FINAL PROGRAM

26th Annual Meeting
of the
Council on Ionizing Radiation Measurements and Standards

"RADIATION TECHNOLOGIES FOR THE FUTURE"

April 16 – 18, 2018
National Institute of Standards and Technology
Gaithersburg, Maryland

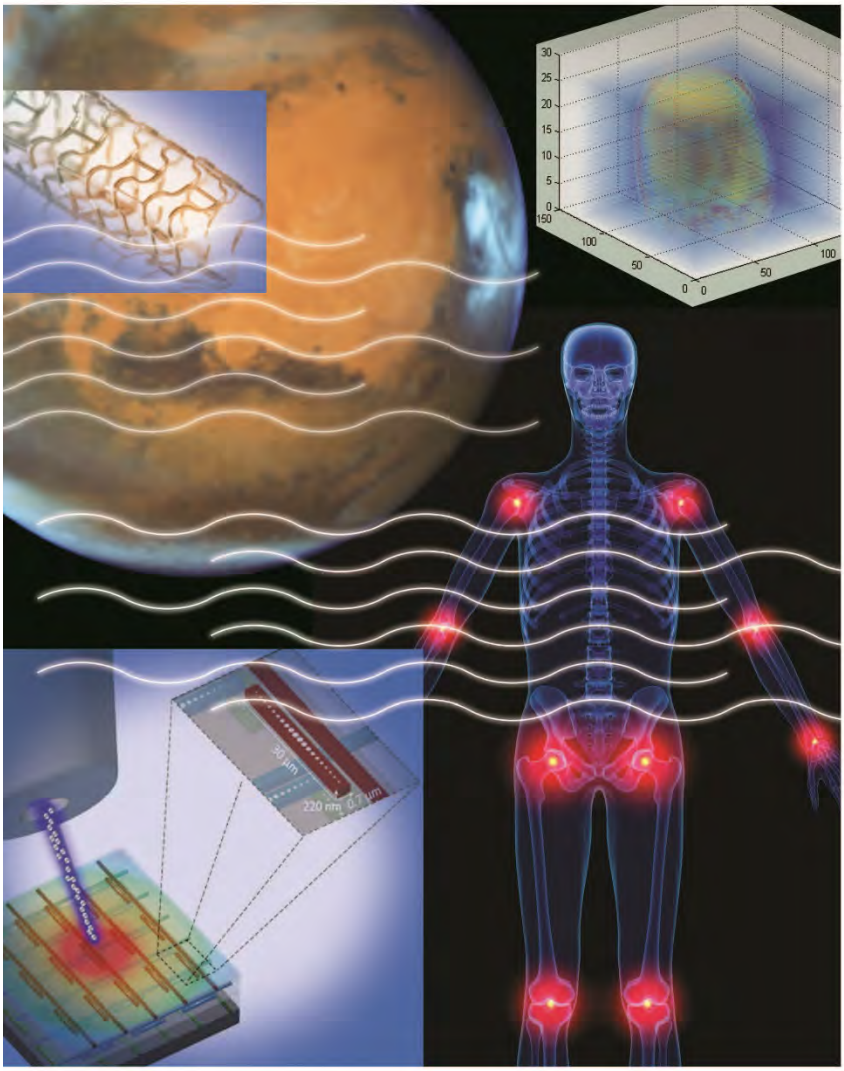
TABLE OF CONTENTS

CIRMS

COUNCIL ON IONIZING RADIATION MEASUREMENTS AND STANDARDS

RADIATION TECHNOLOGIES FOR THE FUTURE

26TH ANNUAL MEETING



APRIL 16-18, 2018
AT NIST
GAITHERSBURG, MD

CIRMS SPONSORS

American Association of Physicists in Medicine (AAPM)
American College of Radiology (ACR)
ASTM International
Bruker BioSpin Corporation
Eckert & Ziegler Isotope Products
Hopewell Designs, Inc.
IBA Industrial, Inc.
Kent State University
Landauer
National Institute of Standards and Technology (NIST)
National Physical Laboratory, UK
NRC
ScanTech Sciences
Sterigenics
Steris Corporation
SUNY – ESF
Theragenics Corporation
The University of Texas at Dallas
University of Wisconsin - Madison ADCL
UT MD Anderson Cancer Center ADCL

NIST
NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY
U.S. Department of Commerce

www.cirms.org

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

CORPORATE

Bruker BioSpin Corporation

Eckert & Ziegler Isotope Products

Hopewell Designs, Inc.*

IBA Industrial, Inc. *

Landauer *

ScanTech

Sterigenics *

Steris Corporation

Theragenics Corporation

ORGANIZATIONAL

American Association of Physicists in Medicine (AAPM)

American College of Radiology (ACR)

ASTM International

Kent State University

National Institute of Standards and Technology * (NIST)

National Physical Laboratory, UK

U.S. NRC

SUNY - ESF

University of Texas at Dallas

University of Wisconsin – Madison

UT MD Anderson Cancer Center ADCL

* Sponsors of the Student Travel Grant Awards and Poster Session Competition

CIRMS 2018 OFFICERS AND SUBCOMMITTEE CHAIRS

President:	Zhichao Lin, U.S. Federal Drug Administration
1st Vice-President:	Regina Fulkerson, Standard Imaging
2nd Vice-President:	Wesley Culberson, University of Wisconsin - Madison
Secretary:	Ryan Howell, Hopewell Designs Inc.
Treasurer:	Regina Fulkerson, Standard Imaging
Administrative Assistant:	Renata Freindorf, University of Texas - Dallas
Immediate Past President:	Mark S. Driscoll, State University of New York at Syracuse - ESF
Science & Technology:	Walter E. Voit, University of Texas - Dallas
Homeland Security:	Mike Unterweger, NIST
Radiation Protection:	Stephanie Healey, FDA
	Jacqueline Mann, NIST
Industrial Applications and Materials Effects:	Kim M. Morehouse, U.S. FDA Division of Analytical Chemistry
	Roberto Uribe-Rendon, Kent State University
Medical Applications:	Ronaldo (Ronnie) Minniti, NIST
	Regina Fulkerson, Standard Imaging
	Wesley Culberson, University of Wisconsin - Madison

MEETING FOCUS

The 26th Annual Meeting of the Council on Ionizing Radiation Measurements and Standards will focus on the "Radiation Technologies for the Future". 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 this year will consist of oral and poster presentations and three parallel working group sessions that address measurement and standards needs in the following topics:

- Medical Applications [microdosimetry, image guided radiation therapy, radiation biology, 3D printing, phantoms, nuclear medicine, big data and machine learning]

- Radiation Protection [advances in detection instrumentation, emergency response, nuclear events, radiochemistry, waste analysis, personnel dosimetry, electronic dosimeters, bioassay and internal dosimetry environmental dosimetry, first responder needs]

- 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

We have an outstanding list of speakers this year on a large diversity of topics including: radiation therapy, radiation biology, space travel, radiation risk, micro dosimetry, imaging, sterilization, materials modification, radiation protection, radioactivity measurements, radiochemistry, first responders' needs, consequence management, homeland security applications, detection instrumentation, 3D phantoms, 3D printing, nanosensors and more.

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 Needs Report published in 2016 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 16, 2018
MORNING PLENARIES- GREEN AUDITORIUM

8:30 am — Continental Breakfast/Registration

9:15 am — **President's Welcome**
Dr. Zhichao Lin, President, CIRMS

Welcome to NIST
Dr. Michael G. Mitch
Acting Chief, Radiation Physics Division, Physical Measurement Laboratory
National Institute of Standards and Technology, MD

9:30 am — **Introduction to the NEEDS REPORT**
Dr. Walter E. Voit
University of Texas at Dallas

9:45 am — **Keynote Address**
Dr. Eric Van Gieson, Biological Technologies Office
Program Manager, DARPA
Unconventional Approaches to Diagnosing and Mitigating the Effects of Radiation and WMD Exposure

About the Speaker: https://www.darpa.mil/staff/dr-eric-van-gieson

10:15 am — **Discussion**

10:30 am — Coffee Break

10:45 am — **Plenary Session I**
Brian Meincke, Assistant Vice President, Business Development
American Society for Testing and Materials (ASTM)
Standards and Innovation

About the Speaker: https://www.astm.org/ABOUT/full_overview.html

11:15 am — **CIRMS Student Travel Grant Awards Presentations:**

11:15 am — **Student Travel Grant Awards Presentation**
Student Travel Grant – sponsored by **NIST**
Alexandra Bourgouin – Carleton University, Canada
Investigation of the Energy Dependence of W_{air} in High Energy Electron Beams

11:25 am — **Student Travel Grant Awards Presentation**
Student Travel Grant - sponsored by **Sterigenics**
Kevin Mecadon – University of Maryland, USA
Radiation Grafting of Ionic Liquids to Synthesize Polymer Electrolyte Membrane Fuel Cells

11:35 am **Student Travel Grant Awards Presentation**
Student Travel Grant - sponsored by **Hopewell Designs, Inc.**
Mary Peters – The University of Texas MD Anderson Cancer Center, USA
Impact of Half Value Layer Geometry on TG-61 Output for a Small Animal Irradiator

11:45 am **Student Travel Grant Awards Presentation**
Student Travel Grant - sponsored by **IBA Industrial, Inc.**
Natalie Viscariello – University of Wisconsin-Madison, USA
Dosimetry Verification in Radiobiology X-Ray Irradiators

11:55 am **Poster Summaries**

12:05 pm **Poster Viewing**

12:45 pm Lunch

MONDAY, APRIL 16, 2018
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

3:30 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

5:30 pm Adjourn Day 1

TUESDAY, APRIL 17, 2018
MORNING PLENARIES- GREEN AUDITORIUM

8:30 am	Continental Breakfast
9:15 am	**President's Welcome** Dr. Zhichao Lin, President, CIRMS
9:30 am	**Plenary Session II** **Dr. Matthew Mille**, National Cancer Institute (NCI)/ National Institutes of Health (NIH) *3D Printing Patient-Specific Phantoms for Imaging and Radiation Dosimetry: Recent Progress, Challenges, and Future Directions* About the Speaker: https://irp.nih.gov/catalyst/v25i4/using-3-d-printing-to-assess-radiation-exposure
10:00 am	**Plenary Session III** **Dr. Christopher Berlind**, Oncora Medical *Patient Safety in the Age of Big Data: Machine Learning, Measurements, and Standards for Making Radiation Treatments Safer* About the Speaker: http://www.chrisberlind.com/home.html
10:30 am	Coffee Break
10:45 am	**Plenary Session IV** **Dr. Peter Klupar**, Director of Engineering, Breakthrough Starshot former Director of Engineering, NASA Ames Research Center *The Breakthrough Initiatives: Search for Life in the Universe* About the Speaker: https://breakthroughinitiatives.org/initiative/3 About the Mission: https://www.youtube.com/watch?v=4ixojIvymxM
11:15 am	**Poster Summaries**
11:30 am	**Poster Viewing**
12:45 pm	Lunch

TUESDAY, APRIL 17, 2018
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
3:30 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
5:30 pm	Adjourn Day 2
6:15 pm	Bus from the hotel to the restaurant
6:45 pm	**Gala Dinner @ GUAPOS Fine Mexican Cuisine**
	Address 9811 Washingtonian Blvd, Gaithersburg, MD 20878
	Phone: (301) 977 5655

WEDNESDAY, APRIL 18, 2018
MORNING PLENARIES- GREEN AUDITORIUM

8:30 am	Continental Breakfast
9:15 am	**Welcome Back** Dr. Zhichao Lin, President, CIRMS
9:30 am	**Plenary Panelists on Future Technologies** **Dr. Neil Kirby**, University of Texas at San Antonio *A DNA Double-strand Break Dosimeter for Radiation Measurements* About the Speaker: http://gsbs.uthscsa.edu/faculty/neil-kirby-ph.d
9:45 am	**Dr. Lynne Wathen,** Biomedical Advanced Research and Development Authority (BARDA) *Radiation Biodosimetry Test Development Continues Apace* About the Speaker: https://www.phe.gov/about/BARDA/Pages/default.aspx
10:00 am	**Kevin O'Hara,** Sterigenics *Radiation-Based Technologies and their Current Industrial Applications* About the Speaker: http://www.sterigenics.com/sterilization_technologies.php
10:15 am	**Panel Discussion** with three panelists
10:30 am	Coffee Break
10:45 am	**Capstone Speaker** **Dr. Mohamad Al-Sheikhly**, University of Maryland *An Eye Opener on the Bright Future of Ionizing Radiation Measurements in Medicine, Processing, and Nuclear Applications* About the Speaker: http://www.mse.umd.edu/faculty/al-sheikhly
11:15 am	**Report on Needs in Ionizing Radiation** **Dr. Walter E. Voit**, University of Texas at Dallas Group leaders **Dr. Walter E. Voit,** University of Texas at Dallas Current/Future Work
12:30 pm	**Closing Address/ New Officers** **Dr. Zhichao Lin**, President, CIRMS
12:45 pm	Lunch
1:45 pm	**Executive Committee Meeting**
3:00 pm	Adjourn Day 3

INDUSTRIAL APPLICATIONS AND MATERIAL EFFECTS
MONDAY APRIL 16, 2018 (AFTERNOON)
LECTURE ROOM D

Chairs: Roberto Uribe (Kent State University) and Kim M. Morehouse (FDA)

