart from providing protection against radiation-induced pneumonitis.

DNA Damage and High LET Radiation and the Clinic – Biologic Dosimetry is the Goal

Jeffrey Buchsbaum
NCI, DCTD, RRP Clinical Radiation Oncology Branch, Bethesda, MD 20892-1682

The talk will be a formal presentation discussing the grand challenge of biologic treatment planning in radiation oncology with a focus on conventional radiation, particle therapy, and the complexity each may bring to the clinic.

The concept of RBE will be introduced. The methods currently employed to “define” it including models in the literature and in treatment planning systems, both in the lab and in the clinic, will be described.

New data supporting how different types of radiation can be seen as “drugs” will be presented in the clinical context. Biological definitions of dose will be presented from the cell culture to the organism to the model device. Monte Carlo calculation systems/environments with biological extensions will be discussed and efforts to prepare the field for the ultimate form of precision medicine, biological treatment planning that is adaptive to the patient will be discussed.

The talk will be one of futurism and review designed to give the audience a perspective on this grand problem and where the field is possibly headed. Primary data will be presented in terms of active projects and research opportunities that are newly available within NCI.

ABSTRACTS OF JOINT SESSION ON CESIUM-137 IRRADIATORS

Session Chair: Dr. Spencer Mickum

Impact from the Potential Shortage of Cs-137 Supply

Spencer Mickum
Hopewell Designs Inc.

Session overview: The status of the supply of cesium-137 will be covered during this session and linked with the recent domestic push to eliminate cesium chloride in blood irradiators - and its impact on the overall radiation industry. The need will be presented for cesium-137 as an industry standard for radiation calibration and a description of the challenges to a decreased supply will be discussed, touching on the shipping of Cesium-137.

Successful Migration from Radioactive Irradiators to X-Ray Irradiators in One of the Largest Medical Centers in the U.S.A.

Jacob Kamen
Mount Sinai Hospital

A case study will be presented on the turnover of a hospital system from using cesium-based irradiators to x-ray radiation-based ones. This presentation will show that the change was overall a success and that both routine hospital applications as well as research applications can be accomplished using an alternative technology to the radioisotope. Emphasis will be on the process to change over as well as several comparison research studies.

Development and Certification of Type B Containers for Self-shielded Irradiators

Lance Garrison
National Nuclear Security Administration

A description will be presented of the cesium irradiation replacement project and the recent legislation that came out encouraging the use of x-ray devices when possible. Viewpoints will include the present status of the NNSA's Type B container development and the ability to transport self-shielded irradiators.

Air Kerma Calibrations at NIST using Cesium-137

Ronaldo Minniti
National Institute of Standards and Technology

A brief review will be presented of the use of cesium-137 irradiators at NIST for maintaining the standard for air kerma and it's dissemination to the end user ensuring traceable measurements to a national standard. The impact of this capability throughout the user community will be discussed.

Challenges Selling both Gamma and X-ray Blood Irradiators

Dan Aitkenhead
Best Theratronics Ltd.

Best Theratronics Ltd. produces blood irradiators currently targeted by the cesium replacement program and will describe the current state of the market given the domestic legislation as well as the company's viewpoint on their future trajectory. The presentation will focus on the challenges of selling both gamma and x-ray irradiators in a global market. The trend in x-ray irradiators is towards units with a self-contained water supply. The challenge for gamma irradiators is that there are now a limited number of countries still accepting caesium-137 sourced units.

CDC'S Rapid Radionuclide Bioassay Screen – Updates, New Methods, and Plans for the Future

Robert L. Jones, PhD
Centers for Disease Control and Prevention, Atlanta, GA, 30341

CDC has been developing a series of urine radionuclide screening and quantitative methods (Radio-Bioassay) to monitor and assess potential internal radiological contamination in people after a radiological or nuclear incident. There are over twenty priority radionuclides considered likely to be present after possible radiological accidents, or incidents like a radiological dispersal device. Rapid identification and quantification for these priority radionuclides is a critical need in determining who has been contaminated, with what radionuclide(s), and how much they have been contaminated, which provides critical information for rapid medical management, treatment and follow-up for hundreds or thousands of people possibly contaminated.

Efforts to enhance our capabilities and capacities include improving existing radiobioassay analytical methods, (e.g. through automation). We have optimized our NaI gamma automated screening systems so that we can load 400 samples on a tray and the system can be unattended while the system analyzes all 400 samples. We have developed/implemented method improvements, specifically for Sr-90, using more "production" type instruments to leverage existing CDC capabilities and make the method faster, easier, and more capable. We have made significant progress on the isolation of Sr-90 from urine by eliminating the labor-intensive vacuum box system with an automated extraction system. We are working to implement this with other radionuclides that have to be extracted using a vacuum box system.

We have also developed several new CLIA compliant analytical methods to increase the number of priority threat radionuclides so we can analyze these in people. We intend to continue method development and improvements in the future, eventually extending our capabilities to have CLIA compliant methods to rapidly analyze all priority radionuclides. Here we report our recent improvements, new methods and future plans.

What is Reference Material for Radioactivity Measurements in Consequence Management

Evgeny Taskaev
Eckert and Ziegler Analytics, Inc.

Current regulatory environment and good laboratory practices require Radianalytical Laboratories to use Reference Materials (RM), Calibration standards, Laboratory QC samples, sources for daily checks of the instruments etc. and to perform analysis of Performance Testing (PT) Samples. Metrology, traceability and usage of those sources is not well definedand somewhat is a gray area.

Developing a Reference Material is a long and expensive process and major National Metrology Institutes (NMI) cannot produce enough Reference Materials (RM) to satisfy industry needs. They have even less capabilities to provide PT samples.

There are efforts in the industry to address shortage of RM and develop reasonable approach based on MARLAP and Measurements Quality Objectives. Application to consequence management radiation measurement is discussed.

The Role of Reference Materials in Risk Analysis for Radionuclides in Food

William Cunningham, Ph.D.
Office of Regulatory Science, Center for Food Safety and Applied Nutrition, U.S. Food and Drug Administration, College Park, MD 20740

Analysis of reference materials (RMs) is an accepted practice in the analysis of nearly all chemical contaminants, including radionuclides. The analysis of reference materials helps ensure that the measurement process and methodology are in control and provide assurance that findings are reliable. They are a critical component of a chemical measurement process. The question of what their role is in risk analysis, however, can seem like a 'trick question'.

Risk analysis (RA) guides the radionuclide in food monitoring program at the U.S. Food and Drug Administration (FDA), and the RA process is comprised of three major components - risk management, risk communication, and risk assessment. Although all three are integrally connected in a kind of equilibrium and with equal importance, it is also true that all efforts feed into the risk management component, because the overall objective is to make sound food safety decisions. Metrology and the function of RMs typically attract minimal attention from risk managers, who focus on overarching issues associated with radionuclide levels, food safety, and messaging to the various stakeholders (the public, state authorities, media, etc.). RMs, therefore, play an important role in radionuclide analysis, but largely in the background.

Development of Radiological Performance Testing Program for Food Emergency Response Network (FERN) Method Development and Laboratory Competence Evaluation

Stephanie Healey, Zhichao Lin, Patrick Regan
Winchester Engineering and Analytical Center, U.S. Food and Drug Administration
109 Holton Street, Winchester, MA 01890

FERN radiological laboratory network is tasked to safeguard nation's food supply from radioactive contaminations. In view of diverse radioanalytical methods used in analysis of a wide variety of foods by member laboratories with varying levels of experience, assessments of method acceptability and laboratory proficiency with respect to FERN's data quality objectives are of vital importance for achieving rapid emergency response and effective consequence management. Despite its importance, development and validation of radioanalytical methods for detecting radioactive contaminants in foods are often constrained by lack of food-based radioactive standards that fit specific methodological needs. Dissemination of new methods and implementation of matrix extension studies within FERN radiological network are also complicated by unavailability of suitable food-based reference materials. The lack of food-based proficiency test samples in representation of different contamination pathways and sources has made it difficult to realistically assess laboratory under real-world conditions. To overcome these challenges, a study project is initiated by FDA to establish a performance-based radiological proficiency testing program in compliance with ILAC-G13, ISO/IEC 17043, and ANSI N42.23. With successful implementation of the PT testing program, it can make FDA better positioned to address radiological food safety and defense concerns with support of a proficient and well prepared radiological laboratory network. Various food-based radioactive PT samples characteristic to different food groups and contamination pathways made available by the program will enable more efficient and comprehensive radioanalytical MDVP studies leading to significantly improved method viability and applicability. In a concerted effort to harmonize radioanalytical methods, the program will also make it possible for FERN radiological laboratories to identify and fulfill method improvement needs arising from analyzing foods with radionuclides and matrices of concern. As an accredited radiological PT program, it will provide a basis for achieving data comparability and traceability and enable prompt and confident decision making, thus positively impacting food safety and public health. This presentation summarizes the approaches in development of various PT test schemes, fit-for-purpose reference materials, performance evaluation method, collaborative method development, network data sharing, and methodology-driven training course.

Considerations and Approaches in Development of Food-Based Reference Materials

Zhichao Lin, Stephanie Healey, Patrick Regan
Winchester Engineering and Analytical Center, U.S. Food and Drug Administration
109 Holton Street, Winchester, MA 01890

With growing risks posed by global aging nuclear facilities and widespread use of radioactive materials, FDA faces increasing challenges in safeguarding the nation's food supply from radioactive contaminations that may arise from nuclear accidents or acts of nuclear terrorism. In the aftermath of a large-scale nuclear or radiological incident, FDA relies on its Food Emergency Response Network (FERN) to gather radioanalytical data from analyzing a wide variety of foods for risk assessment and decision making. To uphold FERN radioanalytical program in compliance with ISO/IEC 17025, commercially available radionuclide standards and rad PT samples are used for instrument calibrations and laboratory performance evaluations. However, lack of suitable food-based radiological PT samples for addressing various methodology and performance issues has prevented FERN from fully evaluating its radioanalytical capability and competency. The unavailability of fit-for-purpose radiological testing materials has been particularly problematic for FERN radiological laboratories to conduct Method Development and Validation Program (MDVP) studies and demonstrate laboratory proficiency. Difficulties and anomalies can arise from radionuclide characteristics, matrix disparities, and sample preparations depending on radioanalytical method used. For instance, analysis of radionuclides exhibiting cascade decay and foods with varying densities by gamma-ray spectrometry requires proper corrections of summing and attenuation effects. It is also known that matrix disparity and radiometric interference can cause abnormalities in preconcentration and separation of radionuclides of interest while performing food analysis. Therefore, it is important for radiological PT samples to be tailored for addressing different method and performance concerns related to radionuclide decay, matrix variation, and sample heterogeneity. In order to meet the needs of FERN rad laboratories, a study project aimed to provide various fit-for-purpose rad PT materials for FERN method validation and laboratory proficiency evaluation is initiated, which is set to develop and produce fresh food products containing radioactive "hot-spot" to mimic heterogeneous nature of food contamination, spiked foods with varying densities for sample-self attenuation correction, foods spiked with cascade decay radionuclides for coincidence-summing correction, foods spiked with fresh fission products imitating radioactive fallout from nuclear power plant accident, food ashes from a variety of foods spiked with radionuclides of concern, etc. This presentation details the considerations and approaches in identification, selection, and development of food-based testing materials used by FERN radiological laboratory network for laboratory competency evaluation and a wide range of radioanalytical method validations.

RADIATION PROTECTION & HOMELAND SECURITY ABSTRACTS

TUESDAY APRIL 9

Proposals to Improve the Accuracy of Calculating Reference Effective Dose in ANSI N43.17 (Security Screening of Persons)

Jack Glover[1,2] and Larry Hudson[1]
[1]National Institute of Standards & Technology, 100 Bureau Drive, Gaithersburg, MD 20899
[2]Theiss Research, 7411 Eads Ave, La Jolla, CA 92037

In today's world, people are intentionally exposed to ionizing radiation for the purpose of security screening. In the US, the national standard that provides guidelines and specific limits for the radiation-safety aspects of the operation of these systems is ANSI/HPS N43.17: Radiation Safety for Personnel Security Screening Systems Using X-Ray or Gamma Radiation. System designs include backscatter systems, transmission portal systems, multi-source systems, and scanners for occupied vehicles.
The ANSI N43.17 standard is undergoing formal revision. The current standard provides a simple formula for "reference effective dose" (EREF) and limits for EREF on a per screening and annual basis. While the formula has the virtue of being simple to use, in real-world applications it has often underestimated the effective dose by up to 30 % relative to more sophisticated methods of estimating dose to persons. We identify four underlying causes for these inconsistencies and propose new formulations for EREF that greatly improves the agreement while still trying to maintain a simple recipe for estimating exposures.

Novel Nuclear Forensics and Emergency Response Technologies (Poster 18)

Robert B. Hayes[1], S. Joseph Cope[1], Ryan P. O'Mara
[1]Nuclear Engineering Department, North Carolina State University, Raleigh, NC, 27695-7909

The research being done at NC State spans an impressive array of technology aimed at radiological emergency response and nuclear nonproliferation forensics. These include radiological air monitoring [1-3], retrospective characterization of nuclear materials [4-6], use of ubiquitous dust particulate as a dosimeter [7], emergency response biodosimetry at the natural background level [8], differential isotopic diffusion [9] and even novel radiation detection platforms [10]. These will all be reviewed in this presentation.

1) Cope SJ, Hayes RB. Preliminary work toward a transuranic activity estimation method for rapid discrimination of anthropogenic from TRU in alpha air samples. *Health Physics.* **114**(3):319-327, 2018
2) Cope SJ, Hayes RB. Emergency Response Transuranic Activity Assay Method for Mixed Alpha/Beta Air Samples. *Trans. Amer. Nuc. Soc.* **119**, p1006-1009, Orlando, Florida, November 11–15, 2018
3) Cope SJ, Hayes RB. Mass Correlation of Presumed Twin Air Filters for Emergency Response Applications. *Trans. Amer. Nuc. Soc.* **117**, 1159-1161, 2017.
4) O'Mara RP, Hayes RB. (2018) Dose deposition profiles in untreated brick material. *Health Physics* **114**(4), 414-420.
5) Hayes RB. Retrospective uranium enrichment potential using solid state dosimetry techniques on ubiquitous building materials *J Nuc Mat Mgmt.* (in press)
6) Hayes R. B., O'Mara RP. Some Spatial Limitations in Retrospective Dosimetry with Bricks When Sample Size is Large. *Trans. Amer. Nuc. Soc.* **117**, 1026-1028, 2017.
7) Hayes RB, O'Mara RP. Enabling Nuclear Forensics Applications from the Mineral Particulate in Contamination Surveys. *Advances in Nonproliferation Technology and Policy Conference*, Wilmington, NC, Sep 23-27, p200-204, 2018.
8) Hayes RB, O'Mara RP. (2019) Retrospective dosimetry at the natural background level with commercial surface mount resistors. *Radiat. Meas*. **121**, 42-48.
9) Hayes RB. Differential Isotopic Diffusion in Nuclear Forensics of Fallout. *Advances in Nonproliferation Technology and Policy Conference*, Wilmington, NC, Sep 23-27, p213-216, 2018
10) Hayes RB. Evaluation of BC-454 for Gamma Spectroscopic and Neutron Detection Applications. *Advances in Nonproliferation Technology and Policy Conference*, Wilmington, NC, Sep 23-27, p196-199, 2018.

MEDICAL APPLICATIONS ABSTRACTS

MONDAY, APRIL 8

Session Topic: Measurement Needs for Validating Dosimetry Methods for Epidemiological Studies of Health Risks Following Radiotherapy

Overview of the National Cancer Institute's Radiation Epidemiology Branch and Key Challenges Faced when Reconstructing Patient Dose for Epidemiological Applications

Choonsik Lee
Radiation Epidemiology Branch, Division of Cancer Epidemiology and Genetics, National Cancer Institute, National Institutes of Health, Bethesda, MD

Advanced imaging methods combined with modern linear accelerator (LINAC) technologies have made it possible to deliver radiation precisely to the targeted tissue. Nonetheless, even the most careful treatment planning still results in unavoidable dose to nearby normal tissues. The impact of this unintended dose on patient long-term health is of increasing concern as survival rates improve. In particular, radiotherapy is known to be an important contributor to second primary cancers and cardiovascular disease which may occur many years after treatment. Furthermore, the efficacy of emerging treatments such as proton and heavy ion therapies have yet to be evaluated through long-term epidemiological follow-up. Improved knowledge on the relationship between organ dose and late health effects is critical for the optimization of treatments and the development of preventative measures for mitigating toxicity, thereby improving quality of life of future survivors. Consequently, the Radiation Epidemiology Branch (REB) of the National Cancer Institute, Division of Cancer Epidemiology and Genetics has initiated or is participating in a number of epidemiologic studies of radiotherapy patients. Radiation exposure assessment is a critical component of these efforts.

Dose reconstruction for epidemiological studies of radiotherapy patients poses a significant challenge. Commercial treatment planning systems (TPS) work well in-field but are not accurate out-of-field where dose can span more than three orders of magnitude. Monte Carlo radiation transport simulation methods can more accurately account for scatter radiation in the patient or LINAC and leakage radiation but are computationally slow. These difficulties become especially apparent in the context of epidemiological studies which typically involve a large number of patients who were treated many years in the past, for whom anatomical images may be inaccessible, and for whom only limited radiotherapy plan information may be known. To resolve these issues, the REB's Dosimetry unit is developing a novel radiotherapy dosimetry system entitled NCIRT. This system combines computational phantoms, accelerated Monte Carlo simulation, and the NIH High-Performance Computing cluster to provide organ dose estimates. This talk will describe the on-going multi-institutional effort to develop and validate NCIRT. The application of NCIRT method to branch and extramural epidemiologic/clinical studies will be described in subsequent talks in this session.