Breakout Session I: Irradiators

1:45-2:05 Chris Howard, PhD, Nordion
Establishing a Canadian-Traceable Calibration of High-Dose Rate Co-60 and Electron Radiation Sources

2:05-2:25 Ryan Howell, Hopewell Designs
GR440 Irradiator developed by Hopewell Designs

2:25-2:45 Mark Driscoll, PhD, The State University of New York (SUNY-ESF)
The Need for a National Electron Beam Irradiation Facility at NIST and How CIRMS can Help Facilitate its Creation

2:45-3:05 Fred Bateman, PhD, National Institute of Standards and Technology (NIST)
Low Energy Dosimetry Standards and Radiation Effects Studies Using a 300 keV Laboratory e-beam Unit

3:05-3:30 Questions for speakers and discussion on "current needs"

3:30-3:45 Break

Breakout Session II: Radiation Processing

3:45-4:05 Jonathan Jansson, Steris
Radiation Processing Industry Direction and NIST Opportunities

4:05-4:25 Emily Craven, Mevex
Challenges in Dose Measurements with Industrial Electron Beam

4:25-4:45 Laura Jeffers, PhD, United States Department of Agriculture (USDA)
Phytosanitary Irradiation: A Flexible Solution in a Rigid Regulatory World

4:45-5:05 Kevin O'Hara, Sterigenics

5:05-5:30 Questions for speakers and discussion on "current needs"

5:30 Adjourn

INDUSTRIAL APPLICATIONS AND MATERIAL EFFECTS
TUESDAY APRIL 17, 2018 (AFTERNOON)
LECTURE ROOM D

Chairs: Roberto Uribe (Kent State University) and Kim M. Morehouse (FDA)

Breakout Session I: Materials Effects and Space Applications

1:45-2:15 Ruthan Lewis, PhD, National Aeronautics and Space Administration (NASA)
Space Weather and Nanosensors for Environmental Monitoring

2:15-2:45 John F. Cooper, PhD, National Aeronautics and Space Administration (NASA)
Interplanetary Energetic Particle Measurements with NASA's Heliophysics System Observatory

2:45-3:15 Amitava Adhikary, PhD, Oakland University
Radiation Chemical Studies of Gamma and Ion-beam Irradiated DNA

3:15-3:30 Questions for speakers and discussion on "current needs"

3:30-3:45 Break

Breakout Session II: Dosimetry and Applications

3:45-4:05 Gary Pageau, GEX Corporation Centennial Colorado
Low Energy Electron Beam Dosimetry Calibration Cha*llenges*

4:05-4:25 Roberto Uribe, PhD, Kent State University
Potential use of PE films as low energy electron beam dosimetry

4:25-4:45 Ileana Pazos, PhD, National Institute of Standards and Technology
Future of Chip-Scaled Radiation Dosimetry

4:45-5:05 Questions for speakers and discussion on "current needs"

5:30 Adjourn

MEDICAL APPLICATIONS
MONDAY APRIL 16, 2018 (AFTERNOON)
LECTURE ROOM A

Chairs: Regina Fulkerson (Standard Imaging), Wesley Culberson (University of Wisconsin), and Ronaldo (Ronnie) Minniti (NIST)

Breakout Session I: Microdosimetry

1:45-2:15 Malcom McEwen, PhD, National Research Council of Canada
Introduction to the Session on Microdosimetry

2:15-2:45 Rowan Thomson, PhD, Carleton University
Challenges in Monte Carlo Simulations for Microdosimetry

2:45-3:15 Gabriel Sawakuchi, PhD, MD Anderson Cancer Center
Nanoscale Radiation Measurements in Mixed Radiation Fields at the Molecular Level

3:15-3:30 Questions for speakers and discussion on "current needs"

3:30-3:45 Break

Breakout Session II: Magnetic Resonance Guided Radiation Therapy

3:45-4:15 Hannah Lee, PhD, MD Anderson Cancer Center
Introduction to MR-Guided Radiation Therapy and the Added Value of Volumetric Dosimeters

4:15-4:45 Daniel O'Brien, PhD, Elekta
Reference Dosimetry Protocols and their Application in Environments with Strong Magnetic Fields

4:45-5:15 Arman Sarfehnia, PhD, MCCPM, Sunnybrook Health Sciences Centre
Calorimetry-based absolute dosimetry in MR-Linac

5:15-5:30 Questions for speakers and discussion on "current needs"

5:30 Adjourn

MEDICAL APPLICATIONS
TUESDAY APRIL 17, 2018 (AFTERNOON)
LECTURE ROOM A

Chairs: Regina Fulkerson (Standard Imaging), Wesley Culberson (University of Wisconsin), and Ronaldo (Ronnie) Minniti (NIST)

Breakout Session I: Radiation Biology Standards

1:45-2:15 Yannik Poirer**,** PhD, University of Maryland
The Current State of Physics and Dosimetry Reporting in Radiation Biology

2:15-2:45 Ceferino Obcemea, PhD, National Cancer Institute and National Institutes of Medicine
The Importance of Radiation Dosimetry Standards in Pre-Clinical Radiobiology Studies

2:45-3:15 Dan Bourland, PhD, Wake Forest School of Medicine
Experience and Dosimetry Standardization for Total Body Irradiations in Research

3:15-3:30 Questions for speakers and discussion on "current needs"

3:30-3:45 Break

Breakout Session II: Frontiers of Medical Physics

3:45-4:15 William F. Blakely, PhD, Armed Forces Radiobiology Research Institute
Update on AFRRI's Cytogenetic Biodosimetry Activities

4:15-4:45 Scott Clarke, MS, 3D Bolus
3D Printing Applications in Radiation Therapy

4:45-5:15 Charles K. Matrosic, MS, University of Wisconsin
Deformable 3D Polymer Gel Dosimetry for the Validation of Motion Management and Deformable Dose Accumulation

5:15-5:30 Questions for speakers and discussion on "current needs"

5:30 Adjourn

RADIATION PROTECTION
MONDAY APRIL 16, 2018 (AFTERNOON)
LECTURE ROOM B

Chairs: Jacqueline Mann (NIST), Stephanie Healey (FDA) and
Stanley Mavrogianis (NSWC)

Breakout Session I

1:45-2:15 Alan Huston, PhD, Navy Research Laboratory (NRL)
Mapping Copper-Doped Fused Quartz: a unique, multifaceted radiation-sensitive material

2:15-2:45 Lt Col Steven Webber, Defense Threat Reduction Agency (DTRA)
Dosimetry DTRA R&D in RN Contamination Avoidance

2:45-3:15 Luis Benevides, PhD, Naval Surface Warfare Center (NSWC)
Using a Novel Additive Manufacturing Technique for Criticality

3:15-3:30 Questions for speakers and discussion on "current needs"

3:30-3:45 Break

Breakout Session II

3:45-4:15 Frederick P. Straccia, CHP, Radiation Safety and Control Services Inc. *Comparison of* ***Moderated AmBe and Moderated Cf for Neutron Dose Calibrations***

4:15-4:45 Mark DiNezza, CHP, Naval Surface Warfare Center (NSWC)
History of Navy's Electronic Personal Dosimeter, 2006 to Present

4:45-5:15 Matthew Spierenburg, CHP, Naval Surface Warfare Center (NSWC)
How to Sample Air for Radioactive Contamination on an Aircraft Carrier

5:15-5:30 Questions for speakers and discussion on "current needs"

5:30 Adjourn

RADIATION PROTECTION
TUESDAY APRIL 17, 2018 (AFTERNOON)
LECTURE ROOM B

Chairs: Jacqueline Mann (NIST), Stephanie Healey (FDA) and
Stanley Mavrogianis (NSWC)

Breakout Session I

1:45-2:15 Robert Jones, PhD, Centers for Disease Control and Prevention
CDC's Rapid Radionuclide Screen: Improvements, New Methods & Plans for the Future

2:15-2:45 Dr. Alison Tamasi, PhD, United States Environmental Protection Agency *Put to the Test:* ***Designing Effective Laboratory Capability Assessments for Hypothetical High-Stakes Radiological and Nuclear Scenarios***

2:45-3:15 Dr. William Cunningham, PhD, Food and Drug Administration
Radionuclides in Food – Where Metrology Matters

3:15-3:30 Questions for speakers and discussion on "current needs"

3:30-3:45 Break

Breakout Session II

3:45-4:15 Zhichao Lin, PhD, Food and Drug Administration (FDA)
Development of food-based proficiency testing materials for laboratory competency evaluation and radioanalytical method validation

4:15-4:45 Stephanie Healy, PhD, Food and Drug Administration (FDA)
An Intercomparison Study on Radioanalytical Methods Used by FDA Food Emergency Response Radiological Laboratory Network

4:45-5:30 Questions for speakers and discussion on "current needs"

5:30 Adjourn

CONFERENCE ABSTRACTS

MONDAY APRIL 16, 2018 - MORNING PLENARIES

KEYNOTE ADDRESS: Unconventional Approaches to Diagnosing and Mitigating the Effects of Radiation and WMD Exposure

Eric Van Gieson
Biological Technologies Office, DARPA

The DARPA Epigenetic Characterization and Observation (ECHO) and Electrical Prescriptions (ElectRx) programs will develop technologies that may be used to explore entirely new ways to both diagnose exposure to ionizing radiation as well as enhance the body's response to insult. The DARPA ECHO program will utilize host-response signatures, such as epigenetic changes that occur in response to exposure, to provide exponentially better sensitivity, specificity, and temporal information for a given dose. In parallel, ElectRx and other programs aim to manipulate our own host-response mechanisms to provide countermeasures for a variety of different types of threats and injuries. ElectRx treatments include targeted stimulation of the peripheral nervous system to moderate the body's immune response and inflammation pathways as well as provide non-pharmacological methods for treating pain and PTSD. These programs aim to continue the mission of sensing and responding to emerging threats using entirely new ways to harness biology for security.

Standards and Innovation

Brian Meincke
American Society for Testing and Materials (ASTM)

ASTM International is a globally recognized leader in the development and delivery of voluntary consensus standards with over 12,000 standards that are used around the world to improve product quality, enhance health and safety, strengthen market access and trade, and build consumer confidence. Technology changes quickly which creates a strong need for a nimble and responsive standards development process. The process for maintaining market relevant content will be covered as well as related program areas that complement our standards development activities. A new innovative approach for filtering research from innovation hubs into ASTM technical committees will also be highlighted.

TUESDAY APRIL 17, 2018 - MORNING PLENARIES

3D Printing Patient-Specific Phantoms for Imaging and Radiation Dosimetry: Recent Progress, Challenges, and Future Directions

Matthew Mille, PhD, Keith Griffin, MS, and Choonsik Lee, PhD
Division of Cancer Epidemiology and Genetics, National Cancer Institute, National Institutes of Health

Physical phantoms are important for the radiation dose assessment of patients undergoing both diagnostic and therapeutic procedures. Unfortunately, however, existing commercial physical phantoms are expensive, have not been revised for decades, and do not adequately represent patients of all body-sizes. A more flexible dosimetry approach is to use computational human phantoms coupled with Monte Carlo radiation transport codes. Nonetheless, such calculations still need to be benchmarked against measurements performed using physical phantoms, and the small variety of phantoms available effectively limits the range of cases which can be experimentally validated. The ability to custom-fabricate phantoms on-demand for research and other applications would represent a significant breakthrough in the field. To address this problem, our research team at the National Cancer Institute is exploring three-dimensional (3D) printing as a method for bringing our computational phantoms to life.

Since the mid-1990s, 3d-printing has been used in medicine for the development of surgical guides, implants, and prosthetics. A variety of technologies can be used ranging from industrial stereolithography to table-top thermoplastic extruders. The cost of many consumer-grade printers has dropped significantly over the past ten years, bring the technology to a far wider audience. This talk will detail our experience with these technologies and the promise they hold for the fabrication of patient-specific phantoms for medical radiation applications. At the same time, there are significant challenges. Key barriers to progress include: (1) The small build volume and speed of many printers which inhibits the fabrication human-size parts; (2) The limited variety of 3D-printing materials for simulating tissues with mass densities ranging from 0.25 g/cm^3 (lung) to 1.85 g/cm^3(bone); and (3) The inability to print parts with multiple materials simultaneously. We have yet to identify a 3D-printing technology which can fully overcome all of these challenges.

While a comprehensive 3D-printing solution remains elusive, our research shows that much can still be accomplished within the limitations of current technology. Results are presented for two different approaches using our thermoplastic extruder. The first involves spatially varying the “fill density setting” (FDS) to control the radiographic density of different regions of a print. A FDS of 100% creates a solid part, whereas a lower value results in a semi-hollow part. As a demonstration, we developed a section of a pediatric torso with five segmented tissues represented: lung, fat, muscle, bone, esophagus (air). The bone and esophagus region regions were left as negative space, with the bone regions being filled with a bone-equivalent casting resin as a post-processing step. The second approach involved using the 3d-printer to create a mold from which parts are subsequently cast out of tissue-equivalent materials. This approach was used to develop a bolus fat layer to place around one of our commercial phantoms to simulate an obese patient.

Acknowledgements: This research was funded by the intramural research program of the National Institutes of Health, National Cancer Institute, Division of Cancer Epidemiology and Genetics. The contents are solely the responsibility of the authors and does not necessarily represent the official views of the National Institutes of Health.

Patient Safety in the Age of Big Data: Machine Learning, Measurements, and Standards for Making Radiation Treatments Safer

Christopher Berlind
Oncora Medical

A primary goal of measurements and standards in the field of radiation medicine is that of ensuring patient safety. Measurements and standards can help make sure patients receive a safe dose of radiation that will not cause harmful side effects to healthy tissues and organs. Equally important is the need to ensure patients receive enough radiation to the appropriate targets to balance the inherent risks of radiation with the potential for medicinal benefit. Unfortunately, the complex radiotherapy planning and delivery process leaves room for numerous sources of error. Error sources include poor clinical decisions, suboptimal treatment planning, machine miscalibration, and improper patient positioning, all resulting in threats to patient safety. The vast amount of historical patient and treatment data now available has made it possible to begin exploring the use of big data and machine learning techniques to help prevent or correct many types of errors in radiation treatments. In this talk, I will discuss how machine learning techniques can be used to mitigate radiation treatment errors, with a particular emphasis on the steps that must be taken to implement these methods in clinical practice. Case studies will be taken from Oncora Medical's work in developing clinical decision support tools for radiation oncology. I will also discuss several ways in which radiation measurements and standards can contribute to higher quality output from machine learning methods and, in turn, improve patient safety.

The Breakthrough Initiatives: Search for Life in the Universe

Peter Klupar
Breakthrough Initiatives Foundation

At the Royal Society in London on July 20, 2015, Yuri Milner, Stephen Hawking and Lord Martin Rees announced a set of initiatives — a scientific program aimed at finding evidence of technological life beyond Earth entitled 'Breakthrough Listen. In addition, atop the One World Trade Center in New York on April 20, 2016, Breakthrough Starshot was announced, an interstellar program to Alpha Centauri. These are the first of several privately-funded global initiatives to answer the fundamental science questions surrounding the origin, extent and nature of life in the universe. The Breakthrough Initiatives are managed by the Breakthrough Prize Foundation. Breakthroughinitiatives.org

WEDNESDAY APRIL 18, 2018 - MORNING PLENARIES

A DNA Double-strand Break Dosimeter for Radiation Measurements

Neil Kirby
University of Texas at San Antonio

Many types of dosimeters are used to measure radiation dose and calibrate radiotherapy equipment, but none directly measure the biological effect of this dose. The purpose here is to create a dosimeter that can measure the probability of double-strand breaks (DSB) for DNA, which is directly related to the biological effect of radiation. The DNA dosimeter consists of magnetic streptavidin beads attached to 4 kilobase pair DNA strands labeled with biotin and fluorescein amidite (FAM) on opposing ends, which are suspended in phosphate-buffered saline. Fifty μL samples of the solution were placed in plastic tubes and utilized as dosimeters. After irradiation, the dosimeters were mechanically separated into beads (intact DNA) and supernatant (broken DNA/FAM) using a magnet. The fluorescence was read and the probability of DSB was calculated. This DNA dosimeter response was benchmarked against a Southern blot analysis technique for the measurement of DSB probability. These results indicate that the DNA dosimeter can accurately determine the probability of DNA DSB, one of the most toxic effects of radiotherapy, for absorbed radiation doses from 25 to 200 Gy. This is an important step in demonstrating the viability of DNA dosimeters as a measurement technique for radiation. This presentation will show the basic dosimetry characteristics and some initial relative biological effectiveness benchmarks of the DNA measurement technique.

Radiation Biodosimetry Test Development Continues Apace

Lynne Wathen, Bonnie Shen, Donna Boston, Paul Eder, Rodney Wallace
Biomedical Advanced Research and Development Authority (BARDA), Office of Assistant Secretary of Preparedness and Response (ASPR), US Dept. of Health and Human Services, Washington DC, USA

In radiation disasters, the population is likely to encounter a number of complex radiation exposure scenarios, including different dose ranges and dose rates. Therefore, performing triage and definitive radiation biodosimetry will require multiple tests to measure absorbed dose. In the aftermath of an improvised nuclear device (IND) detonation or a nuclear accident, having rapid and accurate measurements of absorbed doses in exposed persons can inform life-saving medical decisions. A qualitative point-of-care test is being designed to be administered quickly to determine whether an individual has absorbed a minimum threshold radiation dose and needs further medical care. Quantitative high-throughput laboratory-based tests that estimate the actual absorbed dose a person has received to enable more accurate clinical management are under development. Four promising biodosimetry tests are currently funded by BARDA to identify the most relevant proteomic, genomic and cytologic radiation biomarkers and validate their utility using animal models and humans. Algorithms integrate multiple individual biomarker results into a single test result. The point of care test in development uses immune-capture technology with multiple test lines on a nitrocellulose lateral flow device with up-converting phosphor signal output. This test uses a capillary (finger stick) blood sample to detect host protein biomarker levels that increase following gamma or x-ray exposure. Of the three high-throughput tests under development, two use changes in gene expression patterns to determine the extent of radiation damage, and the third measures chromosomal damage and micronucleus generation to predict absorbed dose. Recently, BARDA filed an application for pre-Emergency Use Authorization with the United States Food and Drug Administration for one of the high-throughput tests. Current work with federal and industry partners will enable the development, regulatory review, and acquisition of radiation biodosimeters within the next few years. The Biodosimetry Program's continued success will help the United States prepare for and respond more effectively to a nuclear incident.

Radiation-Based Technologies and their Current Industrial Applications

Kathy Hoffman and Kevin O'Hara
Sterigenics

Sterigenics utilizes various forms of radiation technologies to treat medical products, pharmaceuticals, food products and advanced materials. We have experience with gamma, e-beam and x-ray radiation technologies, as well as ethylene oxide sterilization. Sterigenics is technology-neutral but works closely with their customers to select the proper sterilization technology to fit the specific application and geographical location for sterilization.

The medical product sterilization landscape has changed dramatically of the last sixty years. Medical devices and pharmaceutical have become more sophisticated. In addition, new medical device materials make it very important to understand the effects of sterilization on end use of the device. Therefore, optimal sterilization methods are evaluated on a case-by-case basis, but finding the right sterilization solution takes in-depth knowledge of the product, potential constraints on the sterilization process, and collaboration between the manufacturer and sterilization service provider. Sterilization processes have evolved and new ones developed to meet the challenges posed by many new medical devices.

Sterilization is a critical step of manufacturing medical products for the healthcare industry. Current commercial sterilization methodologies include radiation based (gamma, e-beam, x-ray) and gas based (EO) sterilization. The industry recently completed and published a holistic comparison of the major sterilization technologies to document a thorough and practical review of the all of these technologies and the practical experiences from them over several years of experience. This comparison helps explain the technologies benefits as well as its potential limitations in the healthcare applications. This understanding is critical to the healthcare industry in providing safe, fit-for-purpose, sterile medical devices and other healthcare products to patients in the US and worldwide.

CAPSTONE PLENARY ADDRESS

An Eye Opener on the Bright Future of Ionizing Radiation Measurements in Medicine, Processing, and Nuclear Applications

Mohamad Al-Sheikhly
University of Maryland

Ever since the dawn of advanced technology, radiation measurements have been vital tools in the modern medical and radiation therapy, radiation processing, nuclear power plants, advanced nano fabrications, reliability and risk assessment, radiation environmental engineering, corrosion inhibition in nuclear power plants, and sterilization of medical equipment. One successful example is the electron beam lithography and its applications in the manufacturing of transistors nano-electronics industry. Another important application is the development and the use of neutron scattering to study the nanostructures of inorganic, organic, and biomaterials, and the implementations of the high-LET irradiation using protons, ions, and alpha particle in radiation oncology. At present, there are numerous emerging nanotechnologies in which radiation measurements play decisive roles. These include nano- magnetic and electronics, biotechnology, diagnostics, fabrication of various fabrics through radiation grafting, and therapy and diagnosis. Based on present pioneering research programs, the future trends in radiation measurements for nuclear applications, nanotechnology, and medicine, can be outlined as follows:

1. Neutrons: High flux reactors are excellent tools for advanced neutron scattering. Neutron irradiation can also reveal insightful information about nano-structure multidimensional self-assembly.
2. Developing a new generation of extra sensitive neutron detection based on nano carbon foam and scintillation of noble gasses
3. Heavy charged particles (i.e. protons and alpha particles): The advancement of radiation oncology requires the application of nano-dosimetry, including measurements of the dose distribution within a single cancer cell. With a further understanding of radiation cell killing mechanisms in a mixed

LET field, new nano-dosimetry based cell survival equations are being developed and benchmarked against experimental results. By introducing quantities on the nanometer scale, corresponding to DNA and chromatin-level lesions, a better model of the mechanisms of cell death and repair can be developed and instituted in radiology.

4. Light charged particles and gamma radiolysis: Low linear energy transfer (LET) irradiation, like in the case of gamma radiolysis, electron beam irradiation (0.3-10 MeV), and positron irradiation will play major roles in synthesis, manufacturing, and material characterization in nanotechnology. This includes, but is not limited to the following:
    - Electron beam and gamma radiolysis manufacturing of nano magnetic composites.
    - Electron beam and gamma radiolysis synthesis of nano gels for drug delivery systems, via intramolecular crosslinking of polymer chains.
    - Electron beam and gamma radiation-induced grafting of nano tubes for bioengineering applications.
    - Electron beam radiation-induced formation of nano particles.
    - Positron irradiation for characterization of nano structures
    - Synthesis of adsorbents to selectively extract uranium from seawater and for other environmental applications.

INDUSTRIAL APPLICATIONS AND MATERIALS EFFECTS ABSTRACTS

Establishing a Canadian-traceable calibration of high-dose rate Co-60 and electron radiation sources

Chris Howard[1], Malcolm McEwen[2], Fatima Hasanain[1]
[1]Nordion, [2]National Research Council Canada

Currently there is no direct link between the Canadian national standards for absorbed dose to water in Co-60 photons and electron beams, established for radiation therapy dose levels, and dose measurements made in industrial processing radiation fields. Canadian users are required to access calibration services offered by other service providers and/or national measurement institutes.
A collaboration has therefore been established between the National Research Council (the NMI for Canada) and Nordion to develop a calibration capability for industrial users based on alanine dosimetry. The ultimate traceability, as for other NMIs, will be the therapy standards already established at NRC (in this case, water calorimeters). The radiation sources at NRC and Nordion will be combined to bootstrap traceability from Gy/min to kGy/min dose rates. For additional robustness, the results from alanine readers at both institutions will be used to eliminate bias and also link in with present calibration capabilities maintained by Nordion.
The project will involve several steps, including:

- Alanine pellets irradiation at NRC Co-60 beams and read out using the standard Nordion protocol (where dosimetry is traceable to NIST through NVLAP accreditation)
- Alanine pellets irradiation at Nordion Gammacell and read out at NRC facility
- Three-way inter-comparison study including NRC, Nordion and NPL
- Comparison of alanine response in Co-60 with that in high-energy x-ray and electron beams

Investigation of Modern Self-Contained, Dry-Storage Irradiators

Ryan Howell
Hopewell Designs Inc.

Previous work has reviewed the benefits of a novel irradiation platform known as the GR440 developed by Hopewell Designs, Inc. This platform was developed to meet the overall size and weight requirements of a legacy self-contained irradiator while introducing improved irradiation performance. In this presentation the design constraints of the GR440 are relaxed for a new design basis that provides a closer link to the legacy system while greatly improving upon the capabilities of the legacy model. A study into optimizing a vertical chamber travel path irradiator design has been undertaken to modernize the legacy system and introduce a suite of new improvements to self-contained irradiation. Improvements in the overall design eliminate concerns of a high radiation field around the irradiator during transition between operational modes. Uniformity within the irradiation chamber and central dose rates are calculated with Monte Carlo simulation.

The Need for a National Electron Beam Irradiation Facility at NIST and How CIRMS can Help Facilitate its Creation

Mark S. Driscoll
Chemistry Department, and Director, UV/EB Technology Center
State University of New York College of Environmental Science and Forestry

Industrial electron beam processing adds over $85 billion US dollars to products worldwide each year. For this industry to continue and grow in the United States educated people are needed to operate the plants, develop new products and methods and conduct state of the art research. Educators will need access to industrial electron beam equipment for educating future operators and researchers. Industrial research and development will need access to electron beam equipment to treat new products and test new procedures.

And finally, academic and government scientists need access to electron beams to study new applications of electron beam irradiation this includes basic and applied research. While there are many commercial electron beam irradiation facilities in the United States most of them are very busy doing contract work and do not have the time needed by researchers to setup and run experiments. There are a few electron beam systems that are available for research including IBA Industrial and Neo Beam, but these facilities are very busy and cannot handle all the research that could be done. The United States needs to have a facility that is designed and setup for work by researchers and educators for research and education on radiation processing. To that end I would like to have a discussion on what industry, academia and government researchers need and want in an irradiation facility. How can CIRMS and its members help facilitate the installation of the two Titan Scan electron beams that NIST has but has not installed.