Out-of-Field Dose Reconstruction for Studies of Health Risks Following Photon Radiotherapy When DICOM-RT Files Are Available

Matthew Mille
Radiation Epidemiology Branch, Division of Cancer Epidemiology and Genetics, National Cancer Institute, National Institutes of Health, Bethesda, MD

A key feature of the NCIRT method for radiotherapy dose reconstruction is the capability to interface with Digital Imaging and Communications in Medicine radiotherapy (DICOM-RT) files which can be retrieved from hospital image archives. For prospective epidemiological studies and clinical trials these data can be exported from the radiotherapy treatment planning system (TPS) and consist of a RTPLAN file describing the radiotherapy plan (beam energy, field size, gantry angle, etc.), a RTSTRUCT file containing the target and normal tissue contours, and an accompanying computed tomography (CT) describing the patient's anatomy. Dose in the out-of-field region is calculated using the accelerated x-ray Voxel Monte Carlo (XVMC) code. The RTPLAN and CT images are used to create an input file for an XVMC simulation of the treatment. Dose is tallied for each voxel in the CT image as well as for each structure described in the RTSTRUCT file. On-going work aims to expand our simulation capability to cover a wide variety of machine types (Cobalt, MV LINAC, Proton LINAC), treatment parameters (beam energy, field size, manufacturer etc.), and LINAC accessories (MLC, physical wedges, dynamic wedge etc.). A key challenge, however, is that measurement data for benchmarking our simulations is not readily available in all cases of interest.

As an example, this presentation will describe how the NCIRT method is being used to reconstruct out-of-field organ dose for 5,000 patients in the National Wilms Tumor Study (NWTS) late-effects cohort. We share data for a pilot study involving 20 patients selected from the NWTS cohort. As CT images of the patients were unavailable, surrogate images were acquired from the Quality Assurance Review Center archive. The treatments consisted of simple AP-PA portals that were easy to reconstruct based on bony landmarks and medical records. The treatment plans were created on the patient images using a commercial TPS at Northwestern Memorial Hospital. The DICOMRT data were then exported from the TPS for performing dose calculations in the XVMC code.

Out-of-Field Dose Reconstruction for Studies of Health Risks Following Photon Radiotherapy When DICOM-RT Files Are Not Available

David Borrego
Radiation Epidemiology Branch, Division of Cancer Epidemiology and Genetics, National Cancer Institute, National Institutes of Health, Bethesda, MD

Substantial improvements in breast cancer treatments, predominantly comprised of radiotherapy in initial treatment, combined with increasing incidence rates have resulted in three million breast cancer survivors in the US. The long-term health of these patients is a clinical and public health concern, with an estimated 10% developing a second cancer ten years after diagnosis. Randomized trials established that radiotherapy results in a reduction of breast cancer mortality 15 years after treatment; However, these trials and other observational studies also demonstrated that radiotherapy increases cardiovascular mortality and second cancer risks, particularly for women with left-sided breast cancer. Reducing these side-effects through careful treatment planning is possible, but some dose to the heart, lungs, esophagus and contralateral breast is unavoidable, especially with certain treatment fields. Using a previously developed retrospective cohort of breast cancer survivors from two Kaiser centers we hope to improve our understanding of the risks associated with high-dose fractionated photon radiotherapy. As CT images and detailed radiotherapy plans (DICOM-RT) are not retrievable from the hospitals for this study, proxy cohorts of breast radiotherapy patients have been established. Using electronic medical record linkage, we are developing methods incorporating breast cancer radiotherapy field information in our exposure assessment of this cohort. We are reporting on a work-in-progress reconstructing out-of-field doses to the lung, heart, and esophagus for these patients using Monte Carlo radiation transport simulations and reference patient models. In this presentation we will identify the dosimetry needs in support of epidemiological studies designed to study radiogenic health risks from photon radiotherapy treatments.

Calibrating CT scanners for Patient Dose Calculations in Proton Beam Radiotherapy

Jerimy C. Polf
Department of Radiation Oncology, University of Maryland School of Medicine, Baltimore, MD

Proton radiotherapy is known for its ability to deliver a uniform dose to a tumor while also delivering a reduced dose (compared to the prescribed tumor dose) to the tissues proximal to the tumor, and a sharp dose falloff at the distal edge of the tumor with little or zero dose delivered to tissues distal to the tumor. However, the realization of these benefits in actual patients depends critically on the ability to accurately calculate the range of the beam and dose delivered to the patient. Uncertainties arise due to limitations in daily patient setup, changes to internal anatomy over the course of treatment, and from limitations in our ability to calculate dose deposition using standard computed tomography (CT) scans. CT scanners used for proton beam treatment planning and dose calculation must have a calibration curve to convert the CT-number of each pixel (in Hounsfield units (HU)) to proton Stopping Power Ratio (SPR) relative to water. The most common method used clinically for HU-to-SPR calibration is the stoichiometric method. Several new methods based on direct determination of SPR from dual energy CT (DECT) scans are beginning to find their way into clinical use. This talk will review the steps of the stoichiometric method for clinical CT scanner calibration, as well as how non-biological materials (hip implants, surgical clips, etc.) in the body are accounted for in the calibration process. We will discuss the uncertainties associated with and limitations of the calibration process and how they affect current proton beam radiotherapy treatments. Additionally we will discuss new methods of determining SPR from DECT scans of the patient, and its potential to overcome some of the uncertainties and limitation of the standard stoichiometric calibration method.

Out-of-field Dose Reconstruction for Proton Therapy and Measurement of Secondary Neutron Dose

Yeon Soo Yeom
Radiation Epidemiology Branch, Division of Cancer Epidemiology and Genetics, National Cancer Institute, National Institutes of Health, Rockville, MD

In radiation treatment of cancer, protons have a great potential to improve treatment conformability and reduce doses to surrounding normal tissues compared with conventional radiation treatments with photons and electrons. However, the dosimetric benefit of proton therapy may be diminished by the fact that normal tissue doses are attributed mostly to

secondary neutrons, the relative biological effectiveness (RBE) of which for cancer induction is uncertain but could be more than 20. Understanding the late effects in proton therapy patients is critical especially for children, who are at a higher risk than adults on long-term adverse health effects and have a long-life expectancy. As a first international effort to address this critical issue, the International Pediatric Proton Therapy Consortium (IPPTC), led by the National Cancer Institute, was launched to conduct large-scale collaborative research on late effects in children following proton therapy. The accuracy in the result of this epidemiological study highly depends on the dosimetry quality, requiring a precise dosimetry method using Monte Carlo (MC) simulation of proton delivery to patients. Simulated doses to normal tissues must be validated by comparison with measurement of out-of-field secondary neutron doses. In this talk, we will introduce our MC model of proton spot scanning beams established by using the TOPAS MC code for dose reconstruction of pediatric patients at the Maryland Proton Treatment Center (MPTC). The results of our experimental validation of secondary neutron doses and technical challenges in the measurements will be discussed.

MEDICAL APPLICATIONS ABSTRACTS

TUESDAY, APRIL 9

Introduction to the Session on Targeted Radionuclides Therapies

Jacek Capala
Division of Cancer Treatment and Diagnosis, *National Cancer Institute, National Institutes of Health*

External radiation therapy employs advanced imaging and sophisticated treatment planning systems to arrive at optimal dose distribution and, thereby, provide the best treatment for individual patients. Similarly, appropriate assessment of the radiation doses deposited in the tumor and normal tissues is crucial for the success of targeted radionuclide therapies (TRT). The advance in imaging and radiation transport allows new approaches to radionuclide therapy treatment planning. By administration of the dosimetric (trace-labeled) dose, and determination of the patient's residence time (a measure of how long the radionuclide is retained in the body), the therapeutic dose can be precisely adjusted to maximize the therapeutic effect and minimize toxicity. To offer the best possible treatment, prospective treatment planning should be performed and a patient-specific maximally tolerated therapeutic radiation dose should be used.

Unfortunately, the current routine prescribing dosage of pharmaceuticals based on the patient weight or body surface is suboptimal and does not utilize the full potential of SRT. Adequate assessment of radiation doses in individual patients and their correlation with the tumor and normal tissues response to radiation is particularly important for analyzing the outcome of clinical trials combining SRT with new chemotherapeutical agents. In addition, the ability to assess the radiation doses delivered by SRT will enable its combination with external RT.

Dosimetry as a Biomarker

Robert F. Hobbs
Johns Hopkins University

Radiopharmaceutical therapy (RPT) is recently undergoing a resurgence in interest, motivated in particular by the recent success of $^{223}RaCl_2$ in the treatment of prostate cancer bone metastases. RPT has commonalities with both chemotherapy as well as traditional radiation modalities such as external beam radiotherapy (EBRT) or brachytherapy. As with chemotherapy, RPT is a systemic therapy where the efficacy will be determined by the specific targeting ability of the pharmaceutical to the disease sites relative to normal organs susceptible to induce toxicity. As with EBRT, the damage to normal tissue and disease is mediated by radiation. More analogous to brachytherapy, this radiation is due to the radiative decay of the radionuclides introduced into the body. Both EBRT and brachytherapy achieve a high level of patient-specific treatment planning using the absorbed dose (AD) as the base currency for both tumor efficacy and normal organ toxicity, a product of decades of data and correlative studies. In chemotherapy, there are no direct measurements of localization and pharmacokinetics of the drug; surrogates for efficacy and toxicity known as biomarkers are searched for and studied for quality of correlation. A logical option is to consider the AD from the RPT as a biomarker: numerous studies have shown correlations between AD and outcome, both for tumor efficacy and normal organ toxicity. That the AD is the cause rather than a consequence of the therapy does not affect its value as a biomarker. Furthermore, in this dosimetry could and should be considered not only the calculation of absorbed dose, but the study of all biomarker/outcome correlates, most of which will most certainly have some connection to or be derived from the AD. Importantly, since pre-therapeutic or theranostic administration of activity coupled with imaging can predict ADs, this biomarker and its derivatives can be used prospectively.

Radiation Dose: External Beam Radiation Therapy Conventions and the Evolving Field of Radiopharmaceutical Therapy

Sara St. James
University of California San Francisco

Nearly two thirds of cancer patients will be treated with radiation therapy and the majority of these patients will have treatments with external beam radiation therapy (photons, electrons or protons). In external beam radiation therapy, models of each and every patient are generated from anatomic images (CT and/or MRI) and the dose to the disease (targets) and healthy structures (organs at risk) are optimized for each patient. For external beam radiation therapy, the core of the quality assurance program relies on traceable calibrations of equipment used to measure radiation dose. Radiopharmaceutical therapy (RPT) is an evolving form of radiation therapy where dose calculations, optimization and calibration are not currently standardized. A comparison of the needs for external beam radiation therapy dose calculations and RPT dose calculations will be presented, along with a discussion of challenges in achieving uncertainties in calculated dose for RPT that would be acceptable in external beam radiation therapy.

Patient Specific Dosimetry in Radionuclide Therapy: To What Extent Can it be Simplified to Move from Research to the Clinic

Yuni K. Dewaraja
Department of Radiology, University of Michigan Medical School

The commercial availability of hybrid SPECT/CT and PET/CT facilitates highly patient specific non-uniform dosimetry down to the voxel level using the patient's own emission imaging based activity maps and CT-based density maps. There is much interest in performing such calculations for dosimetry-driven radionuclide therapy treatment planning instead of using approximations that rely on reference phantom models. Thus far, 3D patient specific dosimetry has been mostly limited to the research setting because of the demand on clinic resources and the imaging burden to patients. Simplifying the dosimetry procedure will facilitate translation to clinical practice, but estimates derived from simplified protocols must first be carefully evaluated/validated by comparison with more sophisticated approaches. Potential simplifications include reducing the imaging time points used for estimating the time-integrated activity and performing voxel-level dosimetry assuming local energy deposition instead of calculations based on Monte Carlo radiation transport for radionuclides that are pure beta emitters (e.g. Y-90) or have only low intensity gamma-rays (e.g. Lu-177). Examples from studies performed at University of Michigan (UM) as well as findings from other recent reports in Lu-177 DOTATAE and Y-90 DOTATOC PRRT, I-131 MIBG and Y-90 radioembolization will be presented. In a pilot dosimetry study of patients (28 neuroendocrine tumors, 16 kidneys) who underwent Lu-177 DOTATATE PRRT at UM the best agreement between single and multi-time point SPECT/CT based Monte Carlo derived absorbed dose estimates, considering both lesions and organs, was generally achieved when ~ day 4 post-therapy was used as the single time point: using this time point, the %difference between single and multi-point absorbed dose estimates had a median value of 4% (range -6% to 16%) for kidney. The agreement for lesions had a wider range (median 0.3%, range -26% to 45%), but was within 20% for 70% of the lesions. In general, the differences were larger for smaller lesions and lesions that were difficult to define. The generally good agreement between absorbed dose estimates based on single and multi- SPECT/CT show the potential for simplifying the protocol for lesion and kidney dosimetry guided treatment in Lu-177 PRRT.

Implications of Heterogenous Dose Distributions for Radiopharmaceutical Therapy Revisited

Bryan P. Bednarz, Ph.D.
University of Wisconsin-Madison

It has been almost 20 years since O'Donoghue investigated the biological consequences of nonuniform dose distributions for radiopharmaceutical therapy. This talk will revisit these calculations in the context of today's evolving radiopharmaceutical therapy paradigm. Under the assumption of a given acceptable loss and uncertainty in tumor control or normal tissue complication rate the required accuracy of patient-specific dose delivery can be derived. The impact of these accuracy requirements on clinical trial design and clinical treatment planning will be considered.

Patient Specific Dosimetry: A Nuclear Medicine Physician's Perspective

Richard L. Wahl, M.D.
Mallinckrodt Institute of Radiology
Washington University School of Medicine, St. Louis, MO

Targeted Radiopharmaceutical Therapies are growing in importance with both alpha and beta emitting therapies FDA approved in the US. In addition, there has been substantial commercial investment in this form of therapy. Most currently approved therapies are either a "one administered radioactivity dose fits all" or have a simple weight based adjustment. If therapeutic margins are large, such simple dosing algorithms are relatively easily deployed in clinical practice. However, many radiopharmaceuticals have heterogeneous biokinetics and biodistributions in vivo. In such settings, one dose fits all approaches, particularly if the therapeutic margin is modest, potentially will underdose patients on average to achieve safety. We have observed 4-6 fold differences in radiation dosimetry in anti CD20 radioimmunotherapeutics. Approaches to integrate dosimetry into treatments can allow more predictable toxicities or profound dose escalations. Deploying dosimetry, especially organ dosimetry, requires technical expertise and suitable theranostic agents. It seems inevitable that dosimetry will be increasingly applied clinially, but careful studies to define the value of such an approach vs. simpler methods are in order. This lecture will review some of our experiences with dosimetry based therapeutics and highlight the logistical barriers to widespread deployment of such methods.

Radium Isotopes as a Weapon Against Cancer

Elisa Napoli
Oncoinvent

Alpha emitting radionuclides, due to their short penetration depth, are capable of destroying tumors while causing very limited damage to surrounding healthy tissue. In fact, an emitted alpha particle will not travel further than 6 cell diameters (*i.e.*, 50 µm to 100 µm). Moreover, compared to other radionuclide therapies, their high linear energy transfer (LET) results in a much more effective treatment, since just a few alpha particles through a cell nucleus are sufficient to produce DNA double strand breaks that deter cancer cell self-reparation.
The discovery of radium by Maria Skłodowska-Curie in 1898, represents a unique chapter in the history of natural sciences. Ra-226, among all isotopes of radium, has the longest half-life ($T_{1/2}$=1600 years) and is also the most abundant isotope in nature, coming from the U-238 family. Other naturally occurring radium isotopes are Ra-228, Ra-224 and Ra-223. In the first third of last century, radium was used extensively in medical practice as it was considered a universal remedy. However, it was later discovered that bone cancer may occur in subjects exposed to Ra-226. Nonetheless, at intermediate dose levels (below 20 Gy to the bone) no significant increase in cancer was observed in humans. Nowadays, there is only one FDA approved α-emitting radiopharmaceutical: Ra-223 ($^{223}RaCl_2$) under the name of Xofigo, distributed by Bayer and is used for treatment of patients with skeletal metastases from prostate cancer.Radium-224 (^{224}Ra), with its convenient half-life of 3.6 days, is a future candidate to be used against micro-metastatic disease from ovarian cancer, that will go under clinical trials in Europe in 2019. NIST has begun work to standardize Ra-224 activity, which will be described in this talk.

Recent Progress in Primary Activity Standards and Nuclear Data for Targeted Alpha Therapy

John Keightley
Principal Research Scientist, National Physical Laboratory, Nuclear Metrology Group, Teddington, TW11 0LW, United Kingdom

Targeted alpha therapy is a rapidly evolving discipline, referring to an emerging class of revolutionary cancer agents delivering alpha-particle-emitting radiopharmaceuticals selectively to cancerous lesions via attachment to appropriate ligands and carriers. Clinically effective alpha particle–emitting radionuclides for cancer therapy exhibit short half-lives, (limiting long-term radiation exposure to patients) and exhibit a high level of radiobiological effectiveness (due to the high-energy and short-range of the alpha radiation) thus limiting damage to non-cancerous surrounding tissue.
The calculation of the absorbed dose delivered to malignant and surrounding normal tissue is a key parameter in optimizing the effectiveness of these treatment modalities, requiring accurate assessment of the activity administered to patients (via demonstrable traceability of clinical Dose Calibrator assay to primary activity standards) as well improvements in the knowledge of radioactive decay scheme parameters/nuclear data for the radionuclides employed.
This report reviews the current status of measurement and standardization needs for Targeted Alpha Therapy, and details recent work performed at the United Kingdom's National Physical Laboratory (and worldwide), to address these key measurement issues for the Targeted Alpha Therapy radiopharmaceuticals ^{223}Ra, ^{227}Th and ^{224}Ra each of which may be considered as the parent of a radioactive decay-chain. The nuances of radioactive decay (and associated progeny ingrowth) for each radionuclide on activity measurements (for primary and secondary standardizations, as well as clinical use) are detailed.

Radioactivity Standards for Image-based, Patient-specific Nuclear Medicine Treatment Planning

Brian E. Zimmerman
National Institute of Standards and Technology, Gaithersburg Maryland

Within the past few years, there has been substantial interest in raising nuclear medicine treatment planning to the same level of rigor that is already required for brachytherapy and external beam radiotherapy. Regulatory requirements, as well as government investment, help serve as strong motivators for this trend.

Adoption of this approach has been hampered by the lack of the necessary metrology tools to ensure accurate and reproducible data at each step in the care of the patient. Radioactivity standards are needed to ensure accurate and reproducible imaging data and to ensure accurate dosage administration. The National Institute of Standards and Technology (NIST) has a specific program dedicated to the development of radioactivity standards for nuclear medicine applications and transferring those standards to clinical end users. Most of the early work of this program was centered on the development of standards for therapeutic applications. While our recent focus has been on developing radioactivity standards for quantitative imaging (e.g., PET, SPECT), work on therapeutic radionuclides, particular alpha-emitters continues to be important. The outputs of this program now make it possible to calibrate the radioactivity measurement instrumentation associated with dosage administration and the scanners to the same standards, thereby providing traceability for all the measurements.

In order to realize truly patient-specific treatment planning and bring it into clinical practice, it will be necessary to make the link between measurements of radioactivity and of absorbed dose. Our future work will be expanded to include the development of in-vivo and in-vitro techniques to determine absorbed dose from systemically administered radionuclides in a way that is traceable to standards of both quantities. It is hoped that in this way, quantifiable relationships can be established between administered dosage, absorbed dose, and patient response.

This talk will discuss the recent work being done by NIST to develop standards for quantitative medical imaging and radionuclide therapy, focusing on our recent work on calibrated PET phantoms and new therapeutic radionuclides. Finally, needs for future standards, including linking radioactivity and absorbed dose together, will be presented.

JUNIOR INVESTIGATOR AWARD ESSAYS

CIRMS Junior Investigator Award Essay – sponsored by Landauer

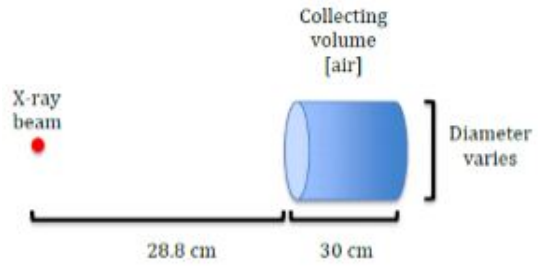
Design of a Medium-energy Free-air Ionization Chamber
(Poster 1)

Emily J. King, Jennifer L. Hull, Larry A. DeWerd
University of Wisconsin
Medical Radiation Research Center

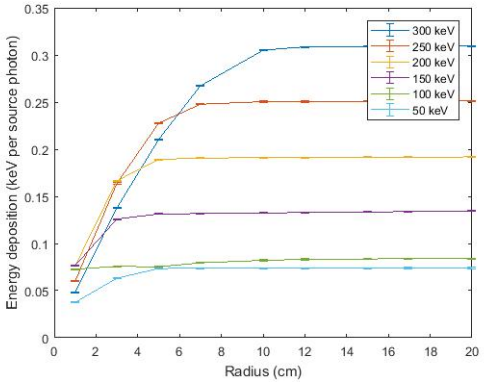
Objective: X-rays ranging from 50 - 300 kV are often used for radiobiology experiments. Often, irradiators designed to produce these medium range x-rays for these experiments are not well characterized or calibrated. Free-air ionization chambers (FAC) are absolute measurement devices that measure exposure directly by collecting ions produced by the electrons resulting from x-ray interactions in a known mass of air and can be used as the standard for X-rays. The purpose of this work was to design and build a FAC for the medium X-ray energy range to be used as a calibration tool and for characterizing these types of x-ray sources. The design is based on the UW Attix FAC[1] and the FAC at the National Radiation Standard Laboratory (NRSL, Taiwan)[2], both which employ a cylindrical chamber of variable length. The variable chamber length allows for the effects of electric field distortion at the ends of the chamber to be removed so electric field uniformity and plate alignment does not need to be maintained. This work will outline the design phase of this project.

Methods: The design of the FAC system was made through collaboration with staff mechanical engineers in the UWMRRC. The size of the FAC, a diameter of 30 cm, was based on Attix's advice in his proposed FAC design and was confirmed through the use of a model in the MCNP6 (Monte Carlo N-Particle 6, Los Alamos, New Mexico) transport code and an energy deposition tally in air. Correction factors were calculated using the EGSnrc (Electron Gamma Shower, National Research Council of Canada) application egs_fac, which is a self-consistent approach for calculating correction factors for scatter, electron loss, and aperture leakage. A shadow correction factor, which corrects for electrons striking the collecting rod before depositing their energy, was calculated using egs_fac as well. The correction factors were determined using monoenergetic photons and are convolved with the X-ray spectrum of the beams or sources being used. The results were validated by comparing the correction factors to the NRSL's correction factors for a FAC of similar size and design. Tolerance testing was done using egs_fac and electric field modeling was done with COMSOL Multiphysics (Stockholm, Sweden). The design was then created using SolidWorks (Waltham, Massachusetts).

Results: A 30 cm diameter collecting volume for the FAC was determined to be sufficient in collecting the electrons produced by photons up to 300 keV (Figure 1). The walls will contribute to scatter and electron loss but will be corrected by correction factors.



(a)



(b)

Figure 1: (a) Monte Carlo setup for determining size of FAC. (b) Energy deposited in different radii collecting volumes. Curves level off once all energy is deposited in the collecting volume.

Figure 2 shows the schematic of the FAC in its extended position. The design has three aluminum cylinders: a fixed center cylinder and two cylinders on either end that are connected to motor stages and limit switches. These cylinders will be at high voltage and the aluminum collecting rod will be at ground to create an electric field. The collecting rod passes through an insulator in the back end of the chamber and connects to an electrometer via a coaxial cable. The aperture will be made of tungsten alloy and machined to a diameter of 1 cm. The lead shielding is present to avoid in-scattered external photons from contributing to the signal.

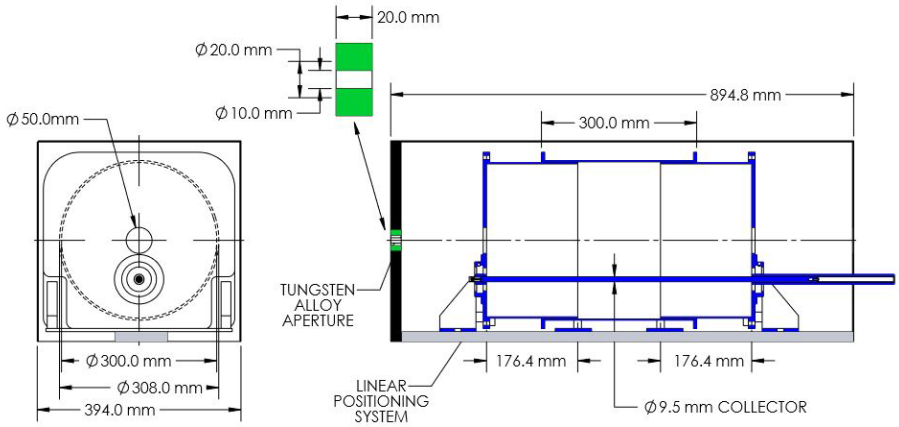
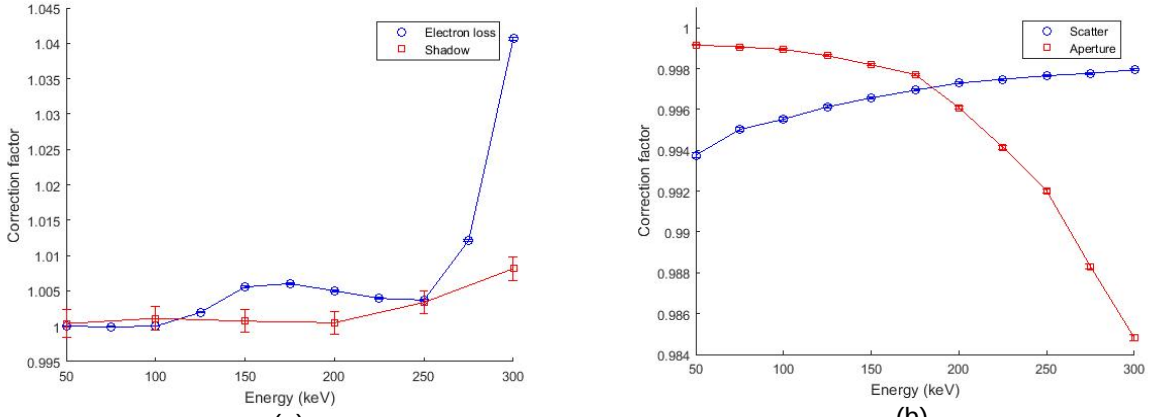


Figure 2: Schematic of the front view and lateral view of the FAC where it is partially extended. The colors denote materials: green is tungsten alloy, black is lead and blue is aluminum.

The scatter correction factors for monoenergetic photons, in increments of 25 keV, are shown in Figure 3. The correction factors approach a value of 1 as energy increases, as higher energy scattered photons more easily leave the chamber without depositing energy first. The electron loss and shadow correction factors for monoenergetic photons are also shown in Figure 3. When the energy of the photons is less than 125 keV, the electron loss correction is approximately 1 because the walls of the chamber are outside of the range of the electrons. Likewise, the shadow correction is approximately 1 until the photon energy reaches 100 keV. The energy is lower because the collecting rod is closer to the beam than the walls. The correction factors have small peaks where the main interaction type switches from photoelectric effect to Compton scatter. The aperture correction for monoenergetic photons is also shown in Figure 3.



(a) (b)

Figure 3: (a) Calculated results of monoenergetic electron loss and shadow correction factors. (b) Calculated results of monoenergetic scatter and aperture correction factors.

Conclusion: A FAC suitable to measure the medium x-ray energy range was successfully designed. The design outlined here is currently in the process of being built. Future work will include testing the FAC with x-ray beams with known air kerma rates.

Relevance to CIRMS mission and first author's goals: This work is a portion of the master's level work performed by the first author involving the design of a medium-energy FAC. This work relates to the CIRMS mission as it can be used directly for dosimetry and calibration with a focus on medium energy x-rays that were previously unable to be measured at the UW. Presently there are no standard beams for the radiobiological X-ray beams. The first author's goal is to become a clinical/academic medical physicist and currently works in a laboratory focused on metrology.

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Scintillator-Based Optical Imaging for Use in Remote Surface Dosimetry
(Poster 2)

Irwin Tendler[1], Petr Bruza[1], Michael Jermyn[1], Benjamin Williams[2,3], Lesley Jarvis[2,3], Brian Pogue[1,3], David Gladstone[1,2,3]
1. *Thayer School of Engineering, Dartmouth College, Hanover, NH 03755*
2. *Department of Medicine, Geisel School of Medicine, Dartmouth College, Hanover, NH*
3. *Norris Cotton Cancer Center, Dartmouth-Hitchcock Medical Center, Lebanon, NH*

Objective:
In radiotherapy, verifying surface dose is essential to both minimizing negative skin reaction and ensuring treatment prescription is executed correctly.[1] Current methods for measuring surface dose either rely on application of wired probes or wireless devices requiring post-exposure processing. The time and resources required for these processes place a burden on radiation oncology staff, thereby minimizing the use surface dosimeters in the clinic.[2,3] Thus, there exists a need for a technology capable of reporting surface dose rapidly, remotely, and with limited human input. This research focuses on the development of an imaging system that captures scintillation emission from plastic discs, attached directly to the patient skin surface, and converts their corresponding pixel intensities to surface dose.

Materials and Methods:
Following preliminary design tests[4], custom-machined discs (15 Ø x 1 mm thick) composed of EJ-212 scintillating plastic (Elijen Technologies, Sweetwater, TX) were selected as candidate samples for this study. An intensified camera (CDose; DoseOptics, Lebanon, NH) was time-gated to linear accelerator pulses and positioned to the side of the gantry head of a linear accelerator (linac). Acquired images were online background subtracted, spatial and temporal median filtered, darkfield subtracted, and flat-field corrected. A MATLAB (MathWorks, Natick, MA) image-processing algorithm was created to convert detected scintillator light output to dose. After fitting a Gaussian-convolved-ellipse function to each scintillator region of interest (ROI) per frame, the maximum amplitude of the fit was summed across all frames producing a single value for each dosimeter. This result was converted to dose using an empirically derived calibration factor.[5] An overview of the imaging setup is shown in Figure 1.
Scintillators were attached to a flat-faced phantom and irradiated using photon and electron beams from a medical linear accelerator (linac) (Varian Medical Systems, Palo Alto, CA). Tests were conducted to evaluate scintillator: dose linearity, radiation damage resistance, emission spectra, as well as energy, temperature, dose rate, angle, and distance dependence. Furthermore, in a human pilot study, the ability of scintillator dosimeters to report surface dose for patients undergoing Total Skin Electron Therapy (TSET) was assessed and compared to standard Optically Stimulated Luminescence Detectors (OSLDs).

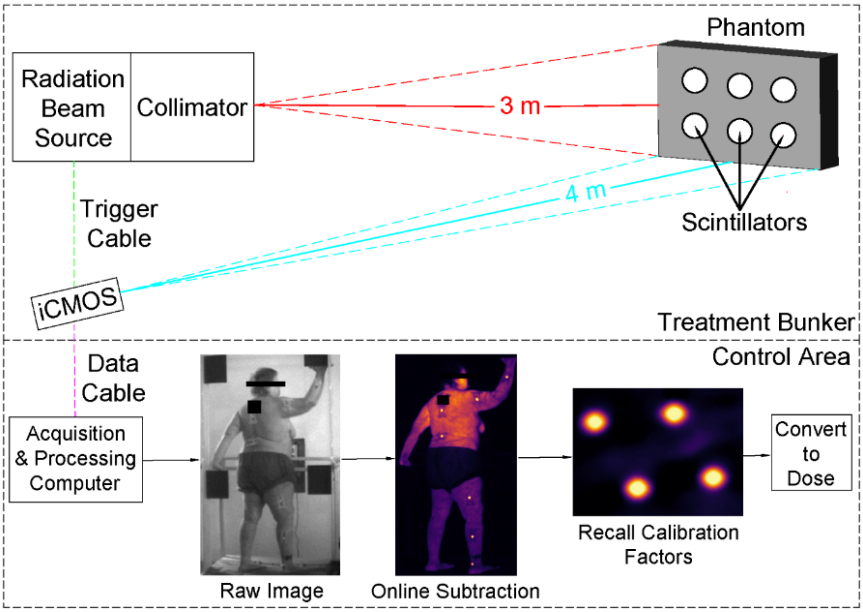

Figure 1: An illustration of the imaging setup. Linac is represented by “radiation beam source” and corresponding “collimator”. Image acquisition is time-gated to linac pulses; a trigger cable is attached between the signal panel of the linac and the camera. Image data is sent to a computer located outside of the treatment bunker via optical data cable.

Results:
It was found that scintillators have a linear response to dose; when comparing scintillator output to dose measure by OSLD, a linear relationship with $R^2 = 0.99$ (RMSE = 3.4e3) exists, Figure 2A. The scintillators function independent of: energy (linear relationship with dose for 6 – 18 MeV electrons, $R^2 = 0.99$, and 6 – 18 MV photons, $R^2 = 0.98$, Figure 2B), dose rate (data shows ≤ 0.05% change from mean across all dose rates tested, Figure 2C), temperature (0.69 ± 0.02% increase in signal for 10° C – 40° C, Figure 2D), angle (camera-scintillator or incident radiation-scintillator ∠ = 0° – 55°)[5], and distance (change in camera-scintillator distance ≤ 1.5 m)[5]. Scintillators were found to have a maximum wavelength of emission of 422 nm, Figure 2D, and are resistant to radiation damage up to 15,000 Gy (0.2% decrease from mean), Figure 2F.