Low Energy Dosimetry Standards and Radiation Effects Studies Using a 300 keV Laboratory e-beam Unit

Fred B. Bateman
National Institute of Standards and Technology

The NIST Dosimetry Group has recently purchased a low-energy laboratory e-beam unit, with delivery expected in early 2019. The system, supplied by Comet ebeam Technologies, will provide a broad range of energies from 100 kV to 300 kV, applicable to most low-energy e-beam processing applications, with dose rates ranging from around 3 kGy to 500 kGy in a single pass.
The presentation will outline the planned uses for this system, including the development of low-energy e-beam dosimetry protocols and standards, and the use of the system for radiation effects and materials modification studies.

Radiation Processing Industry Direction and NIST Opportunities

Jon Jansson
Applied Sterilization Technologies, STERIS

The radiation processing industry is advancing to meet new customer needs and comply with regulatory requirements. Dosimeters need to be accurate, robust under varying conditions, able to meet specific measurement needs and traceable. In addition to routine services NIST has fulfilled, opportunities abound to NIST to advance dosimetry in routine industrial processes. Enhancement of current services can increase utilization in the marketplace. Leveraging of assets between organizations may provide mutual benefits.

Challenges in dose measurements with industrial electron beam

Emily Craven
Mevex

Electron beam processing is a mature technology that has been successfully used for medical device sterilization, materials modification, and food irradiation applications for decades. A challenge that has always been present with electron beam processing is product dose mapping due to 1) the high dose gradients that can exist in materials from dose build up, 2) the resolution of conventional dosimeters when measuring small features, 3) the “black art” of knowing where to place dosimeters to measure actual maximum and minimum doses, and 4) the variability that is inherent in most dose measurement systems suitable for this type of application. As products such as medical devices become more complex and heterogenous, with specialized materials and tight dose uniformity requirements, both measuring and meeting dose specifications become equally challenging.
This presentation will look at ways that industry as a whole can better understand and perform product dose mapping through mathematical modelling. We will also examine how modern electron beam irradiators have evolved to actively control and monitor process output, and what role dosimetry systems should have going forward. The challenge that we present to NIST is to provide a framework of support to validate new modelling and measurement techniques that move us away from conventional dosimetry systems.

Industry Expectations for NIST – A Contract Sterilizer's Perspective

Kevin O'Hara
Sterigenics

Sterigenics utilizes various forms of radiation and gas technologies to treat healthcare products, pharmaceuticals, food products and advanced materials. This evaluation of industry expectations for NIST is solely from the perspective of a contract sterilizer. We recognize the importance of working together with all industry partners to ensure a proper analysis is completed, and establish a path forward (including a meaningful update of the CIRMS Report on Needs in Ionizing Radiation).

Sterigenics has valued NIST's historical role in the development of the radiation-processing industry. Healthcare product manufacturers and contract services providers, however, have seen some deterioration in NIST's historical position. This presentation will provide Sterigenics' vision of what that role should be, and how we can work together to re-establish that position.

Sterigenics' position is that NIST has adequate funding and internal resources to be a world-leader in the following areas:

* Provider of timely and cost-effective calibration services (transfer-standard dosimetry and calibration irradiations);
    - With a dedicated technician for analyzing transfer-standard dosimeters and completing calibration irradiations with X-Ray, E-beam and Gamma sources;

    - Invest in a new Category I irradiator dedicated to calibration services, material testing and dose audits;

    -Lead regular industry proficiency tests to ensure the consistency of dose across the industry; provide active involvement in the development of international standards (ASTM, ISO), including participation in regular industry and customer meetings;

    -Availability for industry consultation, problem solving;

* Be active in the development and use of mathematical methods as applied to the sterilization of healthcare product and food treatment;

* Be active in the improvement of existing dosimetry systems, and the development of new systems.

* Investigate the use of practical, real-time dosimetry systems;

* Be active in blood-irradiation dosimetry (i.e. low dose applications, low energy X-Rays) where traceability may be difficult; and,

* Assist with a major revision of the CIRMS Report on Needs in Ionizing Radiation.

Interplanetary Energetic Particle Measurements with NASA's Heliophysics System Observatory

John F. Cooper
Heliospheric Physics Laboratory, NASA Goddard Space Flight Center, Greenbelt, Maryland

NASA's fleet of geospace and interplanetary spacecraft have collectively provided long-term monitoring of solar, heliospheric, and galactic energetic particles from the inner solar system to the outer heliosphere and now with Voyager 1 in local interstellar space. Most of the measurements can be accessed through the NASA Space Physics Data Facility (SPDF) at spdf.gsfc.nasa.gov with enhanced browser access for many data sets through the associated Virtual Energetic Particle Observatory (VEPO) at vepo.gsfc.nasa.gov. These data can be used in conjunction with radiation transport codes, e.g. GEANT, to specify the short-term to long-term dose rates for irradiation of spacecraft and surfaces of planetary bodies. Example flux spectra and dose profiles are discussed for the inner solar system at the Moon and Mars, for Pluto in the outer solar system, and for extreme Kuiper Belt Objects in the outermost heliosphere and the local interstellar medium.

Radiation Chemical Studies of Gamma- and Ion-beam Irradiated DNA

Amitava Adhikary,[1] David Becker,[1] Thomas Baumann,[2] Keaton Curran,[1] Craig Neal,[3] Cameron Hanson[1], Ananya Adhikary,[1] Samuel Ward,[1] Donovan Whitehead,[1] Sudipta Seal,[3] and M.D. Sevilla[1]

[1]Department of Chemistry, 146 Library Drive, Oakland University, Rochester, MI – 48309
[2]National Superconducting Cyclotron Laboratory, Michigan State University, East Lansing, MI – 48824
[3]University of Central Florida, Engineering 1, Rm 207, P.O. Box 162455, Orlando, FL 32816

Our ongoing ion-beam and γ- irradiation studies of DNA have led to a comprehensive model of DNA radiation-induced damage. This model describes physicochemical events from the initial deposition of energy to DNA ion-radical-excited state formation through hole and electron transfer, to chemical events involving free radical processes that lead to secondary radicals which result in DNA damage - such as, base and sugar damage, strand scission, and its associated base release. Employing samples of hydrated (Γ= 12±2 water molecules/nucleotide) DNA emphasizes direct-type (direct plus quasi-direct) effects. Samples are prepared with and without engineered nanoceria (cerium nanoparticles). Sugar radicals formed in the DNA sugar-phosphate backbone are immediate precursors of radiation-induced DNA-strand breaks that may lead to cell death, mutation, and subsequent neoplastic transformation. The very high global concentration (65 to 220 mg/ml) of macromolecules (DNA, RNA, proteins etc.) in the cell nucleus makes the role of direct-type effects of radiation in cells of crucial importance. This makes formation of sugar radicals via the "direct ionization followed by deprotonation" pathway of the sugar-phosphate backbone in DNA owing to the direct-type effects important. Studies employing electron spin resonance (ESR) spectroscopy of irradiated hydrated DNA samples, HPLC techniques to investigate the unaltered base release, and DFT calculations in our laboratory have unraveled other mechanisms of DNA-sugar radical formation via direct-type effects, viz. (i) excitation of DNA base cation radicals in monomers, oligomers, and in highly polymerized DNA, and (ii) dissociative electron attachment due to low energy electrons (LEE). Various factors influence the sugar radical formation by photoexcitation of base cation radicals in DNA-models, e.g., wavelength of the incident light, pH of the solution, length and the sequence of the oligomer, and the site of phosphate substitution (3'- or 5'-). Employing ion-beam irradiated hydrated DNA samples, we are testing the hypothesis that the yield of sugar radicals from LEE and excited state processes increase as LET increases along the beam path. The C3′-sugar radical without a phosphate, $C3'_{dephos}$•, is used as a marker for LEE-induced processes along the beam path. An increase in the yield of unaltered guanine base release is used as a marker for excitation-induced strand breaks. We employ nanoceria-DNA to investigate how and to what extent nanoceria modify radiation damage processes in DNA. Recently, we found that in irradiated nanoceria-DNA samples (1 nanoparticle/10 base pairs), nanoceria provide near-complete protection against radiation-induced unaltered base release (a surrogate for measurements of radiation-induced DNA strand breaks). These results might have important significance for radioprotection to radiation workers. Supported by: NIH NCI R01CA045424; Research Excellence Fund and Center for Biomedical Research at Oakland University; and The National Superconducting Cyclotron Laboratory at Michigan State University.

Low Energy Electron Beam Dosimetry Calibration Challenges

Gary Pageau
CEO GEX Corporation Centennial Colorado

Low energy electron beam radiation processing is widely used in sterilization, crosslinking and curing applications. However, the measurement of absorbed-dose in products undergoing industrial radiation processing using electron beams with energies between 80-350 keV is problematic because of dose gradient issues in available transfer reference standards as well as currently available routine dosimeters. The single available national standard traceable calibration solution option available to industry uses reference transfer standard Dmu calculated doses that are now limited since the future production of alanine film dosimeters has been discontinued. This presents a near-term industry issue that needs to be addressed.

Possible Use of PE Films for Dosimetry with Low Energy Electrons

R. M. Uribe and O. Al Harbi
Kent State University, College of Aeronautics and Engineering, Kent OH, 44242, USA

In the past few years low energy electron beam units with energies in the range from 80 to 300 keV have been developed as a convenient and non-expensive alternative for radiation curing of coatings, thin film crosslinking and polymerization, and surface decontamination. In many of these applications the process is controlled by means of the beam parameters and the final properties of the irradiated product, but in applications involving compliance with FDA regulations the determination of the dose received by the irradiated product is a basic requirement. Usually this is obtained through measurement with an appropriate dosimetry system. At the present time the only dosimetry system available to perform dose measurements for low energy electron beams is the so-called D_μ technique which involves the use of thin radiochromic films and knowledge about how the beam deposits energy as it penetrates through the dosimeter which is normally obtained by MC calculations. In this presentation we present the results of a project to investigate the suitability of polyethylene (PE) films as radiation dosimeters useful for low energy applications. The response quantity affected by the dose in this case is the infrared absorbance at 965 cm^{-1} wavenumber and was investigated as a function of dose, stability after irradiation, energy of the radiation and dose rate. The presentation will show results regarding the sensitivity of the dosimeter with dose and its independence with respect to energy, dose rate and stability with time after irradiation.

Future of Chip-scaled Radiation Dosimetry

Ileana Pazos
National Institute of Standards and Technology

Over the past year, NIST has assessed the radiation hardness of silicon nano-photonic sensors to determine their utility as high-precision calorimeters. These sensors would have the capability for 1000-fold improved spatial resolution over current technologies, which would expand the application space to a wide range of radiation energies and to non-uniform radiation fields. To date, the silicon photonic sensors have displayed extreme durability *u*nder harsh radiation conditions of up to 1MGy of dose with no systematic impact on the passivated devices. In this talk, future directions of these sensors and their derivatives will be discussed.

MEDICAL APPLICATIONS ABSTRACTS

Introduction to the Session on Microdosimetry

Malcom McEwen
National Research Council of Canada

Challenges in Monte Carlo Simulations for Microdosimetry

Rowan M. Thomson
Carleton Laboratory for Radiotherapy Physics, Carleton University, Ottawa ON, Canada

Monte Carlo (MC) simulations are applied in diverse contexts to model radiation interactions and energy deposition on centimeter (patients) to nanometer (subcellular) length scales. Traditionally, specific-purpose trajectory MC codes were used for low-energy and short-length scale applications, but recent work has extended the range of applicability of multi-purpose codes. While there are many exciting prospects for multi-scale MC simulations, from advancing knowledge of the biological effects of radiation to the development of new treatment techniques, there are also challenges. Trajectory MC simulations ignore the quantum wave nature of the electron, and quantum effects become non-negligible for sub-1 keV electrons with wavelength becoming comparable to biological target size. This presentation will discuss recent work to compare quantum mechanical (QM) and classical trajectory MC treatments of low-energy electron transport in condensed media.

As a full QM treatment of electron transport in condensed media is too complex to be feasible at present, a simplified model is considered of a plane wave electron incident on a cluster of ~10^3 point scatterers representing a water droplet. Scatterer positions are generally random but are constrained by a minimum inter-scatterer separation, d_{min}. The electron wavefield incident on each scatterer is determined by solving a system of ~10^3 coupled equations; QM results are averaged over >10^4 droplets with different scatterer positions. Average QM droplet cross sections and scattering event densities are compared with trajectory MC analogues, and relative errors on MC results are computed.

Differences between QM and MC results vary with single-scatterer cross section, electron wavelength, and structure (d_{min}). Relative errors generally increase with wavelength, differing in magnitude for scattering event density and cluster cross section. Introducing inelastic scatter and/or medium structure (non-zero d_{min}) generally increases relative errors. Future work will aim to develop more realistic models of low-energy electron transport in condensed media.

Nanoscale Radiation Measurements in Mixed Radiation Fields at the Molecular Level

Gabriel O. Sawakuchi
MD Anderson Cancer Center

Mixed radiation fields are present in particle therapy C-ion beams and in the space radiation environment. These mixed fields are composed of different types of particles with a large range of energies, resulting in a large range of ionization densities. The ionization density of a particle track is related to the type and complexity of DNA lesions. Thus, a single cell nucleus is subjected to different types and complexities of DNA lesions simultaneously in mixed radiation fields. Experiments to study the spatiotemporal effects of radiation have been mainly done in microbeam lines coupled to fluorescence microscopy. In these sophisticated setups, a focused micrometer-diameter beam is used to precisely irradiate subcellular structures of fluorescently-tagged live cells, which are visualized with a fluorescence microscope mounted in the beam line. However, a major limitation of microbeam systems is that they can deliver only low-energy beams with low-fluxes, which severely limits their relevance to particle therapy and space radiation. To make possible the precise study of radiation-induced DNA damage response (DDR) in mixed radiation fields, we developed a technique that allows co-localization, LET spectroscopy and spatiotemporal measurement of radiation-induced DDR in live cells in mixed radiation fields with nanoscale spatial resolution. Our technique uses fluorescence nuclear track detectors (FNTDs) in conjunction with

fluorescence confocal microscopy to co-localize single particle track traversals and radiation-induced foci in live cells in real time. Further, it also provides information of the LET of each particle track. Our technique opens the opportunity to precisely study DDR in complex radiation fields relevant to particle therapy and space radiation. This talk presents the technical details of our technique.

Introduction to MR-Guided Radiation Therapy and the Added Value of Volumetric Dosimeters

Hannah J. Lee
UT MD Anderson Cancer Center

With radiation therapy advances allowing for tighter tumor margins and reduced normal tissue toxicity, the integration of MRI into radiation treatment machines provides the best on-board tumor visibility with MRI's superior soft-tissue contrast compared to conventional CT and cone-beam CT. Several systems have been designed for this purpose including the pre-clinical 1.5 T MRI – 7 MV linear accelerator system (MR-Linac, Elekta), 1.0 T – 6 MV Sydney Inline linac (Ingham Institute), 0.5 T – 6 MV Aurora RT (MagnetTx), 0.35 T – Co-60 MRIdian (ViewRay Inc.), and the 0.35 T – linac MRIdian (ViewRay Inc.). The perpendicular orientation of the strong magnetic field (B_0) with respect to the radiation beam in systems integrating an MRI with a linac or Co-60 unit influences secondary electrons resulting in changes in dose deposition in three dimensions. However, conventional quality assurance tools lack the ability to report changes in volumetric dose distributions and discrepancies out of the plane of measurement. The goals of this talk are to introduce some of the dosimetric challenges in MR-guided radiation therapy and to present the need for volumetric dose evaluations. Volumetric dosimeters have been applied to MR-IGRT systems to assess the electron return effect, B_0 field effects on the radiation field penumbra, real-time relative 3D dose acquisition, and the feasibility of 3D dosimeters for treatment plan verification.

Reference Dosimetry Protocols and their Application in Radiotherapy Environments with Strong Magnetic Fields

Daniel O'Brien
Elekta

Recent advancements in MRI-guided radiotherapy (MRIgRT) have led to the development of new linacs with integrated MRI systems. This introduces a powerful magnetic field (from 0.35 T to 1.5 T in current systems) into the radiotherapy environment. Magnetic fields of this magnitude can significantly perturb the trajectories of the secondary electrons produced by photon beams. This not only changes the dose distribution (affecting the determination of beam quality) but also the dose-response of the ionization chambers required by standard reference dosimetry protocols. Additionally, the presence of a magnetic field introduces other subtle effects and puts limitations on the use of solid phantoms or detector inserts. Consequently, the current dosimetry protocols need to be adapted for MRIgRT systems. In this presentation the dosimetry difficulties introduced by magnetic fields are described. The impact of these difficulties on measurements performed in the clinic and at standards laboratories is also discussed. Suggestions for the adaptation of dosimetry protocols are then presented based on the observations found in the literature with a view towards the development of a future reference dosimetry protocol for radiotherapy photon beams in strong magnetic fields.

Calorimetry-based Absolute Dosimetry in MR-Linac

Arman Sarfehnia
Sunnybrook Health Sciences Centre

Given the advent of magnetic resonance imaging in radiotherapy, and the introduction of integrated MRI-linac delivery systems to radiotherapy clinics, it is important to study the feasibility of absolute dosimetry under such environments/conditions. Calorimetry forms an important foundation in radiation dosimetry. It allows for accurate measurement of absolute radiation dose through a direct measurement of radiation-induced temperature rise. In this presentation, two novel calorimeter designs will be described, and their results/performance in presence of radiation beam will be compared. The first device is a water calorimeter specifically designed and built for use in the integrated Elekta/Phillips MRI-linac. The portable 4°C stagnant

water calorimeter (WC) was designed and constructed from plastic and ceramic materials with no metallic/ferromagnetic components. The WC dimensions allow use in conventional linacs, as well as in MRI-linac and GammaKnife. Given the unique design and material choices, the WC is fully MRI-compatible and can be imaged with MRI or CBCT/MV for positioning. The second detector to be discussed is a miniaturized graphite calorimeter probe designed specifically for eventual use in clinical settings. This detector is also fully MRI-safe, and allows for dosimetry in the presence of magnetic field. The encouraging measurement results from these two calorimeters show the feasibility of absolute dose measurement using calorimetry in integrated MRI-linac delivery systems.

The Current State of Physics and Dosimetry Reporting in Radiation Biology

Yannik Poirer
University of Maryland

In recent years, there has been significant discussion surrounding the inability to reproduce or replicate more than half of studies published in peer-reviewed scientific and medical journals. The biological effects of radiation at the cellular, molecular and physiological level in tumor and normal tissue depend on the source and quality of the radiation delivered. In 2011, a symposium held by NIST and sponsored by the NCI, NIAID, and the NIST outlined recommendations to the radiobiology community defining a list of 12 criteria required for a study to be reproducible and interpretable. Despite those recommendations, the research community has been slow to adopt best-practices in radiation delivery and method reporting in the published literature. The objective of this study was to evaluate the current state of reporting on basic radiation physics and dosimetry aspects of the experimental protocol.
We evaluated 3542 peer-reviewed articles from 471 journals published in the last 20 years, representing the first large-scale review of physics and dosimetry reporting in radiation biology research. The methods section of each article was evaluated using the recommendations from the NIST symposium in these broad categories: radiation source specification, dose specification, absolute radiation dosimetry calibration, and irradiation geometry. While nearly all manuscripts reported the radiation source and dose delivered, fewer than two thirds reported the dose rate or the energy/beam quality of the radiation source, and less than a third reported any details concerning the irradiation geometry. Absolute dosimetry was the worst category, with fewer than 13% of studies reporting any details of the calibration of the experimental irradiator.
These data indicate the majority of studies involving radiation fail to report the basic experimental details necessary to interpret and replicate the study results. This has serious implications on the reliability of the reported mechanisms underlying tissue response and efficacy of therapeutic interventions.

The Importance of Radiation Dosimetry Standards in Pre-clinical Radiobiology Studies

Ceferino Obcemea
National Cancer Institute and National Institutes of Medicine

Pre-clinical studies are crucial in providing the evidence for the efficacy of a new treatment modality or its superiority over existing ones. Such studies are also needed to elucidate the cellular and biological mechanisms underlying these new treatment techniques, e.g. in Flash RT, targeted radionuclide therapy, RBE studies of new particle therapy beams, etc.
Radiation dosimetry standards are important in these new techniques so that experimental beams in use can be characterized adequately, and that direct inter-comparison of results between labs and institutions can be made. This will make the findings more translatable, more robust and more reproducible.

Experience and Dosimetry Standardization for Total Body Irradiations in Research

JD Bourland[1, 2, 3], JM Cline[1, 4] and JD Olson[4]
Departments of [1]Radiation Oncology, [2]Physics, [3]Biomedical Engineering and [4]Pathology/Comparative Medicine, Wake Forest School of Medicine and University

Purpose and Objectives

Total body irradiation (TBI) procedures with large animal models are an important component of radiation countermeasures research and development. This presentation reviews single-institution experience in research TBI, compares basic TBI parameters in use for particular research TBI geometries, and discusses challenges, radiobiological significance and the potential value of dosimetry standardization for TBI research procedures.

Materials and Methods

One particular and other TBI geometries and technical parameters used in the research setting are reviewed. Parameters for review include photon beam energy, animal pose, radiation beam field size and geometry, use of build-up materials, and dose and dose rate, among others. TBI geometries are evaluated relative to dose distributions and anatomy for potential biophysical significance.

Results

Research TBI technical parameters are similar, however, not standardized. Large-field procedures needed for research TBI are historically based on human TBI procedures used for conditioning prior to bone marrow transplantation. The selection of research TBI parameters relate to the technical capabilities available for use, including type of radiation source, photon energy, mechanical ranges for positioning and field size, dose rate, and immobilization techniques. Additional important parameters include the logistics for irradiation, including availability of radiation facilities, anesthesia technique, and supportive care before and after irradiation. Challenges for TBI research protocols include communication and standardization of radiation dosimetry parameters for the benefit of the research team, including study design, TBI implementation, and interpretation of results.

Conclusions

Radiation countermeasures research and development relies on specialized irradiations in the research setting. Technical parameters vary with radiation source capabilities and research protocol objectives and logistics. TBI procedures are an initial critical component of these research studies. Building on single-institution experience, communication and standardization of TBI radiation dosimetry parameters remain important opportunities for the multi-disciplinary teams conducting radiation countermeasures research and development.

Acknowledgements

Research supported in part by NIAID U19-AI67798, DOD W81XWH-15-1-0574, and BARDA HHS010020130DD18C.

Update on AFRRI's Cytogenetic Biodosimetry Activities

William F. Blakely, Uma Subramanian, Kuang-Heng Hsiao, Brett O'Brien, Lyudmila Romanyukha, and David L. Bolduc
Scientific Research Department, Armed Forces Radiobiology Research Institute, Uniformed Services University of the Health Sciences, Bethesda, Maryland

Cytogenetic biodosimetry using the IAEA manual and relevant ISO standards is the generally accepted method for radiation dose assessment in cases of suspected radiation over-exposures. The Armed Forces Radiobiology Research Institute (AFRRI) Biodosimetry Center provides biodosimetry capability based on the use of the dicentric chromosome aberration (DCA) and premature chromosome condensation (PCC) cytogenetic assays. In the last year the number of donors contributing to AFRRI's baseline for use of the dicentric chromosome aberration (DCA) assay has doubled to 20, which improves our ability to assess potentially low-dose exposures. We have recently obtained a commercial software application to permit

routine karyotyping of metaphase spreads in cases where radiation-induced chromosome aberrations are detected in order to evaluate for potential clonal aberrations. Our laboratory replaced its automated metaphase finder and applied the use of the automated scoring software to develop a dose-response calibration curve that permits rapid scoring of dicentric aberrations in cases of suspected radiation accidents. In the last few years we have participated in multiple exercises/inter-comparisons and successfully demonstrated blood collection and shipping in a military deployment activity as well as the ability to use both the conventional- and QuickScan-DCA analysis methods for dose assessment. In addition, efforts to establish the premature chromosome condensation (PCC) assay are underway to provide the laboratory with a second cytogenetic biodosimetry assay with robust capability for assessment of partial-body and higher doses (>5 Gy). Blood was exposed to ^{137}Cs gamma ray doses 0 – 26 Gy at 0.59 Gy/min. Cultures were incubated for 2 hr at 37°C following with 48 hrs in the presence of PHA with the final 0.5 hr. with 100 nM calyculin A. Dicentrics in PCC spreads were measured using the centromeric protein nucleic acid (PNA) probe using fluorescence *in situ* hybridization. Results from the analysis of excess PCC fragments, rings, and dicentrics will be reported including the use of the analysis methods for partial-body and high-dose exposure cases.

[The views expressed in this abstract are those of the authors and do not necessarily reflect the official policy or position of DoD, AFRRI, USUHS, nor the U.S. Government. Funding support provided by AFRRI RBB4431317 and RBB4352317.]

3D Printing Applications in Radiation Therapy

Scott Clarke
3D Bolus

Utilizing 3D printing technology allows cancer centres to create patient specific devices to be used throughout the course of radiation treatment. 3D Bolus has developed software applications for the creation of various types of bolus devices as well as surface brachytherapy applicators. These devices have been proven to improve the fit to the patient, resulting in fewer air gaps, decrease set up time on the linear accelerator, and create more conformal dose distributions when treating with electrons.
The Simple Bolus application allows cancer centres to print out objects that have been designed in the treatment planning system (TPS). Consistent density and improved fit of 3D printed bolus devices results in a delivered treatment that better matches the planned treatment when compared to the status quo.
The Modulated Electron Bolus application uses proprietary software to create a structure that is not only custom to the patients anatomy, but is designed in such a way as to conform the electron dose distribution to the unique shape of the planning target volume (PTV) itself.
Patient specific surface brachytherapy applicators can improve the way that skin lesions are treated. These devices can be created programmatically by incorporating catheter trajectories that follow the contours of the patients' surface. These hollow tunnels allow movement of the radioactive source to each dwell position for treatment.

Deformable 3D Polymer Gel Dosimetry for the Validation of Motion Management and Deformable Dose Accumulation

Charles K. Matrosic
University of Wisconsin

Over the past decade, intrafractional motion management and deformable dose accumulation systems have become much more common in radiotherapy clinics to reduce uncertainties in external beam patient treatments. Due to this trend, more robust validation methods are needed to ensure that these systems are accurately delivering patient treatments. A method that shows promise is 3D normoxic polyacrylamide (nPAG) polymer gel dosimetry, which has been shown to be radiologically tissue equivalent, dose rate independent, and energy independent. Polymer gel dosimetry provides 3D dose distributions through the polymerization of monomers mixed into a gelatin matrix, which can be analyzed using optical CT or MRI. Additionally, when placed in a deformable mold, nPAG can mimic the effects of patient motion and deformation, allowing for 3D measurements that can be related to the initial undeformed anatomy. Due to

this ability, nPAG gel dosimeters can be incorporated into motion phantoms and used to measure the dosimetric effects of gating or tracking patient treatments. Also, deformable gel dosimeters can be irradiated with and without static deformation during irradiation and the measurements can be compared to estimations made by deformable dose accumulation systems.