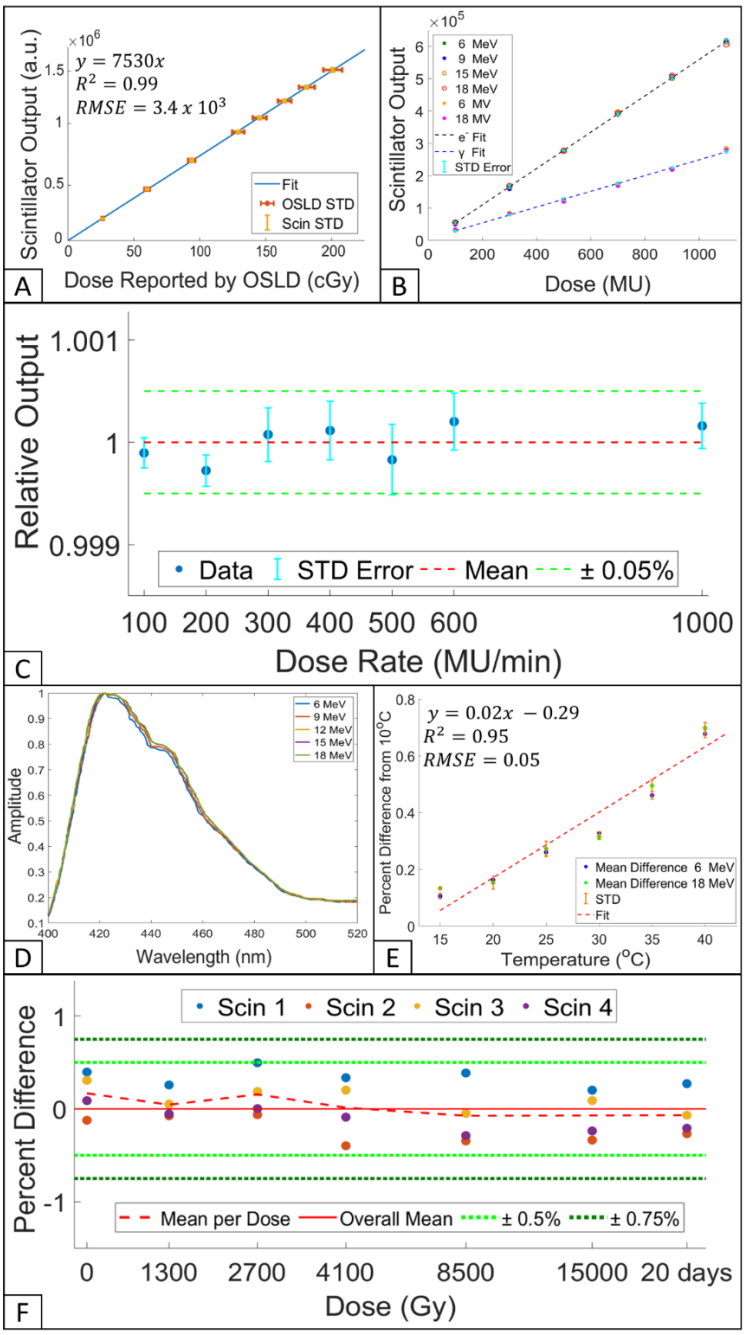

Figure 2: Results for scintillator characterization tests.

Scintillators were used to measure surface dose in 5 patients undergoing TSET. Sample cumulative images containing Cherenkov and scintillation intensity maps are shown in Figure 3. Scintillator light output is not impacted by tissue optical properties as is seen in Cherenkov emission where a distribution of Cherenkov pixel intensities is observed.

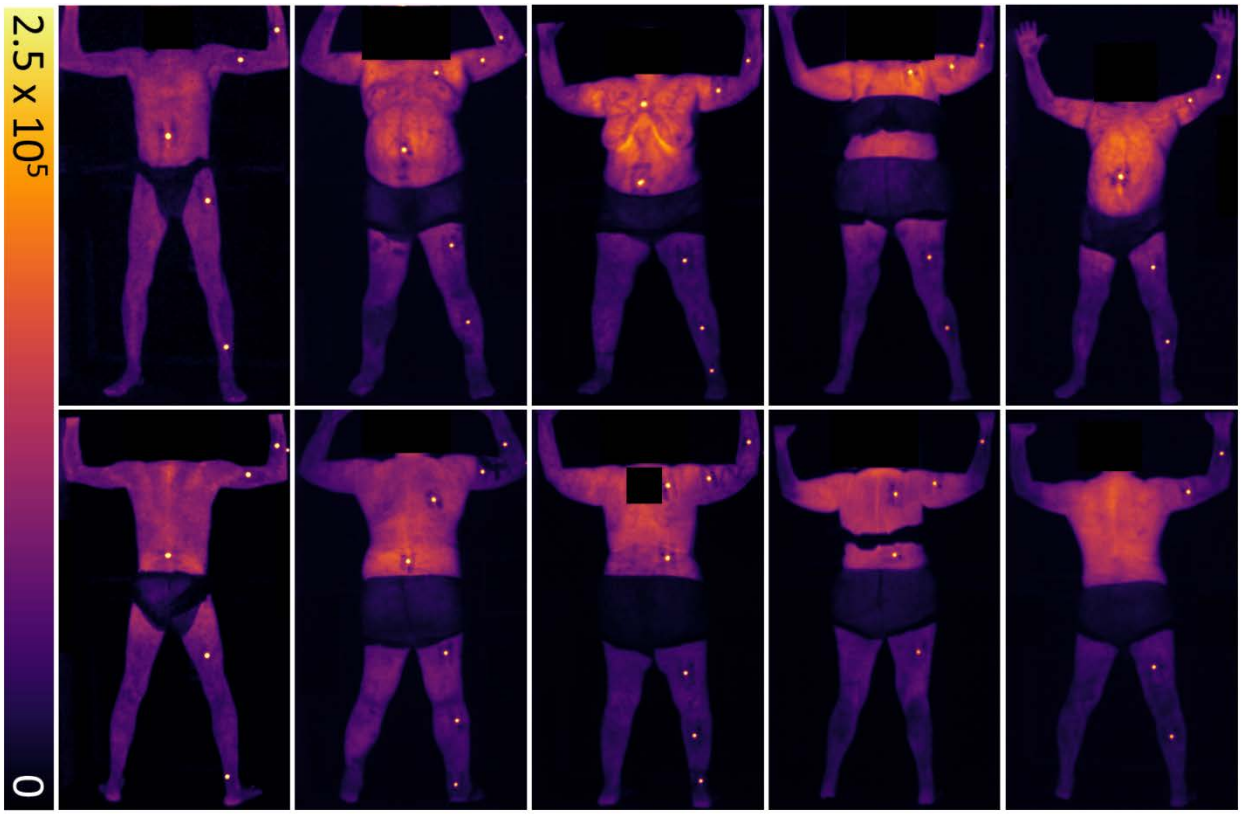

Figure 3: Cumulative, background-subtracted, Cherenkov, and scintillation-intensity maps for patients undergoing total skin electron therapy. Color-intensity scale is in digital units.

When analyzing surface dose reported per dosimetry site, it was found that there exists a linear correlation (R^2 = 0.95 & RMSE = 1.1 cGy) between scintillator and OSL dosimeters (Figure 4A). Compared to OSLDs, scintillators reported surface dose in TSET patients with < 5% and < 3% difference in 162/163 and 147/163 cases, respectively (Figure 4B).

Conclusions and Significance:

Scintillator dosimeters have been shown to accurately measure surface dose in both phantom and human studies. Independence of energy, dose rate, temperature, etc. of these dosimeters make them ideal for radiotherapy clinical dosimetry applications. Use of scintillators can streamline surface dosimetry-associated workflow.

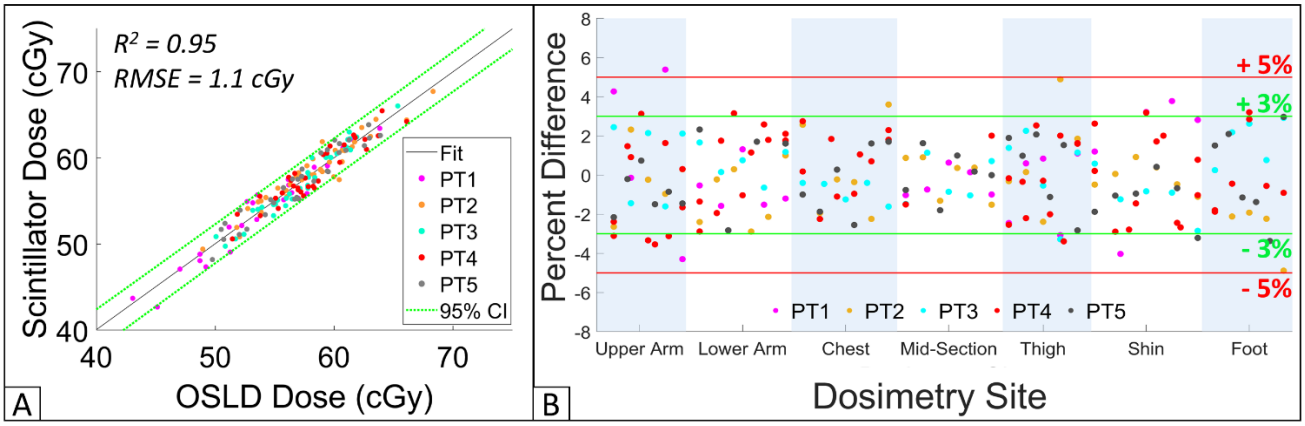

Figure 4: Comparison of surface dose measured by scintillator and OSLD for 5 patients undergoing TSET.

Relevance to CIRMS:

This body of work addresses a need in clinical surface dosimetry, it therefore aligns with one of CIRMS' primary goals: to "discuss, review and asses developments and needs" of therapeutic ionizing radiation. My professional goals are to develop a career in clinical medical physics. As I progress forward, I hope to actively engage in image-related research to improve the standard of care in radiation oncology. Given that CIRMS is a widely recognized forum for discussion of radiation measurement-related topics, I plan on actively reading reports originating from and participating in future council meetings. This project is related to the mission of CIRMS because it proposes a potential solution to a scientific and technical issue in radiation therapeutics.

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Quantifying Differences between Theoretical Models in Calculations of Compton Mass Energy-transfer Coefficients

(Poster 3)

X.J. Wang[a], B. Miguel[b], J. Seuntjens[a], J.M. Fernández-Varea[c]

[a]McGill University, 3600 University, H3A 2T8, Montréal, Québec, Canada

[b]Universidad Politécnica de Cartagena, Paseo Alfonso XIII 44, E-30203 Cartagena, Spain

[c]Universitat de Barcelona, Diagonal 645, E-08028 Barcelona, Catalonia, Spain

Background and Objective

Basic photon interaction data used in dosimetry, such as mass energy-transfer and mass energy-absorption coefficients, require as a main component the incoherent scattering energy-transfer fractions [1]. The simplest approach for calculating incoherent scattering cross sections is the Klein-Nishina (KN) model, in which the photon is scattered by a free electron initially at rest. As an improvement on KN, a well-known and frequently-used approximation is the Waller-Hartree (WH) model which accounts for binding effects approximately through the incoherent scattering function, but which neglects the spread in energy of photons scattered at a given angle. The relativistic impulse approximation (RIA) incorporates both binding effects and Doppler broadening and yields an expression for the DDCS differential in outgoing photon angle and energy. The key ingredient to the calculation of the RIA cross sections is the Compton profile (CP) of each atomic or molecular orbital, which is computed from the corresponding linear momentum distribution. The atomic CPs typically used are from the tabulation of Biggs et al [2].

An important and frequently cited source of photon interaction data is from Seltzer [3], who derived mass energy-absorption coefficients for elements and compounds using the WH model for Compton binding effects. In addition, interaction coefficients for compounds used in dosimetry were modeled using an independent-atom approach.

In this work we investigated for three materials of dosimetric interest (air, water, and carbon) the impact of using a molecular CP on the Compton energy-transfer cross section derived within the RIA. We also studied the difference between the RIA and the WH approach to modelling binding effects. The new energy-transfer cross sections are relevant for μ_{tr}^{C}/ρ values in the tens of keV range, where for these materials Compton becomes the dominant interaction.

Methods

We calculated Compton cross sections within the RIA [4], which includes relativistic effects. The CPs were integrated from momentum densities obtained through self-consistent Hartree-Fock calculations, with wave functions expanded in a cc-pVTZ Gaussian basis set [5]. We performed the RIA calculations employing both molecular and atomic CPs in order to quantify the effect of using more accurate CPs to describe molecules. The atomic and molecular binding energies were taken from tabulated experimental data.

It should be noted that in our calculations of mass energy-transfer coefficients, we neglected for now the emission of characteristic x-rays in the relaxation process after the Compton interaction, as the magnitude of this effect is very small for low-*Z* atoms below 1 MeV.

Results

Figure 1 shows the Compton component of the mass energy-transfer coefficients for air and water calculated in the different formalisms discussed above, with insets showing eachμ_{tr}^{C}/ρnormalized by the$\mu_{tr}^{C}/\rho$for KN. Both RIA curves (molecular and atomic) are significantly closer to the KN mass energy-transfer coefficients than the WH model. The latter can differ by a large amount from the other models in the tens of keV range (e.g. ~6-10% at 20 keV).

We find that there is very little difference between the RIA with atomic and molecular CPs, thus the RIA does not seem to be particularly sensitive to the specific shape of the CPs. However, it can be slightly more sensitive to the choice of binding energies. Nevertheless, by far the biggest impact comes from the type of formalism which is employed.

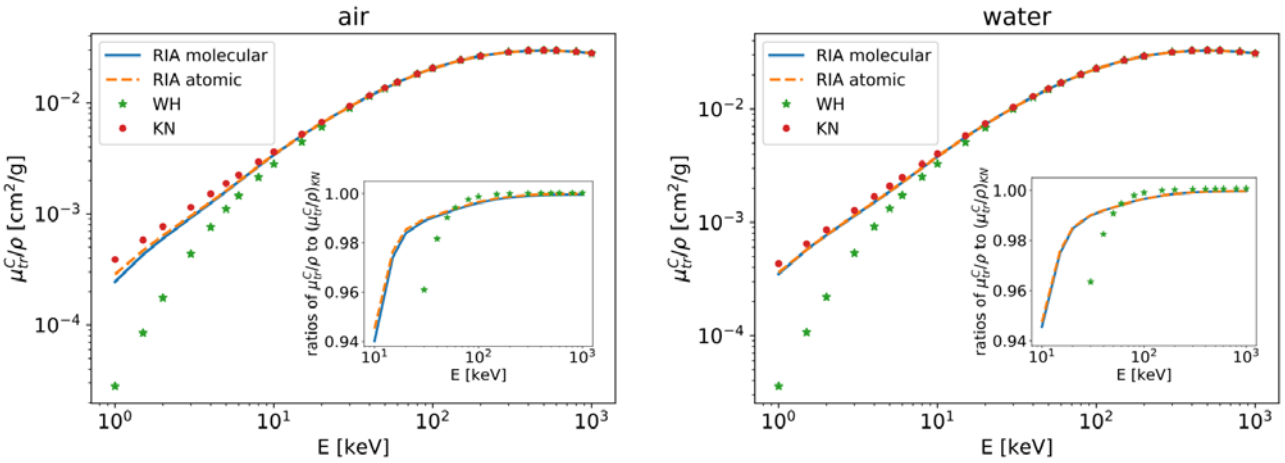

Figure 1: Mass energy-transfer coefficients for air (left) and water (right) calculated within KN, WH, and RIA (atomic & molecular CPs). The insets show data normalized to KN μ_{tr}^{C}/ρ.

Conclusions

In calculating the mass energy-transfer coefficient, the RIA using a variety of different CPs is always much closer to KN than to WH. In the immediate future we will continue with the main goal of this project, which is to determine the differences in the mass energy-absorption coefficient$\mu_{en}/\rho$from using the various Compton cross sections. We will incorporate fluorescence emissions and radiative losses, and include all other relevant photon interactions, to fully quantify the dosimetric impact.

Relevance to CIRMS

Basic photon cross section data is essential to accurately model and measure most dosimetry quantities, and is at the foundation of established standards for ionizing radiation. Any potential improvement in such data therefore contributes to the core of the CIRMS mission. This work is especially of interest for techniques using lower energy radiation, such as brachytherapy or intraoperative radiotherapy. It represents one part of a broader doctoral project involving theoretical calculations in atomic and molecular physics with the aim of expanding the existing interaction cross section data sets for photons and electrons. The first author hopes to follow a primarily research-focused career in either an academic or clinical environment, and the CIRMS meeting provides an excellent opportunity to no only present this work, but also to foster future ideas and collaborations.

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Determination of W_{air} in High-energy Clinical Electron Beams using Aluminium Detectors (Poster 4)

Alexandra Bourgouin[1,2], Malcolm McEwen[1]
[1]National Research Council, Ottawa, Canada,[2] Department of Physics, University of Carleton, Ottawa, Ontario, Canada

Objective:
The recent report on dosimetric key value (ICRU 90) reaffirmed the accepted value of W_{air}, to be a constant, above 10 keV, with a value of 33.97 ± 0.12 eV. A recent publication[1] has showed a possible energy dependence and to investigat this further, an experiment was carried out [2] reproducing the Domen and Lamperti investigation[3]. Although the experiment yielded a value consistent with the ICRU90 value, it highlighted the problems of using graphite detectors[2], particularly related to density variations. The goal of this project is to obtain additional experimental data in high-energy electron beams to determine W_{air} using a different material, namely pure aluminium.

Materials and Methods:
To measured W_{air}, which is the quotient of charge released in dry air, Q_{air}, and energy deposited in this mass of air, $D_{air} \cdot m_{air}$, an ion chamber and a calorimeter have been designed and constructed using pure aluminum. The ionometric, and calorimetric measurements, Q_{air} and D_m respectively, are combined with a Monte Carlo dose calculation (effectively a stopping power ratio) to obtain W_{air}:

$$W_{air} = \frac{D_{air} \cdot m_{air}}{Q_{air}} = \frac{D_{al}}{Q_{air}/m_{air}}\left(\frac{D_{air}}{D_{al}}\right) = \frac{D_m}{Q_{air}/m_{air}} SPR_{al}^{air} \qquad \text{Eq.1}$$

The quantity m_{air} in equation (1) means that the volume of the ion chamber must be determined as for a cavity standard, and both mechanical and capacitive measurements were used. The calorimeter used was an open-to-atmosphere design using calibrated NTC thermistors in an AC Wheatstone Bridge to determine the radiation-induced temperature rise, and thus the dose to aluminium. Measurements were made in electron beams produced by the Elekta Precise linear accelerator at the NRC facility. Twenty-two different configurations were used to provide a range of electron energies at the point of measurement, and also vary the thermal environment for the calorimeter. The primary electron beam energy were 8, 12, 18 and 22 MeV with a range of aluminum buildup thickness between 0.0 to 1.0 cm. The Irradiation time was also varied as was the source-detector distance, to further investigate geometrical and thermal influence quantities.

Results:
Prior to the measurements described above, the ion chamber was extensively tested to demonstrate it met the requirements of a reference-class detector. Results for ion recombination, polarity and leakage current were as expected.
The type A uncertainty for a series of calorimeter runs at a doserate of 3 Gy min^{-1} was consistent with literature values and analysis of temperature-time plots indicates that thermal isolation of the core was superior to the previous graphite calorimeter design. At this time, it has not been possible to carry out the necessary Monte-Carlo simulations to derive the theoretical dose conversion from aluminium to air, so monoenergetic mass stopping powers have been substituted in equation 1. This is a significant simplification but is useful as a first step in analyzing the data (Table 1).

Table 1: Radiation and buildup set-up for all different configurations with associated mass stopping power ratios and W_{air} values calculated. Uncertainties shown are only type A uncertainties.

Nominal Energy MeV	Al. thickness (total) cm	Energy at cavity MeV	Stopping power ratio -	Wair value eV	diff. with ICRU (%)
8	0.194	6.59	1.1300	31.14 ± 0.02	8%
	0.392	5.62	1.1300	31.51 ± 0.02	7%
	0.591	4.65	1.1300	31.94 ± 0.05	6%
12	0.194	10.16	1.1246	30.20 ± 0.02	11%
	0.392	9.10	1.1271	30.37 ± 0.02	11%
	0.693	7.50	1.1299	30.87 ± 0.03	9%
18	0.194	14.99	1.1065	28.92 ± 0.07	15%
	0.392	13.82	1.1109	29.25 ± 0.04	14%
	0.591	12.05	1.1175	29.46 ± 0.06	13%
	0.693	9.11	1.1271	30.17 ± 0.07	11%

22	0.194	19.11	1.0900	28.16 ± 0.05	17%
	0.392	17.85	1.0947	28.45 ± 0.11	16%
	0.591	15.95	1.1027	28.71 ± 0.02	15%
	0.693	12.76	1.1159	29.35 ± 0.09	14%

There is a significant energy dependence of the results and the all the values are significantly lower than the current recommended value. Using aluminium is advantageous in that it is an elemental material with no significant crystalline structure but the higher atomic number means that the fluence perturbation in electron beams could be significant and explain the deviations seen in the final column. Monte Carlo calculations, reproducing the entire geometry of the experiment will show the magnitude of this effect.

Conclusions and Significance:
Although initial measurements with the aluminium ionization chamber and calorimeter indicate expected performance, preliminary analysis of the data yield a value for W_{air} different from recommended data. Further Monte Carlo and thermal simulations are required to investigate this further and additional measurements at higher electron beam energies are planned.

Relevance to CIRMS:
The presented work is the main doctoral project of the first author. This project suite with the conference theme because of the impact of any W_{air} energy dependence would have on radiation measurements and standards. W_{air} is the key 'constant' of ion chamber measurement, and this detector is currently the gold standard in medical radiation dose measurement. The first author aims to pursuit a career in metrology, radiation measurement, after her PhD. This project and attending to metrological conference, such as CIRMS meeting, are key step to reach that goal.

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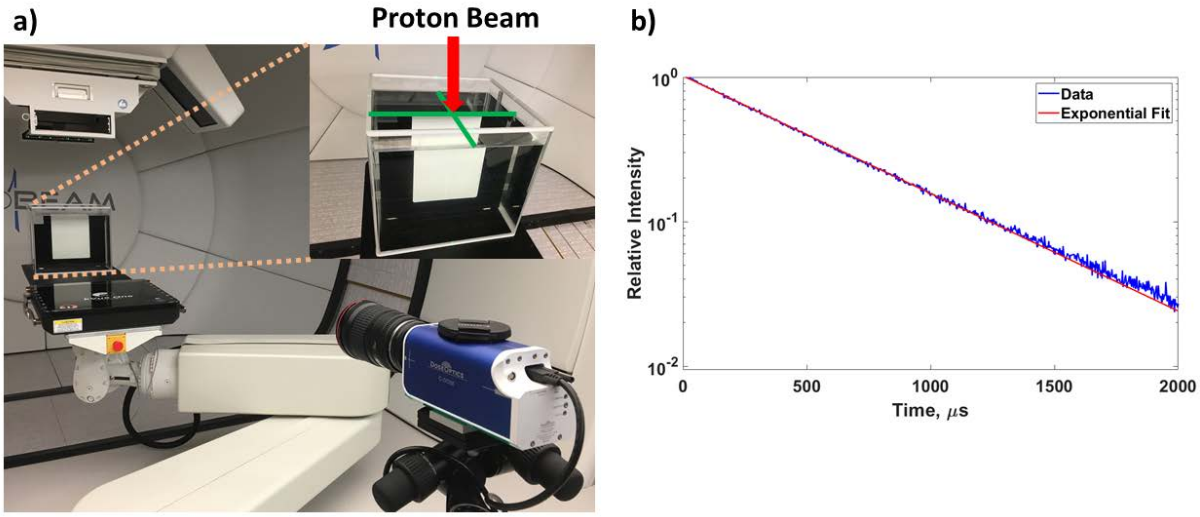
Remote Time-gated Imaging of 2-D and 3-D Profiles of both Photon and Proton Beams using Scintillating Film (Poster 5)

Mahbubur Rahman[1], Petr Bruza[1], Rongxiao Zhang[2], Victor Borza[1,3], Brian Pogue[1,3]
[1]Thayer School of Engineering, Dartmouth College, Hanover, NH [2]Emory Proton Therapy Center, Atlanta, GA [3]Dose Optics, LLC, Lebanon, NH

Objective: Water phantoms and ionization chambers are currently used to measure and calibrate beam profiles of radiation therapy linear accelerator performance. The cross-beam profiles, percent depth dose curves, and isodose lines are required measurements for beam verification and for input to treatment planning algorithms. Ionization chambers dose measurements at individual point inside the phantom take significant time and require interpolation. In this study, scintillation sheets (radiographic film-screen components) were used to show that image of the dose delivery can be achieved with remote imaging, creating direct 2-D and 3-D profiles of photon and proton beams using CMOS camera.

Method: Time-gated intensified cameras are experimentally proven to image scintillation and Cherenkov emitted from interaction of linear accelerator radiation beams with tissue or water and the signal is linearly proportional to dose deposition. In this study scintillation from a radiation beam was imaged with a Green 600 Speed Screen film (from Penn-Jersey X-ray, Morrisville, PA). The scintillating sheet was submerged in an CNMC acrylic water tank (Nashville, TN) and the edge of the scintillating sheet aligned with the surface of the water as shown in figure 1a. The sheet was parallel to the direction of radiation propagation with water surface at isocenter (100 cm SSD). Varian (Palo Alto, CA) CLINAC 2100c linear accelerator (at Dartmouth Hitchcock Medical Center, Hanover NH), and Varian Probeam cyclotron (at Emory Proton Therapy Center, Atlanta, GA) provided 6MV 6cm x 6cm photon and 150 MeV pencil proton beam, respectively. The CMOS camera was aligned with the water surface and orthogonal to the scintillating sheet plane. There is negligible amount of Cherenkov produced in water tank for proton beam but contributes to light acquisition by CMOS camera for photon beam. Utilizing the decay time of light



intensity from scintillation sheets (figure 1b) with a half-life of 369.9 microsecond, the CMOS camera acquired images 10 microsecond after linear accelerator beam pulsed to suppress Cherenkov while imaging scintillation at the sheet plane. The scintillation sheet was shifted laterally at increments of 0.6 cm away from isocenter to provide 2D profiles slices and construct a 3D profile of photon beam.

Figure 1: a) CNMC water tank and CMOS camera aligned with the water surface at SSD, Scintillation sheet parallel to radiation beam (red arrow) at isocenter (intersection of green lines) and camera orthogonal to scintillation sheet b) Light output intensity over time after a single radiation beam pulse for Green 600 Speed Screen film ($\tau_{1/2} = 369.9\,\mu s$) acquired based on time gating on PIMAX CCD camera

Results: The 2D profiles resolution of the 6MV 6cmx6cm photon beam (figure 2a) and 150MeV pencil proton beam (figure 2b) was limited by pixel size (18.47 pixel/cm and 53.9 pixel/cm respectively). The percent dose deposition was indicated by the relative intensity at each pixel. The images provide a description of the attenuation of the radiation: the maximum intensity occurred a few cm deep into water for photon beam indicating buildup region with gradual attenuation at greater depths and the high intensity occurred at approximately 15 cm depth for proton beam indicating Bragg peak. The 2D photon

beam intensity slices were shifted and imaged a maximum of 6 cm lateral distance from isocenter in both directions. The slices were constructed to create the 3D beam profile shown in figure 3. The beam profile shows dose deposition up to of depth of 27 cm in water. To Image at greater depths, the camera can be tilted with the CMOS chip fixed to water surface height without compromising spatial resolution. Camera lens focal length can be changed, and larger scintillation sheets

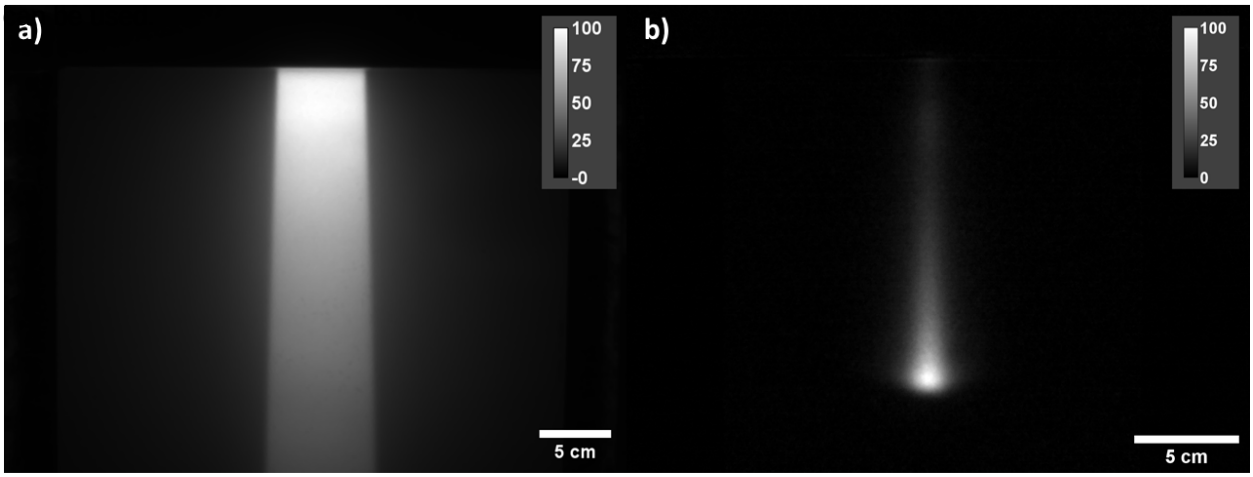


Figure 2. a) Relative Intensity profile of 6MV 6cm x 6cm Photon Beam b) Relative Intensity profile of 150 MeV Pencil Proton Beam

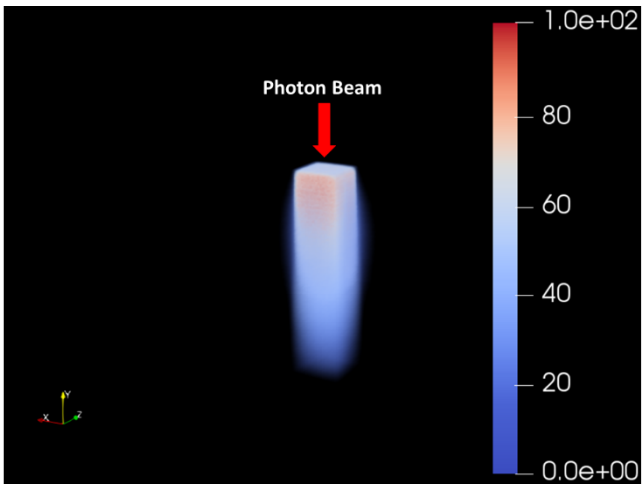


Figure 3. 3-D Profile of 6cm x 6cm 6MV Photon Beam constructed from slices of 2D profiles.
Red arrow included to show direction of radiation beam

Conclusion: While ionization chamber may require a significant number of measurements to create a dose deposition profile, direct imaging the scintillation sheet provides 2D profile from one beam on event. The fast and accurate acquisition using scintillation sheet and CMOS camera will provide faster QA testing of radiation therapy machines. The image resolution reduces the need for interpolation between dose measured at different points in phantom. In the future, the beam profiles will be compared to accepted beam profile data (i.e. cross beam profile, PDD). The imaged intensity will be calibrated to ensure accuracy and light intensity correlates to dose deposition in water. Furthermore, acquisition of the 3D beam profiles will be automated for faster acquisitions.

Relevance to CIRMS: As a graduate student pursuing opportunities in clinical medical physics, the first author intends to contribute to CIRMS and NIST goal of improving dosimetry precision of radiation beams composed of X-rays, and heavy particles. This study provides the framework for reduced number of measurements, increased spatial resolution, and fast dose deposition profiles acquisitions. Based on 2011 “Fifth Report on Needs in Ionizing Radiation Measurements and Standards” from CIRMS, due to rise in intensity modulated radiation therapy and 3D conformal radiation therapy, there is a need for 3D phantom measurement and this study provides method of accumulating beam slices to produce 3D beam profile and dose deposition details.

ABSTRACTS SUBMITTED FOR POSTER PRESENTATIONS

The Mismatch of Radiation Beam Quality for Dosimetry in Cardiovascular Angiography Equipment (Poster 6)

Pei-Jan Paul Lin
Department of Radiology, Virginia Commonwealth University Medical Center
Richmond, Virginia 23298-0615

Various filters (aluminum, copper, silver, gold, rhodium, tin, etc.) are commonly employed in diagnostic radiology to reduce the patient entrance exposure while trying to maintain the image quality of fluoroscopy and radiography. In the past decade, copper filter of thicknesses varying from 0.1 mm to 0.9 mm is extensively utilized in interventional angiography equipment. Typically, the interventional fluoroscopy for average size patient operates at 60 to 80 kVp with 0.9 mmCu. For pediatric application and some adult studies, 60 kVp with 0.9 mmCu is often employed in various angiographic examinations. See the figure below, from a typical angiography system.

On the other hand, the calibration of dosimeters at the kVp range of 60~80 kVp at 0.9, or 0.6 mmCu are not available in the International Standard IEC 61267 ed. 2.0 (2005). Medical diagnostic X-ray equipment – Radiation conditions for use in the determination of characteristics. Geneva, Switzerland: International Electrotechnical Commission. http://www.iec.ch. See the attached table.

Currently, there is no Nation Standards Organization that accommodate the needs of these new calibration points. This presentation is aimed to bring the attentions of basic science community to be aware of this mismatch and solicit National Standards Organizations to address the needs of diagnostic radiology community.