RADIATION PROTECTION ABSTRACTS

Mapping Copper-Doped Fused Quartz: A Unique, Multifaceted Radiation-sensitive Material

Alan Huston
Navy Research Laboratory (NRL)

We have developed a method for diffusing copper into monolithic fused quartz materials produce brightly luminescent, optically transparent, radiation-sensitive glasses that can be used for a wide variety of applications. The copper diffuses readily into the glass and is trapped at natural defects that are well-known to exist in silica glasses. The mechanism for this process is not known, but we do know that the copper exists in a plus one state (Cu^{+1}) and is uniformly distributed throughout the entire volume. Under UV illumination, the glass exhibits a broad luminescence that appears blue-green and is centered at about 500 nm. At wavelengths below about 250 nm, many Cu^{+1} ions are ionized to Cu^{+2} and the electrons become trapped in metastable states near the parent ion. The trapped electrons can be driven to recombine with the parent ion, emitting luminescence that is characteristic of excited state Cu^{+1}. The driving force can be heat, as in thermoluminescence (TL) or light as in optically stimulated luminescence (OSL). Upon exposure to ionizing radiation, a large fraction of the Cu^{+1} ions do not ionize further to produce Cu^{+2}, but instead produce excited state $*Cu^{+1}$ ions that relax to the ground state giving off their characteristic blue-green emission as in radioluminescence.

The remarkable ability of Cu to diffuse into relatively large pieces of fused quartz have made a number of applications possible. Fused quartz rods with a diameter of 2.5 cm and a length of 1m have been use to produce a km of 400 micron diameter optical fiber. Flat, polished disks cut from the rod were used to write optical gratings to reflect specific optical wavelengths, and to write high-resolution images that can be stored and read out months later using OSL.

One of the most significant applications for the optical fiber was the demonstration of real-time radiotherapy monitoring without interference from Cerenkov radiation. The performance of fiber probe that used a 1 mm length of the doped fiber, fusion spliced to a commercial fiber was shown to be as precise as a high-performance ionization chamber, but was capable of measuring doses in much smaller areas. This talk will describe in more detail many of the applications made possible with this unique optically transparent, radiation-sensitive material.

Dosimetry DTRA R&D in RN Contamination Avoidance

Lt Col Steven Webber
Defense Threat Reduction Agency (DTRA)

Countering nuclear terrorism and maintaining the capability of the U.S. military to fight and win in a WMD environment are essential missions for the Department of Defense. The Defense Threat Reduction Agency (DTRA) conducts novel and innovative research and development in nuclear detection technologies to address both of these missions. This presentation will outline how DTRA has leveraged technologies originally developed for the countering nuclear terrorism mission to enable the warfighter to operate in a WMD environment more effectively than ever before.

Using a Novel Additive Manufacturing Technique for Criticality

Luis Benevides
Naval Surface Warfare Center (NSWC)

The field of additive manufacturing (AM) is a 21-century's transformative technology. The idea that we can design a device in computer aided design and build it through the process of additive manufacturing in a short period of time provides a world of possibilities. Today, we are asking the next question, how we can modify the AM materials toward an intended purpose. In this presentation, we will provide an example of this technology applied to ionizing radiation. The field of criticality dosimetry has an active and passive component. The active methods are used to monitor operation in real-time whereas the passive systems provide energy insights to accidents through activation. While the technologies used for passive

monitoring have not changed since their inception in the late 30's and 40's, the application of these technologies can take advantage of modern tools. In this presentation, we will provide data that AM in conjunction with nano-particle technology can provide a new twist on this technology to create and deploy passive criticality dosimetry. We have used nano-technology to incorporate criticality elements into the additive manufacturing material. The challenge was to develop a material which contained a sufficient amount of the criticality components without degradation of the additive manufacturing properties of the based material. We used polylactic acid (PLA) and Au nanoparticles (AuNP) to evaluate the concept. Navy Research Laboratory developed a method to dissolve the Au-nanoparticles into PLA by moving the Au from an aqueous solution to an organic solution. The PLA was also subsequently dissolved in an organic solution. Both solutions were brought together and the organic solvent was removed forming the AuNP loaded PLA. The next phase of the project was to verify the material retained its additive manufacturing properties specifically the melting properties. We evaluated the material using a differential scanning calorimetry analysis and determined that the material retained its properties. The final concept test was to determine if the concentration was sufficient to provide information from a radiological perspective. A sample of the material was irradiated at the US Naval Academy using a PuBe source. The material was subsequently evaluated using gamma spectroscopy which showed a prominent Au-198 peak. Now that the technology has been validated using Au, we would like to develop methodologies for sulfur, indium and copper. The final process will be to calibrate and provide a protocol to read the embedded material. The application of this technology presented here would revolutionize personnel neutron accident dosimeter or fixed nuclear accident dosimeters by incorporating criticality components into their respective holders.

Comparison of Moderated AmBe and Moderated Cf for Neutron Dose Calibrations

Frederick P. Straccia
Radiation Safety and Control Services Inc. (RSCS)

Requirements for calibration of neutron dose and dose rate instruments are described in various national and international standards. Neutron sources described in these standards include neutrons produced via α/n reactions (AmBe, PuBe) as well as spontaneous fission sources (bare and moderated Cf). The average neutron energies of these sources differ significantly, varying from 4 – 5 MeV for the α/n sources, 2 MeV for bare Cf, and 0.55 MeV for moderated Cf. While the lower energy neutrons from Cf sources are often better suited for calibration due to their closer match to fission spectrum neutrons, the costs associated with maintaining these sources are very expensive. This is due to the high cost of the Cf sources as well as the relatively short half live. This paper provides information on moderated α/n sources as an alternative to Cf. The energy reduction from moderation with HDPE and other moderators provides better alignment with fission spectrum neutrons. A review of recent literature as well as data from HDPE-moderated AmBe will be discussed.

History of Navy's Electronic Personal Dosimeter, 2006 to Present

Mark DiNezza
Naval Surface Warfare Center (NSWC)

The Navy acquired Electronic Personal Dosimeters (EPDs) in 2006 as part of a major procurement to replace secondary dosimeters, Self-Indicating Pocket Dosimeters (SIPDs), at that time. The Navy currently manages over 35,000 EPDs fielded to end users in the Naval Nuclear Propulsion Program (NNPP), Radiological Affairs Support Program (RASP), Command Naval Installations Command (CNIC) for emergency use, and the Bureau of Medicine and Surgery (BUMED). A summary of acceptance test results since the inception of the EPD contract will be presented. Additional test results acquired and certifications obtained by the Navy for the EPD will be presented. Finally, problems encountered and lessons learned throughout the acquisition period will be presented along with a path forward for the Navy's EPD over at least the next decade.

How to Sample Air for Radioactive Contamination on an Aircraft Carrier

Matthew Spierenburg
Naval Surface Warfare Center (NSWC)

The US Navy is replacing the existing Geiger Mueller (GM) based IM-239/WDQ Air Particle Detector (APD) with the solid state based IM-272A/WDQ. The change in detector medium has multiple benefits: increase beta efficiency, better alpha-beta discrimination and, due to the detector configuration, reduced weight to meet gamma rejection requirements. Use of the solid state detector allows the IM-272A/WDQ to gather additional data not achievable with the IM-239/WDQ. This presentation will describe the solid-state detector, how it is utilized in the system, method of calibration and other technical aspects of the IM-272A/WDQ.

CDC's Rapid Radionuclide Screen: Improvements, New Methods and Plans for the Future

Robert Jones
Centers for Disease Control and Prevention (CDC)

CDC has been developing a series of urine radionuclide screening and quantitative methods (Bioassay) to monitor and assess potential internal radiological contamination in people. 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 analytical methods, (e.g. through automation). HPGe gamma spectrometry capability has been extended to a total of six detectors, all of which are now automated. 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 are also developing new methods to increase the number of priority radionuclides addressed as well as we have automated half of our Gross Gamma screening method detectors. We intend to continue method development and improvement in the future, eventually extending our capabilities to rapidly analyze for all priority radionuclides.

CDC has reported extensively on methods, instrumentation and procedures toward this end, but we are continually working to improve these methods so we can provide higher quality data more quickly in the incident response. Here we report our recent improvements, new methods and future plans.

Put to the Test: Designing Effective Laboratory Capability Assessments for Hypothetical High-Stakes Radiological and Nuclear Scenarios

Alison Tamasi
United States Environmental Protection Agency (USEPA)

Because of the potentially devastating consequences of a nuclear or radiological event in the US, planning response efforts is imperative. Once the initial plans are in place, an important aspect of continued readiness is testing to assess whether those laboratory response efforts will be effective, and to proactively identify and address issues. Given the hypothetical nature of such incidents, it is difficult to realistically assess a lab's performance during a nuclear or radiological event without resorting to potentially unreliable samples. The considerations for developing a testing paradigm in which capabilities are assessed rigorously but fairly will be discussed in the context of EPA's new effort to evaluate readiness using simulated radiological urban matrix materials and other matrices.

Radionuclides in Food – Where Metrology Matters

William Cunningham
Food and Drug Administration (FDA)

Metrology has an important role in the U.S. Food and Drug Administration (FDA) radionuclide in food monitoring program. It is a fundamental component of laboratory operations and a core reason we report analytical results with confidence. Once results are reported, however, metrology is also quite invisible. When results can be trusted, risk managers are free to focus solely on overarching issues of food safety, communications staff can address concerns raised by media, the public, and various authorities, and risk assessors can address any follow up technical questions that are raised.

In the context of radiological analyses of food, there is also a dichotomy associated with metrology. At very low radioactivity levels, which are central to food safety decisions, a significant health risk can occur only when contamination levels remain elevated and large amounts of the affected food are consumed both on an on-going basis and over an extended period of time (months/years). Since this type of exposure is extremely unlikely, only negligible amounts of radioactivity would typically be ingested, even in times of emergency response. Exposures would therefore be so low that health would not be jeopardized even if there were large errors in analytical measurements. It would seem, then, that metrology would be of little importance but this is not the case. Metrology is the foundation on which results are reliable and food safety can be confirmed. It therefore has an impact on the agency's reputation, in general.

Development of Food-based Proficiency Testing Materials for Laboratory Competency Evaluation and Radioanalytical Method Validation

Zhichao Lin
Food and Drug Administration (FDA)

Safeguarding the nation’s food supplies includes the development and validation of various radioanalytical methods to measure radioactive contamination in a broad range of foods. This is a difficult process because there are numerous radiochemical approaches and types of radiation detection techniques available. These present several unique methodological challenges depending on the objective of the sample analysis and the nature of the food to be tested. This is particularly the case for Food Emergency Response Network (FERN) that uses diversified methods for screening and quantifying various radioactive contaminants in a wide variety of foods during a nuclear or radiological emergency response. In gamma spectrometry analysis of foods, the sample density variation and coincidence-summing effect are known to bias measurement results, but correction techniques are not uniformly applied throughout the FERN network. Also, in radiochemical analysis of foods for alpha- and beta-emitting radionuclides, the separation and recovery of analytes of interest are largely affected by sample matrix complexity and composition, therefore, the robustness of different radiochemical methods used by the FERN network for analyzing a wide range of foods needs verification. In acquiring food-based test samples, those resembling actual fresh food products are rarely available due to their short shelf life. In support of method validation and laboratory competency evaluation, fit-for-purpose test samples prepared from selected representative foods must be developed and made available to the FERN network for addressing its specific methodological and application needs. A series of representative foods were developed to accommodate FERN radioanalytical method validation and laboratory competency evaluation. This presentation details the experimental studies and findings on the identification, selection, and development of food-based testing materials used by FERN radiological laboratory network for laboratory competency evaluation and radioanalytical method validation.

An Intercomparison Study on Radioanalytical Methods Used by FDA Food Emergency Response Radiological Laboratory Network

Stephanie Healy
Food and Drug Administration (FDA)

Globalization of food production, trade, and distribution presents immense food safety challenges to the Food and Drug Administration (FDA), such as a major nuclear or radiological incident when local food contamination can rapidly become a national and global emergency. Prompt detection and effective consequence management of the radioactive contamination of food calls for a proficient laboratory network with a full range of radioanalytical capabilities and sufficient sample surge capacity. While the establishment of Food Emergency Response Network (FERN), which consists of federal and state laboratories, increases the FDA's ability in monitoring a broad range of radioactive contaminants in foods during a major nuclear or radiological emergency, the use of proven methods and the evaluation of laboratory competency is essential as protective action decision-making will be based on large pools of data from different laboratories using diversified radioanalytical methods. Ambiguous or inconsistent findings will inhibit the FDA from taking prompt and effective protective action. Therefore, method acceptability, data comparability, and efficient data reporting must be evaluated and demonstrated. With the FERN's data quality objectives in mind, various interlaboratory comparison studies were conducted for identifying, screening, and quantifying radionuclides in foods over the years. The results of these studies indicated that there are continuing improvements in data quality, method performance, and laboratory proficiency. This presentation summarizes observations and findings from the studies intended for the validation of radioanalytical techniques used by the FERN radiological laboratories and evaluation of laboratory competency. The needs for method harmonization, development of fit-for-purpose test samples, and technical trainings are also discussed.

STUDENT ABSTRACTS

CIRMS Student Travel Grant – sponsored by NIST

Investigation of the Energy Dependence of W_{air} in High Energy Electron Beams (Poster 1)

Alexandra Bourgouin[1], Malcolm McEwen[2]
[1]*Carleton University, Ottawa, Ontario, K1S 5B6, Canada*
[2]*Ionizing Radiation Standards, National Research Council of Canada, Ottawa, Ontario, K1A 0R6, Canada*

Purpose:

ICRU Report 90 on key dosimetry data (2016) has reaffirmed the accepted value of the mean energy required to create ion pair in air, W_{air}, to be 33.97 eV. The report also indicates that this 'constant' of radiation dosimetry is energy independent above 10 keV, since there is no theoretical or experimental evidence to the contrary. However, an extreme interpretation of the available data would suggest a variation of up to 2% in the clinical energy range is possible, which would have a significant impact on absorbed dose measurements using ionization chambers. The goal of this project is to obtain additional experimental determinations of W_{air} to verify the suggested energy independence.

Methods:

W_{air} is the quotient of charge released, Q_{air}, and energy deposited, $D_{air} \cdot m_{air}$, in an air volume. A way to realize this is to combine ionometric and calorimetric measurements, D_m, using the same material for both detectors combined with a dose ratio calculated by Monte Carlo $(D_{air}/D_m)_{MC}$.

$$W_{air} = \frac{D_{air} \cdot m_{air}}{Q_{air}} = \frac{D_m}{Q_{air}/m_{air}} \left(\frac{D_{air}}{D_m}\right)_{MC} \quad \text{Eq.1}$$

$$D_m = \Delta T \cdot c_m \cdot k_{hc} \quad \text{Eq.2}$$

Equation 2 show the calorimetric dose measurement calculation which is dependent on; the change in temperature of the calorimeter core, ΔT, the specific heat capacity of the medium, c_m, and the temperature correction factor for the heat lost, k_{hc}. In this study, a graphite parallel plate chamber and graphite calorimeter of similar dimensions and with the same sensitive volume were used (see figure 1). Measurements were made in electron beams from the NRC Vickers linear accelerator. Fourteen different configurations were used to provide both a range of electron energies at the point of measurement and varied thermal environments. As listed in table 1, two incident energies were used (20 MeV and 35 MeV), seven measurement depths (from 0.1 to 4.0 cm) and two irradiation times (15 and 30 sec.). Influence factors have been investigated with particular focus on the calorimeter analysis algorithm.

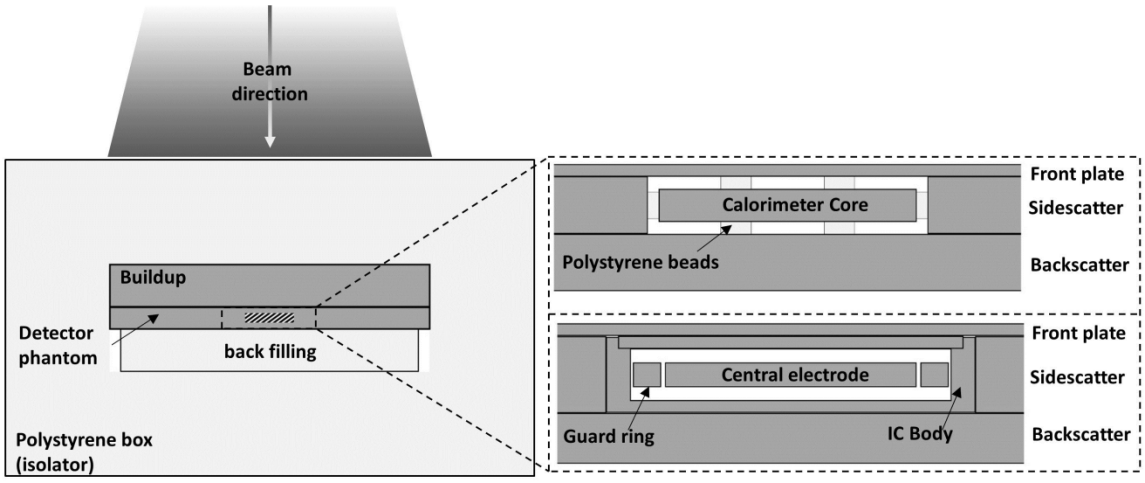


Figure 1: Detector phantom assembly. The "null" listing in table 1 indicates no additional build-up material, just the front plate of the calorimeter and ion chamber. The "back filling" is low density material to ensure good thermal contact between the graphite plates.

Table 1: Radiation and buildup set-up for all different configurations

Radiation			**Buildup**		**Electron spectrum in air cavity**
Energy *MeV*	Duration *sec.*	# of measurement -	Thickness *cm*	Density g/cm^3	Mode ± FWHM *MeV*
20	15 and 30	15 and 10	null	-	15.8 ± 3.0
20	15 and 30	10 and 10	0.953 ± 0.011	1.836 ± 0.001	13.0 ± 3.4
20	15 and 30	10 and 10	1.906 ± 0.010	1.755 ± 0.002	10.2 ± 4.2
35	30	14	null	-	29.5 ± 3.2
35	30	32	0.318 ± 0.001	1.848 ± 0.003	28.6 ± 3.4
35	15 and 30	10 and 10	1.906 ± 0.010	1.755 ± 0.002	23.9 ± 4.6
35	30	10	1.994 ± 0.010	1.773 ± 0.041	23.6 ± 4.6
35	15 and 30	5 and 10	3.812 ± 0.014	1.755 ± 0.002	17.8 ± 7.4
35	30	13	3.988 ± 0.014	1.773 ± 0.041	17.1 ± 7.6

Results:

Thermal modelling with the COMSOL Multiphysics system was used to inform the analysis of calorimeter irradiations and various fitting techniques were tested for robustness against electrical and thermal noise. Combining the calorimeter analysis with an EGSnrc calculation of the dose deposition ratio of both sensitive volumes (calorimeter core and air cavity) yielded a value for W_{air} of 33.77 ± 0.13 eV over the electron energy range investigated. This is not consistent with the recommended value as shown in figure 2.

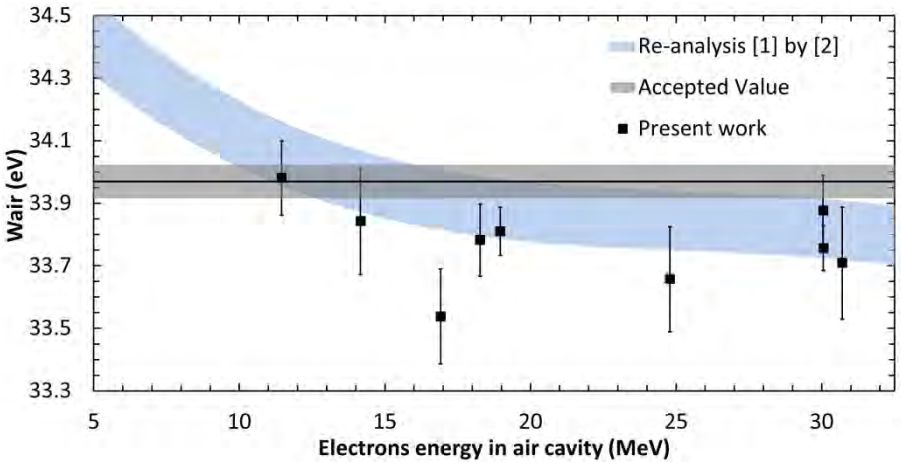


Figure 2: Results of W_{air} measurement compared to accepted value (shaded region indicates uncertainty) and calorimeter/ion chamber ratios measured by Domen and Lamperti [1] re-analysed by Tessier *et al.* [2].

Conclusion:

Results show an average value 0.6 % lower than expected. The W_{air} determination is directly dependent on the evaluation of some key parameters such as the specific heat capacity and the mass of the air cavity (as shown in equations 1 and 2). An error in these parameters could explain the difference with the expected value. No statistically significant energy dependence of W_{air} was obtained and the values are consistent with a recent re-analysis [2] of calorimeter/ion chamber ratios obtained in high-energy electron beams by Domen and Lamperti [1] as shown in Fig. 2. The results to date indicate the feasibility of the method. Further focus will be directed toward improving the evaluations of the specific heat capacity of the graphite used for the calorimeter and the mass of the air cavity in the ionization chamber. The energy range will be increased, and thus reduce the uncertainty on the estimate of W_{air} and its possible energy dependence.

Relevance to CIRMS mission and fist author's goals:

The presented work is the main doctoral project of the first author. This project fits with the conference theme because of the impact of any W_{air} energy dependence would have on future radiation technologies but mainly on future absolute dosimetry standard. This project is also directly linked to CIRMS mission since any energy dependence would have a direct impact on radiation dosimetry. 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 pursue a career in metrology, radiation measurement, after her PhD. This project and attending to a metrological conference, such as the CIRMS meeting, are key steps to reach that goal.

Information on collaborators:

Malcolm McEwen, National Research Council, Ottawa, Canada

Carl Ross, National Research Council, Ottawa, Canada

Claudiu Cojocaru, National Research Council, Ottawa, Canada

References

[1] S. R. Domen and P. J. Lamperti, "Comparisons of calorimetric and ionometric measurements in graphite irradiated with electrons from 15 to 50 MeV," *Med. Phys.*, vol. 3, no. 5, pp. 294–301, Sep. 1976.

[2] F. Tessier, C. D. Cojocaru, and C. K. Ross, "Extracting W air from the electron beam measurements of Domen and Lamperti," 2017.

CIRMS Student Travel Grant – sponsored by Sterigenics

Radiation Grafting of Ionic Liquids to Synthesize Polymer Electrolyte Membrane Fuel Cells (Poster 2)

Kevin Mecadon, Mohamad Al-Shiekhly, Fred Bateman, Joseph Robertson
Laboratory for Radiation and Polymer Science, University of Maryland, USA

Objective:

The purpose of this project is to design, synthesize and analyze innovative anhydrous fuel cell membranes that can operate at temperatures above 120°C, allowing for improved performance and reliability. Polymers were selected for grafting based on the following properties: high proton conductivity, low electrical conductivity, high mechanical properties, high chemical resistance, and high temperature and humidity stability. The method used to synthesize anhydrous polymer electrolyte membranes (PEMs) was radiation grafting using heterocyclic protic ionic liquid monomers and fluorocarbon substrates. The goal is to produce solid state proton conducting PEMs that do not rely on water for proton conductivity at high temperature. After synthesis, the extent and uniformity of PEM composition will be analyzed using FTIR microscopy, SEM/EDS, U-/SANS and their proton conductivity measured using 4-point probe EIS. Through the investigation of several protic ionic liquids, further insight can be gained into how their chemical structure and properties impact the conductivity of PEMs. Trends found in this research will help develop future anhydrous PEMs with higher conductivity and durability at high operating temperatures.

Methods:

The Medical Industrial Radiation Facilities (MIRF) at the National Institute of Standards and Technology (NIST) was used to radiation graft heterocyclic protic ionic liquids onto fluorocarbon substrates to create PEMs. These materials were chosen to synthesize a PEM that would have: high proton conductivity, low electrical conductivity, high mechanical properties, high chemical resistance, and high temperature and humidity stability. The MIRF is a 10MeV electron beam accelerator with pulse rate of 120pulses/sec. and average pulse current of 100μA. Indirect radiation grafting was used to treat the bulk substrate and requires no chemical additions, solvents or additives to generate free radicals for grafting. As shown in Figure 1, the entire indirect grafting synthesis is performed under an inert atmosphere. The samples were purged with argon to prevent radicals from reacting with oxygen, forming peroxyl radicals, which can lead to backbone scissions. Samples were irradiated under dry ice conditions to preserve radicals by lowering their mobility and preventing unwanted crosslinking. After samples were irradiated free radicals are generated in the fluorocarbon substrates which acted as grafting sites. A glove bag with an inert atmosphere was used to add the ionic liquids to the samples, which grafted and polymerized at the free

radical sites. Samples were then placed in an oven for a post heat treatment (PHT) at 80°C for 5 hours to promote diffusion and bulk grafting: this is depicted in Figure 1. Samples were analyzed to determine their composition, degree of grafting, extent of grafting and proton conductivity.