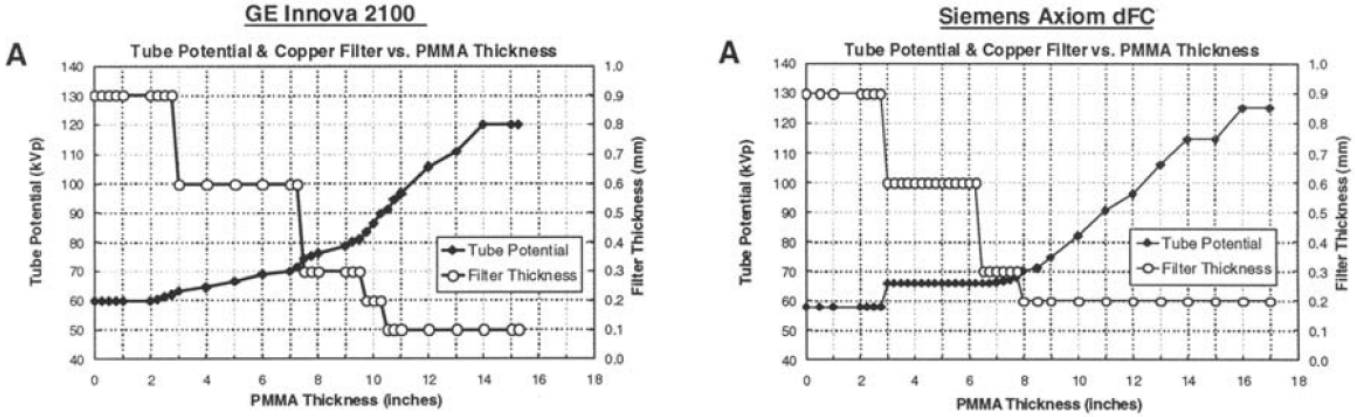


Table 5. Characterization of Standard Radiation Qualities RQA 2 to RQA 10

Standard Radiation Quality	X-Ray Tube Voltage (kVp)	Added Filter Thickness of Aluminum (mm)	Nominal First HVL in Thickness of Aluminum (mm)
RQA 2	40	4	2.2
RQA 3	50	10	3.8
RQA 4	60	16	5.4
RQA 5	70	21	6.8
RQA 6	80	26	8.2
RQA 7	90	30	9.2
RQA 8	100	34	10.1
RQA 9	120	40	11.6
RQA 10	150	45	13.3

Derivation of Preliminary Derived Concentration Guideline Level (DCGL) According to Kori Unit 1 Containment Building Reuse Scenario
(Poster 7)

SangJune Park[1], HoSeong Ji[1], Seokyoung Ahn[1]
1 Department of Mechanical Engineering, Pusan National University, 63 Busandaehak-ro, Geumjeong-gu, Busan, Republic of Korea

Abstract: The Kori Unit 1 will be decommissioned in 2022 after a permanent shutdown in June 2017. South Korea's criteria for limited and unlimited site release is 0.1 mSv/yr. The Kori Unit 1 is South Korea's first commercial NPP and decommissioning case. Therefore, if the containment building is reused as a memorial hall, it will contribute to the improvement of public understanding and enhance the public's acceptance of NPPs. Additionally, such a reuse scenario may also prevent economic recession. The exposure dose was calculated using the following scenarios: worker in containment building, visitor in containment building. The exposure dose in the buildings was calculated by the RESRAD-BUILD probabilistic analysis developed by the Argonne National Laboratory (ANL). In this study, Preliminary exposure dose and derived concentration guideline level (DCGL) of Kori Unit 1 was derived and evaluated.

Development of Unmanned Airborne High-resolution Spectrometric Monitoring System for Radiological or Nuclear Emergency Preparedness
(Poster 8)

Jan Rusnak[1], Jaroslav Solc[1], Jiri Suran[1], Petr Kovar[1], Petr Sladek[2], Jiri Nohyl[3]
[1]Czech Metrology Institute, [2]Nuvia, [3]Military Technical Institute

After a nuclear or radiological event, radiation protection authorities and other decision makers need quick and credible information, based on reliable radiological data, on the areas affected. However, the potentially large areas affected and risks to people in the vicinity pose difficult measurement challenges.
The currently ongoing European Metrology Programme for Innovation and Research (EMPIR) project Metrology for Mobile Detection of Ionising Radiation Following a Nuclear or Radiological Incident (Preparedness) is addressing this issue by developing new measurement techniques and traceable calibration methods for determining ground surface activity concentrations using data collected by unmanned aerial vehicles, and for radioactivity in air measurements using transportable air-sampling systems. This will support timely, effective action that protects the public and environment against the effects of ionizing radiation in the aftermath of nuclear and radiological emergencies.
The flagship of this project is the development of unmanned airborne spectrometric system equipped with an HPGe detector. Such a spectrometric system enables quick and safe identification of released radionuclides and thus level of technology disruption and determination of emergency and contamination zones. Considering accident conditions, the system has to be reliable and heavy-duty. That is why highly compact, reliable, mechanically cooled HPGe-spectrometer and electromagnetically susceptible electronics for detection, data processing and telemetry is employed. As a carrier, an unmanned helicopter with sufficient payload and flying range is used.
In this contribution the adaptation of HPGe detector for airborne use, performance testing, integration with telemetry devices and development of the dedicated measurement software for dose rate and radionuclide concentration monitoring is presented.
This work was supported by the EMPIR joint research project 16ENV04 which has received funding from the European Union. The EMPIR initiative is co-funded by the European Union's Horizon 2020 research and innovation programme and the EMPIR Participating States.

Estimate Paralyzing Dead-Time on SPECT Cameras Using Dual Source Dead-Time Phantom
(Poster 9)

Jianqiao Luo, PhD, DABR
Department of Radiology, VCU Medical Center, Richmond, Virginia

Purpose: Evaluate photon attenuation and scattering in measurements of paralyzing dead-time on SPECT cameras using Dual Source dead-time phantom.

Method: A dual source phantom was used to simulate paralyzing model of dead-time in SPECT, which including scatter in 278 MBq - 555 MBq to generate count rate at 20 kcps. The phantom was imaged on five cameras from Philips (Vertex/MCD, Forte, Argus and Cardio) including one 5/8" crystal and 3/8" for others. Different collimators (LEGP, VXGP, VXHR and VXUR) were loaded and source to collimator geometry was adjusted to test the paralyzing dead time under various count rates and scattering conditions. Furthermore, the test tubes were measured outside phantom for scatter free. Cameras were set up 140 keV (20%), 100 seconds acquisition time; the phantom was at gantry center with tubes near collimator surface.

Result: Measured dead time: Vertex (5/8") 4.92 usec at 296 MBq (10 kcps), 4.40 usec at 555 MBq (20 kcps) when high resolution collimator was loaded; same set up with general purpose collimator, 4.26 usec and 4.58 usec respectively. Other dual head cameras (3/8") showed the similar results at 370 MBq each tube with VXGP collimators. Detector far from the test tubes showed higher dead time (5.13 to 5.38 usec for Vertex). When the test tubes were kept out of phantom, the dead time were 2.10 usec for the detector near and 2.06 usec when far from it. Single head camera with LEGP collimator measured 2.40 usec at 370 MBq each tube.

Conclusion: Paralyzing dead time measurement was sensitive to scattering conditions which depends primarily on geometry and attenuation media. Other factors (crystal thickness, collimator, activity and tube volume) did not show significant impact on the measurements. Count rate from each tube was about 15 to 23 kcps but 20 kcps should be used for consistency.

Backbone-to-base Hole Transfer Occurs in One-electron Oxidized Guanine Nucleoside Phosphorodithioate but not in One-electron Oxidized Guanine Nucleoside Phosphoroselenoates
(Poster 10)

Renata Kaczmarek[1], Dipra Debnath[2], Taisiya Jacobs[2], Samuel Ward[2], Dariusz Korczyński[1], Michael D. Sevilla[2], Roman Dembinski[1,2], Amitava Adhikary[2]

[1] Centre of Molecular and Macromolecular Studies, Polish Academy of Sciences, Sienkiewicza 112, 90-363 Łódź, Poland
[2] Department of Chemistry, Oakland University, 146 Library Drive, Rochester, Michigan 48309-4479, USA

In-house synthesized 5'-*O*-phosphorodithioate (PO_2SS^-)-deoxyguanosine (G-P-2S) and 5'-*O*-phosphoroselenoate (PO_3Se^-)-deoxyguanosine (G-P-Se) have been employed to investigate backbone-to-base hole transfer process using ESR spectroscopy. Two-center three-electron σ^2-σ^{*1}-bonded adduct radical (-P-Se∴Cl) formation via $Cl_2^{\bullet-}$ addition to phosphoroselenoate is observed. However, -P-Se∴Cl did not oxidize G in G-P-Se in contrast to one-electron oxidation of G by -P-S∴Cl in phosphoromonothioates. Therefore, ESR studies conclude that backbone-to-base hole transfer process does not occur in phosphoroselenoate-incorporated DNA-oligomers (Se-oligomers). However, one-electron oxidation of G by -P-2S∴Cl at low concentration of G-P-2S (ca. 0.5 mg/mL) was observed. The combination of ESR and theoretical studies show that in -P-2S∴Cl from G-P-2S, spin is distributed over the S-Cl--S moiety. The formation of the dimer anion radical $[\text{-P-2S}\therefore\text{2S-P-}]^-$ is found at higher concentrations of G-P-2S (ca. 6 mg/mL).

Patient Specific Dosimetry: A Nuclear Medicine Physician's Perspective
(Poster 11)

Richard L. Wahl, M.D.
Mallinckrodt Institute of Radiology
Washington University School of Medicine
St. Louis, MO

Targeted Radiopharmaceutical Therapies are growing in importance with both alpha and beta emitting therapies FDA approved in the US. In addition, there has been substantial commercial investment in this form of therapy. Most currently approved therapies are either a "one administered radioactivity dose fits all" or have a simple weight based adjustment. If therapeutic margins are large, such simple dosing algorithms are relatively easily deployed in clinical practice. However, many radiopharmaceuticals have heterogeneous biokinetics and biodistributions in vivo. In such settings, one dose fits all approaches, particularly if the therapeutic margin is modest, potentially will underdose patients on average to achieve safety. We have observed 4-6 fold differences in radiation dosimetry in anti CD20 radioimmunotherapeutics. Approaches to integrate dosimetry into treatments can allow more predictable toxicities or profound dose escalations. Deploying dosimetry, especially organ dosimetry, requires technical expertise and suitable theranostic agents. It seems inevitable that dosimetry will be increasingly applied clinically, but careful studies to define the value of such an approach vs. simpler methods are in order. This lecture will review some of our experiences with dosimetry based therapeutics and highlight the logistical barriers to widespread deployment of such methods.

Excited States of One-Electron Oxidized Guanine-Cytosine Base Pair Radicals: A Time Dependent Density Functional Theory Study
(Poster 12)

Anil Kumar and Michael D. Sevilla*
Department of Chemistry, Oakland University, Rochester, Michigan 48309, United States

One-electron oxidized guanine ($G^{\bullet+}$) in DNA generates several short-lived intermediate radicals via proton transfer reactions resulting in the formation of neutral guanine radicals (scheme 1). The identification of these radicals in DNA is of fundamental interest to understand the early stages of DNA damage. Herein, we used time-dependent density functional theory (TD-ωB97XD-PCM/6-31G(3df,p)) to calculate the vertical excitation energies of one electron oxidized G and guanine(G)-cytosine(C) base pair in various protonation states: $G^{\bullet+}$, $G(N1\text{-}H)^{\bullet}$ and $G(N2\text{-}H)^{\bullet}$, as well as $G^{\bullet+}$-C, $G(N1\text{-}H)^{\bullet}$-(H^{+})C, $G(N1\text{-}H)^{\bullet}$-$(N4\text{-}H^{+})$C), G(N1-H)•-C and G(N2-H)•-C in aqueous phase. The calculated UV-vis spectra of these radicals are in good agreement with experiment for the G radical species when the calculated values are red-shifted by 40 - 70 nm. The present calculations show that the lowest energy transitions of proton transferred species ($G(N1\text{-}H)^{\bullet}$-(H^{+})C, $G(N1\text{-}H)^{\bullet}$-$(N4\text{-}H^{+})$C), and G(N1-H)•-C) are substantially red-shifted in comparison to the spectrum of $G^{\bullet+}$-C. The calculated spectrum of $G(N2\text{-}H)^{\bullet}$-C shows intense absorption (high oscillator strength) which matches the strong absorption in the experimental spectra of $G(N2\text{-}H)^{\bullet}$ at 600 nm. The present calculations predict the lowest charge transfer transition from C→$G^{\bullet+}$ is π→π* in nature and lies in the UV-region (3.4 – 4.3 eV) with small oscillator strength.

First Primary Standardization of Ra-224 Activity
(Poster 13)

Elisa Napoli, Denis Bergeron, Jeffrey T. Cessna, Ryan P. Fitzgerald
Oncoinvent AS, University of Oslo, NIST

Alpha-emitting radiotherapies can offer cancer patients highly effective treatments with minimal side effects. For cavitary micro-metastatic diseases, a new therapy consisting of a suspension of injectable microparticles labeled with Ra-224 is showing promise in pre-clinical studies. With a 3.631(2) d half-life and a decay scheme that includes the emission of two energetic beta particles and four energetic alpha particles, Ra-224 can deliver a high dose of therapeutic radiation to the tumor over <100 Âμm range in tissues, resulting in double-strand DNA breaks and non-reparable tumor cell death with minimal toxicity to surrounding healthy tissues. Prior to commencing clinical trials, it is essential to develop a radioactivity standard for Ra-224 to assure consistent dosage administration and to accurately calculate dose-response relationships.

The primary activity standardization was performed at NIST with two liquid scintillation-counting based methods: live-timed $4\pi\alpha\beta(LS)\text{-}\gamma(NaI)$ anticoincidence counting (LTAC) and triple-to-double coincidence ratio (TDCR) counting. Monte Carlo simulations were used to model instrument responses, assuring appropriate corrections and establishing theoretical links between methods. The activities determined by multiple methods and across multiple experiments were consistent within uncertainties. The primary activity standard carries a combined standard uncertainty of 0.30 %. Preliminary measurements were also performed on several clinical dose calibrators, providing an enduring link with the measurements that will directly impact patients, when Ra-224-based radiopharmaceuticals will be available for clinical use.

Establishment of an Optically Stimulated Luminescence Dosimetry System at the National Cancer Institute for Measuring Medical Radiation Exposure
(Poster 14)

Matthew Oh[1], Keith Griffin[1], Ronaldo Minniti[2], Michelle O'Brien[2],
Roberto Maass-Moreno[3], Choonsik Lee[1], Matthew Mille[1]
[1]Division of Cancer Epidemiology and Genetics, National Cancer Institute, National Institutes of Health
[2]Radiation Physics Division, National Institute of Standards and Technology
[3]Department of Nuclear Medicine, National Institutes of Health

The Radiation Epidemiology Branch of the National Cancer Institute's Division of Cancer Epidemiology and Genetics conducts a broad-based research program to identify, understand, and quantify the risk of cancer in populations exposed to radiation. Medical radiation exposure is a key priority area because it accounts for nearly half of the total radiation exposure of the U.S. population from all sources. Furthermore, patient populations offer unique insight into the link between radiation exposure and subsequent cancer risk as the procedures are ordinarily well documented in the medical records, allowing organ doses to be reconstructed retrospectively. Organ doses are reconstructed using computational methods because of the need to individualize the dosimetry for cohort members. Nevertheless, it is important to benchmark the computational dosimetry methods against measurements. The present study describes an effort to establish an optically

stimulated luminescent (OSL) dosimetry system at the National Cancer Institute to measure organ dose for experimental validation.

The objectives of this study were to: (1) Calibrate the OSL dosimeters for various x-ray computed tomography (CT) imaging beam qualities; (2) Create a method for annealing the OSL dosimeters with light for reuse; and (3) Use the OSL dosimetry system to measure the dose delivered to a pediatric phantom from a typical brain CT scan.

The OSL dosimeters were calibrated in the NIST x-ray beams in terms of air kerma at a fixed distance, realized by the NIST x-ray standard, the Wyckoff-Attix free-air ionization chamber. Calibration factors for different x-ray beams were calculated by comparing the dosimeter readings to the delivered air kerma. An annealing box was designed and fabricated which could clear 99.8% of the radiation induced signal on the dosimeters by illuminating them with a LED light for 20 minutes. As a first application of the dosimetry system, approximately 100 OSL dosimeters were inserted into a 5-year-old anthropomorphic physical phantom. The dose to selected organs was measured for a typical pediatric brain CT scan. The CT scans were performed at the National Institutes of Health Clinical Center. Detailed results from these experiments will be presented.

Shannon Hartley Theorem using Quantum Mechanics using 5G 802.21 802.22
(Poster 15)

Nisha Mithal
Alphabet Inc.

In information theory, the Shannon–Hartley theorem tells themaximumrate at which information can be transmitted over a communications channel of a specified bandwidth in the presence of noise. It is an application of the noisy-channel coding theorem to the archetypal case of a continuous-time analog communications channel subject to Gaussian noise. The theorem establishes Shannon's channel capacity for such a communication link, a bound on the maximum amount of error-free information per time unit that can be transmitted with a specified bandwidth in the presence of the noise interference, assuming that the signal power is bounded, and that the Gaussian noise process is characterized by a known power or power spectral density. The law is named after Claude Shannon and Ralph Hartley. Formulated by: {C=B\log {2}\left(1+{\frac {S}{N}}\right)}

Cognitive Radio Spectrum Sensing, Cooperative Spectrum Sensing, Network Resource Sharing and Scheduling Molecular and Nano Communications, Optical and Quantum Communication Theory
(Poster 16)

Nisha Mithal
Alphabet Inc.

With Cognitive Radio being used in a number of applications, the area of spectrum sensing has become increasingly important. As Cognitive Radio technology is being used to provide a method of using the spectrum more efficiently, spectrum sensing is key to this application. The ability of Cognitive Radio systems to access spare sections of the radio spectrum, and to keep monitoring the spectrum to ensure that the Cognitive Radio system does not cause any undue interference relies totally on the spectrum sensing elements of the system. For the overall system to operate effectively and to provide the required improvement in spectrum efficiency, the Cognitive Radio spectrum sensing system must be able to effectively detect any other transmissions, identify what they are and inform the central processing unit within the Cognitive Radio so that the required action can be taken.

Half-value Layer Measurements in Computed Tomography: Correlating Broad-beam Geometry to Narrow-beam Geometry
(Poster 17)

N.A. Ruiz González[1], J.K. Lancaster[1], G.D. Clarke[1]
[1]Department of Radiology and Research Imaging Institute, UT Health San Antonio, San Antonio, Texas, USA 78284

Purpose: Half-value layer (HVL) is a beam quality metric used in quality control programs on projection-type imaging equipment. Here, we present a reliable and practical methodology for measuring the HVL in computed tomography (CT).

Methods: A patent-pending apparatus, a cylindrical step wedge (CSW), presents a surface area of different thicknesses of aluminum perpendicular to an incident x-ray beam from a rotating CT x-ray tube while positioned at the center of rotation. A pencil ion chamber was used to evaluate HVL in a CT scanner (LightSpeed® RT 16, GE, Milwaukee, WI) using an axial scan (one rotation/s) for a single 1.25, 5.0 and 10 mm slice thickness (ST). The procedure was repeated for multiple kVp

settings and bow-tie (BT) filters. HVL-CSW measurements were fitted using linear regression models to HVL values quoted by the manufacturer (HVL-GE); the Pearson product-moment correlation and confidence intervals (CI) were also calculated.

Results: The average percent error between the HVL-GE and the HVL measured using the scout method was 4.79%. The maximum percent-difference between the average HVL-CSW of the three different ST for each kVp (small BT) and the HVL-CSW for ST=5 mm (small BT) was 0.90 %. The maximum percent-difference between the average HVL-CSW for three ST's at each kVp (large BT) and the HVL-CSW for ST=5 mm (large BT) was 1.14%. For the linear regression models; the coefficients of determination were $r^2 \geq 0.9985$, ($p \leq 0.0007$), with percent errors $\leq 4.22\%$, and Pearson product-moment correlation coefficients were $r \geq 0.99$ ($p \leq 0.0007$, 95% CI = 0.96-0.99).

Conclusions: An apparatus for measuring the HVL in CT and correlating broad-beam geometry to narrow-beam geometry was successfully designed and validated. In performing beam attenuation measurements, the patent-pending CSW can be used without the need to stop the x-ray tube's rotation for HVL calculations with standard equipment.

Novel Nuclear Forensics and Emergency Response Technologies
(Poster 18)

Robert B. Hayes[1], S. Joseph Cope[1], Ryan P. O'Mara
[1]Nuclear Engineering Department, North Carolina State University, Raleigh, NC, 27695-7909

The research being done at NC State spans an impressive array of technology aimed at radiological emergency response and nuclear nonproliferation forensics. These include radiological air monitoring [1-3], retrospective characterization of nuclear materials [4-6], use of ubiquitous dust particulate as a dosimeter [7], emergency response biodosimetry at the natural background level [8], differential isotopic diffusion [9] and even novel radiation detection platforms [10]. These will all be reviewed in this presentation.

1) Cope SJ, Hayes RB. Preliminary work toward a transuranic activity estimation method for rapid discrimination of anthropogenic from TRU in alpha air samples. *Health Physics.* **114**(3):319-327, 2018
2) Cope SJ, Hayes RB. Emergency Response Transuranic Activity Assay Method for Mixed Alpha/Beta Air Samples. *Trans. Amer. Nuc. Soc.* **119**, p1006-1009, Orlando, Florida, November 11–15, 2018
3) Cope SJ, Hayes RB. Mass Correlation of Presumed Twin Air Filters for Emergency Response Applications. *Trans. Amer. Nuc. Soc.* **117**, 1159-1161, 2017.
4) O'Mara RP, Hayes RB. (2018) Dose deposition profiles in untreated brick material. *Health Physics* **114**(4), 414-420.
5) Hayes RB. Retrospective uranium enrichment potential using solid state dosimetry techniques on ubiquitous building materials *J Nuc Mat Mgmt.* (in press)
6) Hayes R. B., O'Mara RP. Some Spatial Limitations in Retrospective Dosimetry with Bricks When Sample Size is Large. *Trans. Amer. Nuc. Soc.* **117**, 1026-1028, 2017.
7) Hayes RB, O'Mara RP. Enabling Nuclear Forensics Applications from the Mineral Particulate in Contamination Surveys. *Advances in Nonproliferation Technology and Policy Conference*, Wilmington, NC, Sep 23-27, p200-204, 2018.
8) Hayes RB, O'Mara RP. (2019) Retrospective dosimetry at the natural background level with commercial surface mount resistors. *Radiat. Meas*. **121**, 42-48.
9) Hayes RB. Differential Isotopic Diffusion in Nuclear Forensics of Fallout. *Advances in Nonproliferation Technology and Policy Conference*, Wilmington, NC, Sep 23-27, p213-216, 2018
10) Hayes RB. Evaluation of BC-454 for Gamma Spectroscopic and Neutron Detection Applications. *Advances in Nonproliferation Technology and Policy Conference*, Wilmington, NC, Sep 23-27, p196-199, 2018.

Uncertainty Issues Unresolved in Modern Radioaerosol Measurements
(Poster 19)

Robert B. Hayes
Nuclear Engineering Department, North Carolina State University, Raleigh, NC, 27695-7909

Abstract: The methods used for radiological air monitoring have largely been unchanged since their inception in the past century. Physics related to aerosol dynamics and evolution are addressed through current definitions of representative sampling. This poster will review recently published aspects of aerosol physics which demonstrate how most air sample assays conducted today have underestimated the true dispersion in the measurement by as much as an order of magnitude or two.

A Rapid Conservative Transuranic Estimator for Air Filters
(Poster 20)

S. Joseph Cope, Robert B. Hayes
Nuclear Engineering Department, North Carolina State University, Raleigh, NC, 27695-7909

Abstract: A novel graded approach to assay of anthropogenic activity on air filters at low levels in the presence of radon progeny is presented. This work is highly novel and constituted the research component of a masters in nuclear engineering and received a formal press release from the university (https://news.ncsu.edu/2018/02/airborne-radiological-detection-2018/) due to its potential impact and ingenuity.

EGSnrc Reexamination of Accurate Measurements of Collision Stopping Powers for 5 to 30 MeV Electrons
(Poster 21)

Frédéric Tessier 1, Carl K. Ross 1, 2
1 Ionizing Radiation Standards, NRC Metrology, 1200 Montreal Road, Ottawa ON K1A 0R6
2 Retired

The NRC Report PIRS-0626 published in 1998 provides measurements for the electronic stopping powers for several materials. In essence, that work compared measured spectra of electrons passing through thin absorbers against EGS4 Monte Carlo simulation using the stopping power values tabulated in ICRU Report 37, and determined if these data required any correction in order to reach agreement. The general conclusion of the report is that experiment and simulation agree, thereby validating the ICRU values. However it established that, contrary to the ICRU recommendation, the grain density for graphite is to be used for stopping power calculations. Unfortunately, the curves representing ICRU data in the NRC report were incorrect: they correspond to the stopping power calculated using an approximate density effect correction, proposed by Sternheimer and Peirels in 1971. After a careful review of the data files underlying the results presented in PIRS-0626, we have determined that the EGS4 simulations themselves did rely on the ICRU Report 37 stopping powers. Hence, fortunately, the confusion amounted to a plotting mistake, and did not jeopardize the outcome. Most significantly, the conclusion about the graphite grain density remains unchanged. We have recently reexamined the 1998 work using EGSnrc, an overhauled and more accurate version of EGS4, especially in terms of the electron transport algorithm, in particular the inclusion of spin effects in the elastic scattering cross section. We performed simulations using both EGS4 and the newer EGSnrc version, and improved the regression analysis. We find significant differences compared with the 1998 analysis, and while the overall validity of the ICRU data stands, the much higher precision attainable today with Monte Carlo affords us insight into the sensitivity to experimental and simulation parameters for this kind of comp rison. We are looking forward to repeat measurements with a germanium detector on the short term.

Body-size Dependence of Photon Dose Coefficients from Contaminated Soil: Application to Post-Chernobyl Environmental Studies
(Poster 22)

Keith Griffin, Vladimir Drozdovitch, Choonsik Lee
Division of Cancer Epidemiology and Genetics, National Cancer Institute, National Institutes of Health

The environmental exposure of radionuclides to members of the public, such as after the Chernobyl accident, have brought about a need to evaluate organ doses from soil contamination. This scenario is unique, in that a person's height can play a stronger role than usual in affecting organ absorbed dose. However, as in most external environmental evaluations, dosimetry modeling is typically only performed using a "reference person", which can often be misrepresentative in size. To determine the effect of body size for this contamination scenario, we computed a large dataset of body-size dependent photon dose coefficients from a ground surface source using the UF/NCI phantom library. 96 adult male and female phantoms of varying height (160 to 190 cm, 150 to 175 cm, respectively) and weight (50 to 105 kg, 50 to 95 kg, respectively) were chosen based on population data of the greater Chernobyl area. Radiation transport onto the phantoms was performed in MCNP6 using a two-step process, with 25 mono-energetic photon energies ranging from 10 keV to 8 MeV covered; from these, radionuclide-specific dose coefficients may be interpolated. Our findings showed that an increasing individual's height played a limited role in dose reduction; only the brain, extrathoracic region, and thyroid showed significant differences (e.g. at 300 keV, 10% reduction in female brain dose from 25 cm height gain). On the other hand, body mass proved to be a very significant factor for nearly all organs (e.g. at 300 keV, 21% reduction in male active marrow dose from 55 kg weight gain). These differences are often much more pronounced at lower energies and diminished at higher energies, as will be shown. From this work, fitted polynomial equations will be developed to enable future adjustments of "reference"soil contamination organ doses for an individual based on his or her body size.

Circulating Free DNA (cfDNA) Correlates with Integral Dose and Identifies Radiotherapy Patients Who Develop Gastrointestinal Toxicity
(Poster 23)

Steven G. Swarts, Natalie Lockney, Randal Henderson, Steven Zhang, Zhenhaun Zhang, Sadasivan Vidyasagar, Katherine Casey-Sawicki, Robert Zlotecki, Paul Okunieff
Department of Radiation Oncology, University of Florida, Gainesville, FL 32610

A holistic measure of total-body toxicity along with organ-specific toxicity, including radiation exposure, trauma, burns, and intercurrent disease, is critically important for triage in the case of a radiological/nuclear event. Toxicity from radiation is related to physical factors (radiation dose and radiation quality) and unknown biological factors (including concurrent disease, trauma, infection, etc). Clinically, physicians employ dose-volume histograms (DVH) to predict toxicity, however, there is no method of identifying the subgroup that will get toxicity. As a means to supplement this information to the DVH we developed a method for personalized radiation toxicity detection.

A proprietary bDNA based method (RadTox®, DiaCarta Inc, USA) is used to rapidly measure the concentration of circulating cell-fee DNA (cfDNA) that is released systemically from tissues exposure to ionizing radiation. Here, we will described how the RadTox assay was used in assessing the extent of normal tissue toxicity in patients undergoing prostate radiation therapy. cfDNA in plasma collected from prostate cancer patients was measured before radiotherapy and after each of the first 5 treatments. Patients were followed to determine acute (during treatment) and late (>90 days after treatment) gastrointestinal (GI), genitourinary (GU) and general toxicity. The results of the study showed that there was a significant correlation between integral dose, treatment with photons versus protons, cfDNA concentration, and observed acute and late GI toxicities. For example, acute GI toxicity was significantly correlated with cfDNA levels obtained on any of days 1, 2, 3, 4, and 5 of R T ($p<0.0$ 05). Late GI toxicity, was significantly correlated with cfDNA levels obtained on day 5 of RT ($p=0.017$).

The results from this clinical study have shown the potential of using cfDNA concentrations in blood to assess extent of radiation-induced tissue toxicity and to detect individuals who go on to develop GI toxicity after receiving otherwise similar radiation treatment.

Development and Validation of a TG-21 Calibration Procedure for a Novel Stereotactic Radiosurgery Device
(Poster 24)

Stewart Becker
1Department of Radiation Oncology, University of Maryland School of Medicine, Baltimore, Maryland USA 21201, 2Xcision Medical Systems, Columbia, MD USA 21045

Purpose: To develop and implement an American Association of Physicists in Medicine Task Group 21 (TG-21) calibration procedure for the GammaPod, a novel dedicated prone breast stereotactic radiosurgery (SRS) device recently developed at the University of Maryland Medical Center. This device uses multiple Co-60 sources that rotate around the patient's breast to create a highly conformal dose distribution for boosts, partial breast irradiation, or presurgery SRS. In this study, we describe the development, implementation, and validation of calibration of the device utilizing the TG-21 protocol for dosimetric evaluation. This work was done to create a standard calibration method for future GammaPod sites.
Methods: An absolute dose calibration using TG-21 was performed using an Exradin A1SL thimble chamber and a CDX 2000B electrometer. Measurements were performed in a polymethyl methacrylate breast-mimicking phantom (PMMA) and a water-filled breast cup. Verification was performed using the thermoluminescent dosimeter remote monitoring service from the Imaging and Radiation Oncology Core (IROC) calibration laboratory. We assumed that chamber response for these small fields sizes are unity compared to a 10x10 field size.
Results: TG-21 measurements in the acrylic phantom agreed within 1% and 2% with the IROC measurements for the 25- and 15-mm collimators, respectively. Measurements compared to the treatment planning system for acrylic, water, and breast-density water all agreed within 2% and, in most cases, within 1%.
Conclusion: We successfully implemented the first GammaPod calibration procedure based on the TG-21 protocol. These results demonstrate that the GammaPod can be used to precisely and accurately deliver the predicted radiation absorbed dose. Based off recent IAEA TR 483, chamber response for small field sizes may be a possible source of error and will be discussed.

A New Approach in Modeling Microdosimetry
(Poster 25)

Ramin Abolfath, Yusuf Helo, Mohammad Reza Parishan Alejandro Carabe, Robert Stewart, David Grosshans, Radhe Mohan
U. Penn, Philadelphia and MD Anderson Cancer Center

ICRU Report 36 on microdosimetry provides a general formula for the mean chord length, l, in the volume of interest. Accordingly, l is the mean length of randomly oriented chords in that volume and can be calculated based on the geometrical structure of the target of interest. For a convex volume, this formula recommends l = 4 V / A where V is the volume and A is the surface area of this volume. This formula, which is based on a straight and uniform energy deposition of the tracks in the volume, has been used vastly in the literature regardless of the type and quality of ionizing radiation.
Methods: In this study, we revisit the formulation of the mean chord length for a scanning beam of proton. We further employ an event by event Monte Carlo simulation and calculate l in terms of the statistical average of the energy deposition stepping length, as a function of proton energy and depth. We examine the validity of the ICRU formula, for a range of target sizes from 1 nm to 1 mm, location of the target and the nominal energy of proton.
Result: We show that l continuously drops as a function of depth and asymptotically saturates to a minimum value in low energies, where it exhibits a universal scaling behavior. Throughout this calculation, we further investigate the validity of the Kellerer's equation where a linear relation between y_D = <y^2> / <y> and LET_d has been assumed. More specifically, we show that the Kellerer's formula breaks down in low energies where a non-linear relation between y_D and LET_d is developed. This is due to a transition in distribution of energy loss from high to low energies.
Conclusion: This study reveals the limitation and validations of the mean chord length and Kellerer formula recommended in ICRU 36 report. We provide a more general formulation of these quantities. Further investigation and measurement is required to validate our new formulation.

Application of Novel Electron Beam Accelerator for Environmental Remediation, Medical Sterilization and Advanced Manufacturing
(Poster 26)

Slavica Grdanovska, Charlie Cooper
Fermi National Accelerator Lab

At Fermi National Accelerator Lab's Illinois Accelerator Research Center we are developing a novel electron beam accelerator. The accelerator is more energy efficient and therefore cheaper to operate. It is high power allowing for treatment of large mass flow rates. And finally, the accelerator is compact to the point it can fit on a truck to treat material at remote locations. Since this accelerator will open up new applications, we are concurrently developing applications in the areas of environmental remediation, medical sterilization and advanced manufacturing. This poster will discuss the advances in cryocooled superconducting RF accelerator technology that are being incorporated in this novel accelerator as well as the progress in various application areas mentioned above.

PAST PRESIDENTS OF CIRMS

1993 - Marshall R. Cleland, IBA Industrial, Inc.
1994 - Peter Almond, Univ. of Louisville
1995 - R. Thomas Bell, U.S. Dept. of Energy
1996 - Anthony J. Berejka, Ionicorp
1997 - Larry A. DeWerd, Univ. of Wisconsin
1998 - Robert M. Loesch, U.S. Dept. of Energy
1999 - Thomas W. Slowey, K&S Associates
2000 - X. George Xu, RPI
2001 - Joseph C. McDonald, PNNL
2002 - Arthur H. Heiss, Bruker BioSpin Corp.
2003 - Geoffrey S. Ibbott, UT M.D. Anderson
2004 - James A. Deye, Nat'l Cancer Institute
2005 - R. Craig Yoder, Landauer, Inc.
2006 - Mohamad Al-Sheikhly, Univ. of MD
2007 - Shawna Eisele, Los Alamos Nat'l Lab.
2008 - Manny Subramanian, Best Medical
2009 - Nolan Hertel, GA Tech
2010 - Kim Morehouse, US FDA
2011 - Chip Starns, ScanTech
2012 - Roberto Uribe, Kent State University
2013 - Robert Rushton**,** Hopewell Designs Inc.
2014 - Kim M. Morehouse, US FDA
2015 - Walter E. Voit, UT Dallas
2016 - Mark S. Driscoll, SUNY – ESF
2017 - Zhichao Lin, FDA
2018 – Present: Regina Fulkerson, Varian Medical Systems

*RANDALL S. CASWELL AWARD FOR DISTINGUISHED ACHIEVEMENT IN THE FIELD OF IONIZING RADIATION MEASUREMENTS AND STANDARDS

* The Randall Caswell Award was established in 2002. Prior to that date, it was named the CIRMS AWARD.

2000 **Randall S. Caswell,** National Institute of Standards and Technology (retired)
2002 **H. Thompson Heaton, II**: Center for Devices and Radiological Health, US FDA (retired)
2004 **Anthony J. Berejka,** Ionicorp +
2006 **Kenneth L. Swinth**, Swinth Associates
2007 **Bert M. Coursey**, National Institute of Standards and Technology, U.S. DHS (retired)
2008 **Larry A. DeWerd**, University of Wisconsin
2009 **Marshall R. Cleland**, IBA Industrial, Incorporated
2010 **Geoffrey S. Ibbott,** UT MD Anderson Cancer Center
2011 **Kenneth G.W. Inn,** National Institute of Standards and Technology (retired)
2012 **Joseph C. McDonald**, Pacific Northwest National Laboratory (retired)
2014 **Stephen M. Seltzer**, National Institute of Standards and Technology (retired)
2015 **X. George Xu,** Rensselaer Polytechnic Institute
2016 **James A. Deye,** National Cancer Institute, RRP
2017 **Peter R. Almond**, UT MD Anderson Cancer Center (retired)
2019 **Roberto Uribe**, Kent State University

JUNIOR INVESTIGATOR AWARD* RECIPIENTS

*former Student Grant Award program

2019	Emily King	University of Wisconsin, Medical Radiation Research Center
	Irvin Tendler	Dartmouth College, Thayer School of Engineering
	Xiaoya (Judy) Wang	McGill University, Medical Physics, Canada
	Alexandra Bourgouin	Carleton University, Medical Physics, Canada
2018	Alexandra Bourgouin	Carleton University, Canada
	Natalie Viscariello	University of Wisconsin-Madison
	Mary Peters	The University of Texas MD Anderson Cancer Center
	Kevin Mecadon	University of Maryland
2017	Alexandra Bourgouin	Carleton University, Canada
	James Renaud	McGill University, Canada
	Susannah Hickling	McGill University, Canada
	Manik Aima	University of Wisconsin - Madison
2016	Manik Aima	University of Wisconsin - Madison
	Khalid Gameil	National Research Council of Canada
	Yvonne Roed	UT MD Anderson Cancer Center
	Blake Smith	University of Wisconsin - Madison
	Kejia Yang	University of Texas at Dallas
2015	Mitchell Carroll	UT MD Anderson Cancer Center
	Travis Dietz	University of Maryland - College Park
	Jon Hansen	University of Wisconsin - Madison
	Sameer Taneja	University of Wisconsin - Madison
2013/2014	Mitchell Carroll	MD Anderson Cancer Center
	Kuan-Chih Huang	Rensselaer Polytechnic Institute
	Cameron Maher	Texas A&M University
	Dwayne Riley	University of Wisconsin
	Séverine Rossomme	Université Catholique de Louvain
	Steven Shaffer	University of Texas at Dallas
	Anjali Srivastava	Missouri University of Science and Technology
	Samantha Steele	SUNY ESF
	Angela Weier	University of Wisconsin – Madison
	Bennett Williams	University of Illinois
	Yana Zlateva	McGill University
2012	Kevin Casey	MD Anderson Cancer Center
	Olivia Huang	MD Anderson Cancer Center
	Fahima Islam	Missouri U. of Sci. & Technology
	Lisa Meyers	University of Cincinnati
	Joshua Reed	University of Wisconsin
	James Renaud	McGill University
	Dwayne Riley	University of Wisconsin

	Vaibhav Sinha	Missouri U. of Sci. and Technology
	John Michael Briceno	UTexas Health Science Center San Antonio
2011	Austin Faught	University of Texas
	Adam Paxton	University of Wisconsin
	Gina Paek	Chapman University
2010	Keith Hearon	Texas A&M University
	Steven Horne	LLNL Nuclear Forensics Internship Program
	Regina Kennedy	University of Wisconsin
	Charlotte Rambo	Texas A&M University
2009	Marina K. Chumakov	University of Maryland
	Ryan Grant	University of Texas M.D. Anderson Cancer Center
	Jessica R. Snow	University of Wisconsin
	Walter Voit	Georgia Institute of Technology
2008	Regina M. Kennedy	University of Wisconsin
	Matthew Mille	Rensselaer Polytechnic Institute
2007	Jianwei Gu	Rensselaer Polytechnic Institute
	Arman Sarfehnia	McGill University
	Sarah Scarboro	Georgia Institute of Technology
	Zachary Whetstone	University of Michigan
2006	Kimberly Burns	Georgia Institute of Technology
	Maisha Murry	University of Cincinnati
	Karl Benjamin Richter	University of Minnesota
	Reed Selwyn	University of Wisconsin
2005	Eric Burgett	Georgia Institute of Technology
	Mark Furler	Rensselaer Polytechnic Institute
	Andrew Jensen	University of Wisconsin
2004	Jennifer R. Clark	University of Kentucky
	Stephen D. Davis	University of Wisconsin
	Carlos Roldan	University of Massachusetts – Lowell
2003	Sheridan L. Griffin	University of Wisconsin
	Malcolm P. Heard	University of Texas M.D. Anderson Cancer Center
	Shannon Miller-Helfinstine	Kent State University
	Baodong Wang	Rensselaer Polytechnic Institute
2002	Wes Culberson	University of Wisconsin
	Ramazan Kizil	Penn State University
	Dickerson Moreno	University of Missouri
	Michael Shannon	Georgia Institute of Technology
2001	Matt Buchholz	Oregon State University
	Michael Czayka	Kent State University
	Bridgette Reniers	Universite' Catholique de Louvain
	Kurt Stump	University of Wisconsin
2000	Lesley Buckley	University of Wisconsin
	Peter Caracappa	Rensselaer Polytechnic Institute
	Scott Larsen	State University of New York
1999	Ahmet Bozkurt	Rensselaer Polytechnic Institute

Ariel Drogin	University of Kentucky
Kurt Marlow	Idaho State University
Oleg Povetko	Oregon State University
Jennifer Smilowitz	University of Wisconsin

CIRMS MEETINGS AND WORKSHOPS

April 2018	26th Annual Meeting Focus: "The Radiation Technologies for the Future" Working groups: Industrial Applications and Materials Effects Medical Applications Radiation Protection / Homeland Security
March 2017	25th Anniversary Meeting Focus: "The Past, Present and Future" Working groups: Industrial Applications and Materials Effects Medical Applications Radiation Protection / Homeland Security
April 2016	Annual Meeting Focus: "A Matter of Scale: Measurement Standards from the Nano to the Giga" Working groups: Industrial Applications and Materials Effects Medical Applications Radiation Protection / Homeland Security
April 2015	Annual Meeting Focus: "Fundamentals of Ionizing Radiation" Working groups: Industrial Applications and Materials Effects Medical Applications Radiation Protection / Homeland Security
March 2014	Annual Meeting Focus: "Advanced Manufacturing and Technology" Working groups: Industrial Applications and Materials Effects Medical Applications Radiation Protection / Homeland Security
October 2012	Annual Meeting Focus: "Confidence through Measurement Traceability" Working groups: Industrial Applications and Materials Effects Medical Applications Radiation Protection / Homeland Security
October 2011	Annual Meeting Focus: "Public Perception of Radiation" Working groups: Industrial Applications and Materials Effects Medical Applications Radiation Protection / Homeland Security
October 2010	Annual Meeting Focus: "Ionizing Radiation Sources: Users, Availability, and Options" Working groups: Industrial Applications and Materials Effects Medical Applications Radiation Protection / Homeland Security
October 2009	Annual Meeting Focus: "Radiation Measurements and Standards for Incident Response" Working groups: Industrial Applications and Materials Effects

	Medical Applications Radiation Protection / Homeland Security
October 2008	Annual Meeting Focus: "Radiation Measurements and Standards at the Molecular Level" Panel Discussion: Radiation Source Use and Replacement Break-out session workshops: Industrial Applications and Materials Effects Medical Applications Radiation Protection / Homeland Security
October 2007	Annual Meeting Focus: "Measurements and Standards for Radiation Based Imaging" Break-out session workshops: Industrial Applications and Materials Effects Medical Applications: " Imaging for Radiation Therapy Planning and Delivery" Radiation Protection / Homeland Security
October 2006	Annual Meeting Focus: “Implications of Uncertainty in Radiation Measurements and Applications” Break-out session workshops: Industrial Applications and Materials Effects Medical Applications: “Imaging for Radiation Therapy Planning and Delivery” Radiation Protection / Homeland Security
October 2005	Annual Meeting Focus: “The Impact of New Technologies on Radiation Measurements and Standards" Break-out session workshops: Industrial Applications and Materials Effects Radiation Protection Medical Applications: “Unconventional Measurements and Standards”
October 2004	Annual Meeting Focus: "Biological Dosimetry Measurements and Standards" Break-out session workshops: Medical Applications Homeland Security Industrial Applications and Materials Effects Radiation Protection Department of Homeland Security and CIRMS workshop on the Development of REALnet - Radiological Emergency Analytical Laboratory Network
October 2003	Annual Meeting Focus: "Radiation/Radioactivity Measurements and Standards in Industry" Break-out session workshops: Medical Applications Homeland Security Industrial Applications and Materials Effects Radiation Protection
April 2003	Advances in High Dose Dosimetry
October 2002	Annual Meeting Focus: "Traceability for Radiation Measurements and Standards" Break-out session workshops: Traceability and Standards in High-Dose Applications Traceability and Standards for Homeland Security Traceability and Standards in the Medical Physics Community
September 2002	Electron Beam Treatment of Biohazards

February 2002	Ultra-Sensitive Uranium Isotopic Composition Intercomparison Planning Meeting
October 2001	Annual Meeting Focus: "Radiation Standards for Health and Safety" Break-out session workshops: Specifications for Standard *In-Vivo* Radiobioassay Phantoms Food Irradiation Technology Advancements and Perspectives Measurements and Standards for Intravascular Brachytherapy Sources
October 2000	Annual Meeting Focus: "Advanced Radiation Measurements for the 21st Century" Break-out session workshops: Dosimetry for Radiation Hardness Testing: Sources, Detectors, and Computational Methods Measurements and Standards Infrastructure for Brachytherapy Sources Laboratory Accreditation Program for Personnel Dosimetry: Review of the Status of Implementation of New Standards Drum Assay Intercomparison Program
May 2000	Estimating Uncertainties for Radiochemical Analyses
April 2000	Computational Radiation Dosimetry: New Applications and Needs for Standards and Data Radiation Measurements in Support of Nuclear Material and International Security
May 1999	R-level Measurements and Standards for Public and Environmental Radiation Protection
April 1999	Measurements and Standards for Prostate Therapy Seeds Standards, Intercomparisons and Performance Evaluations for Low-level and Environmental Radionuclide Mass Spectrometry and Atom Counting
September 1998	Radiation Dosimetry Protection
April 1998	Measurements and Standard for Intravascular Brachytherapy
March 1998	NIST Radiochemistry Intercomparison Program
October 1997	High Dose E-Beams Electronic Personnel Dosimetry
March 1997	Iodine -125 Brachytherapy
February 1997	NIST Radiochemistry Intercomparison Program
September 1996	Standards and Measurements for Therapeutic Radionuclides for Use in Bone Palliation
July 1996	Mid-year workshops Mutual Accreditations
June 1996	Radiation Sterilization Medical Devices
April 1996	Mutual Accreditations Absolute Dose
September 1995	MQA Gamma Processing
March 1995	New NVLAP Criteria Radionuclide Speciation
June 1994	Ocean Studies SRM

Please save the date:

28th Annual Meeting CIRMS 2020
April 20-22*, 2020

*** Exact dates still to be confirmed**

Visit www.cirms.org for

► more information about CIRMS

► presentations from the previous Annual Meetings

► CIRMS Report on Needs in Ionizing Radiation Measurement and Standards

► membership application

► and more...

Contact us at: CIRMS@CIRMS.org

Council on Ionizing Radiation Measurements and Standards
P.O. Box 262333, Plano, TX 75026 • 301-591-8776 • email: cirms@cirms.org • www.cirms.org

CIRMS 2019 Sponsorship

Types of available annual sponsorship and membership levels and benefits:

Exclusive Dinner event sponsor at the annual meeting ($5,000)

Booth space at CIRMS annual meeting
Booth space at CIRMS annual meeting
Dinner/social event sponsor on Tuesday evening of meeting
Complimentary conference registration for 2 people from your organization
Full page Ad Space on back cover of CIRMS conference material, and listed in meeting program as dinner sponsor
CIRMS membership for 2 individuals
Listed as sponsor in program

Exclusive coffee break/networking sponsor at the annual meeting ($3,000)

Booth space at CIRMS annual meeting
Sponsor of all coffee breaks at annual meeting (3 in total)
Complimentary conference registration for 2 people from your organization
3”x 6.5” Ad Space in CIRMS conference program
CIRMS membership for 2 individuals
Listed as sponsor in program

Coffee break/networking sponsor at the annual meeting ($1,500)

Booth space at CIRMS annual meeting
Sponsor of one coffee break at annual meeting (3 in total)
Complimentary conference registration for 1 person from your organization
2 1/4”x 3” Ad Space in CIRMS conference program
CIRMS membership for 1 individual
Listed as sponsor in program

Junior investigator sponsor ($1000)

Recognition in CIRMS Junior Investigator presentation session
Listed as sponsor in program
CIRMS membership for 1 individual

Corporate sponsor ($1000)

Your company logo, along with the CIRMS logo on marketing media
Complimentary conference registration for 1 person from your organization
Booth space at annual meeting
CIRMS membership for 1 individual
Listed as a sponsor in program

Ad space in the Program Book

All current sponsors (and only sponsors that contributed for the current year through one of the sponsorship and/or membership levels described in the structure above) can, in addition, purchase the ad spaces in our Program Book (a la carte) as listed below:

Full page: $500

½ page is $250

¼ page is $150

Submission deadline for artwork: March 4, 2019

Organizational Membership ($850 for 1 year)

Qualified educational institutions like universities, governmental agencies or 501c3 nonprofit organizations qualify for the membership rate of $850 per year.
Mentioned in CIRMS conference program.

Individual Members ($50 for 1 year)

Individual Members can stay abreast of the latest trends and discoveries in the radiation world (medical, industrial, materials, homeland security, protection, regulation and measurement) through interactions with the CIRMS community through its mailing list, promotions, updates and our global network in radiation measurements and standards.
Individual members will gain access to give feedback to the Needs Report to help determine the future direction of the radiation measurements and standards community.

Student Members ($25 for 1 year)

Student Members receive the same benefits as individual members but get the student discount with a valid school ID from a high school or a community college, trade-school, graduate or post-doctoral programs at colleges and universities.
Student members must still register and pay the conference registration fee to attend CIRMS annual meetings.

CIRMS Membership Application

Instructions

Complete this form and print it. Mail or Fax 972-883-5725 the completed form and send payment to: CIRMS P.O. Box 262333, Plano TX, 75026

Membership Class

Select which membership class:

____ Exclusive Dinner Event Sponsor $5000.00
____ Exclusive Coffee Break/Networking Sponsor $3,000.00
____ Coffee Break/Networking Sponsor $1,500.00
____ Junior investigator Sponsor $1,000.00
____ Corporate Sponsor $1,000.00
____ Government / Non-Profit Organization Sponsors $850.00
____ Individual Member $50.00
____ Student Member $25.00

Member Information

Name and Address of Applicant. Corporate and Organizational Sponsors may name up to four.

Representative Name: _____
Organization: _____
Address: _____
City: _____
State: _____
Zip- Code: _____
Phone: _____
Fax: _____
Email: _____

_____

Representative 2 Name: _____
Phone: _____
Email: _____
Representative 3 Name: _____
Phone: _____
Email: _____
Representative 4 Name: _____
Phone: _____
Email: _____

Areas of Interest

	Rep 1	Rep 2	Rep 3	Rep 4
Homeland Security	☐	☐	☐	☐
Industrial Applications & Materials Effects (IAME)	☐	☐	☐	☐
Medical Applications (MED)	☐	☐	☐	☐
Radiation Protection (RP)	☐	☐	☐	☐
Sponsor Ad Program Book				
Full Page Ad- $500.00	☐			
½ Page Ad- $250.00	☐			
¼ Page Ad- $150.00	☐			

Payment Options

Check # _____

Please make Check payable to CIRMS and mail or fax information to the address above.

Credit Card Type: Visa Master Card American Express

Name On Card: _____ Expire Date: _____

Card Number: _____

Signature: _____