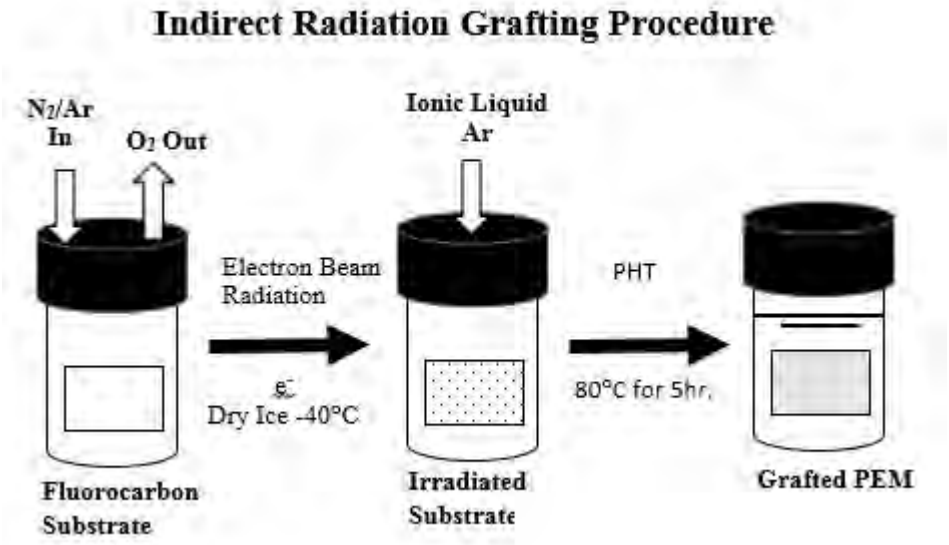


Figure 1: Overview of indirect radiation grafting procedure used to synthesize PEM

Results:

- Optimize the degree of grafting and uniformity of grafting ionic liquids onto fluorocarbon substrates to synthesizing anhydrous PEM, using radiation parameters and PHT
- Improve high temperature proton conductivity of PEM by using protic ionic liquids
- Determine humidity and temperature effect on proton conductivity and activation energy
- Find trends between chemical and structural properties of grafted ionic liquids and proton conductivity and activation energy of synthesized PEM
- Determine the mechanism for proton conductivity in the grafted PEM

Conclusion

This study shows that indirect radiation grafting can be used to successfully graft ionic liquids onto fluorocarbon substrates to synthesize PEMs. The chemical properties and structure of the grafted ionic liquids greatly affects the proton conductive mechanisms present in the PEMs. Through the course of this research, PEM preparation using radiation grafting and heterocyclic protic ionic liquids will be optimized. Prepared PEM will be assessed for the impact of their chemical structure and properties on proton conductivity. Trends found in this research will help the development of future anhydrous PEM with higher conductivity and durability at higher operating temperatures.

Relevance to CIRMS Mission:

This work is part of the first author's doctorial research to understand radiation synthesis of new PEM systems to improve their reliability and efficiency at high temperatures. This work is related to the CIRMS mission, of developing new develop new commercial product manufacturing methods and Industrial Applications and Material Effects. The versatile bulk grafting of fluorocarbon polymers demonstrated as part of this research is key to the development of functionalized membranes.

CIRMS Student Travel Grant – sponsored by Hopewell Designs Inc.

Impact of Half Value Layer Geometry on TG-61 Output for a Small Animal Irradiator (Poster 3)

Mary Peters, Ramesh C. Tailor, Joshua S. Niedzielski, David S. Followill, Stephen F. Kry, Sunil Krishnan, Rebecca M. Howell

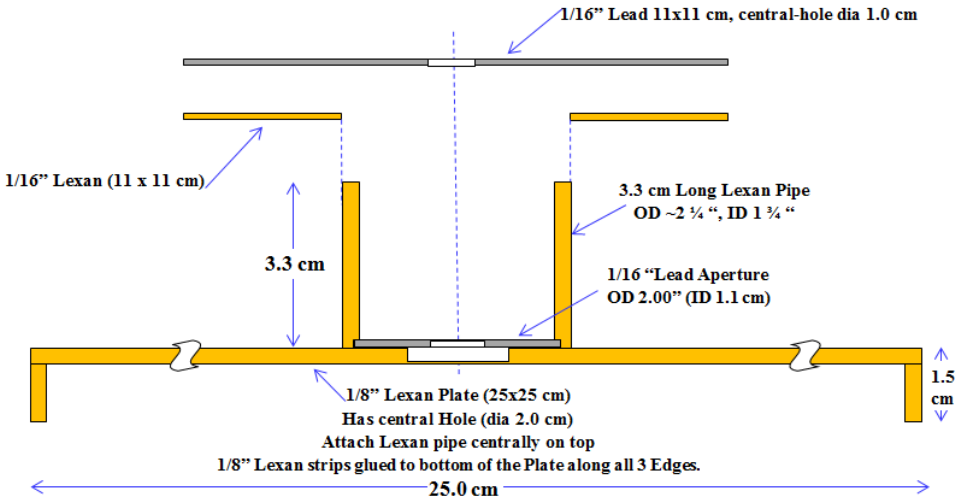
The University of Texas MD Anderson Cancer Center, USA

Purpose: Dosimetry in small animal irradiators has not been standardized to the same degree as it has been for MV linear accelerators. Presently, there are no regulations requiring that calibrations of animal irradiators be performed by medical physicists. For many research laboratories, calibrations of these irradiators are performed by the manufacturer, not by medical physicists. Additionally, there is no widely available service for independent peer review of the machine output. For MV linear accelerators, independent peer review is available from several different agencies/groups including the International Atomic Energy Agency (IAEA), MD Anderson Radiation Dosimetry Services (RDS), and Imaging and Radiation Oncology Core (IROC) Houston. However, there is no parallel service offered for small animal irradiators. The overall objective of this project is to develop and commission an independent peer review system for small animal irradiators. In particular, we will focus on a commonly used animal irradiator, the X-RAD 225Cx (Precision X-Ray, North Branford, CT). Once developed, this methodology can be further expanded to include other types of commercially available irradiators.

Accurate and reproducible dosimetry in animal experiments is an essential component of radiation biology studies to ensure reproducibility of results and applications to human treatments. However, it has been suggested that approximately 50% of all preclinical research in the United States is not reproducible (Guterman 2015). The results of two recent studies involving mail audits of small animal irradiators demonstrate the output variability that exists and the need for dosimetric verification. One study found that only 4 out of 7 institutions were able to deliver doses within 5% of the prescribed dose (Seed 2015). The second study tested 12 beams at 10 different institutions, and found that only 5 out of the 12 were within 5% accuracy (Pedersen 2016). These studies demonstrate a clear need for standardization and peer review in radiation biology studies.

Methods: AAPM task group 61 (TG-61) is a protocol for determining dosimetry in orthovoltage units.

There are many challenges in applying the TG-61 protocol to orthovoltage animal irradiators, as these irradiators have unique scatter environments and geometric constraints. Application of this protocol requires accurate measurement of half-value layer under narrow-beam geometry. An in-house (Tailor) narrow-beam collimator (Figure 1) was designed to achieve true narrow-beam geometry in the X-RAD 225Cx unit. The collimating device consists of two Cerrobend plates of 1.6 mm thickness, separated by a vertical distance of 1.5 cm, with a 1.0 cm diameter aperture. The removable collimator was designed to be placed on top of a Styrofoam stand (Figure 2), which houses the attenuating material (copper) and the ion chamber (Exradin A1SL) according to good geometric conditions. In this study, the Styrofoam stand was used to determine half-value layer with (Figure 3a) and without (Figure 3b) narrow-beam collimation. The TG-61 “in-air” method was then conducted to determine the effect of narrow-beam collimation on dose rate calculations.



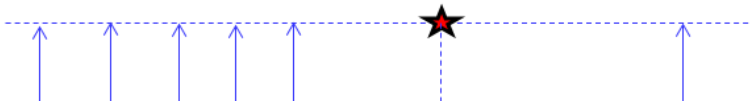


Figure 2: Schematic of the narrow-beam collimator on top of the Styrofoam stand (dimensions are in centimeters unless stated otherwise)

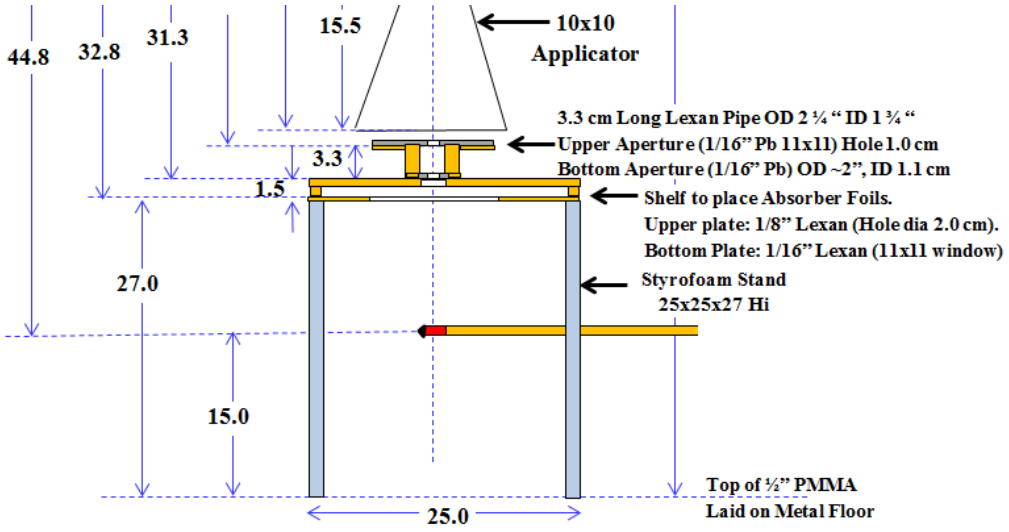


Figure 1: Schematic of the narrow-beam collimator

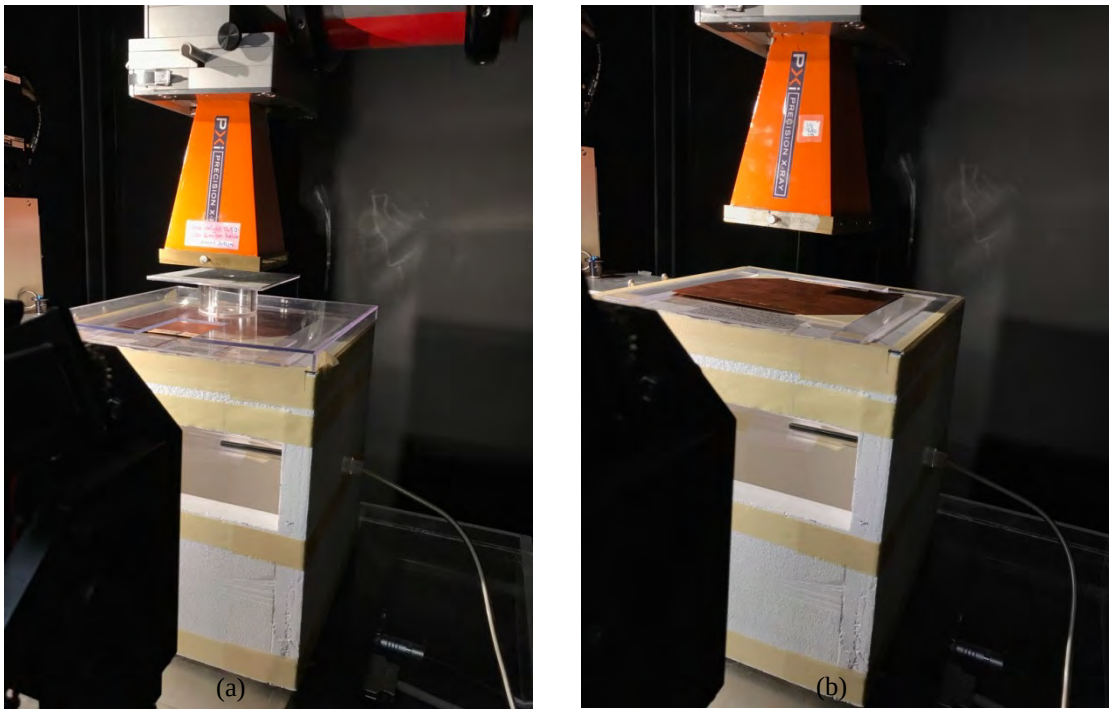


Figure 3: (a) Experimental setup for measuring half-value layer under narrow-beam geometry, and (b) experimental setup for measuring half-value layer under good geometry

Results: The narrow-beam collimated half-value layer was determined to be 0.86 mm Cu. The half-value layer under good geometry, without narrow-beam collimation, was determined to be 0.91 mm Cu. The 6% increase in half-value layer when the narrow-beam collimator is not used can be attributed to an increase in scattered dose reaching the ion chamber. The TG-61 "in-air" method was used to determine absorbed dose to water at the surface of a water phantom for each half-value layer result. An absorbed dose to water rate of 4.360 Gy/min and 4.354 Gy/min was determined for the narrow-beam geometry and good geometry, respectively.

Conclusions: Using our narrow-beam collimation device resulted in the most accurate dose rate calculation for the X-RAD 225Cx small animal irradiator. However, using good geometry without narrow-beam collimation proved to have a minimal impact (0.14%) on the resulting calibrated output. Future steps for this project include determining the variation of the air-kerma calibration factor, N_K, with distance from the source to the ion chamber. For the TG-61 calculations above, it was assumed that N_K calibrated at a distance of 100 cm was applicable to measurements at 30 cm SSD in the animal irradiator. The validity of this assumption needs to be investigated. After investigating N_K variations with SSD, the energy correction factor for TLDs in mouse phantoms will be determined, and a feasibility study of the audit service will be conducted.

Theme of radiation technologies for the future: In recent years, there has been a decline in ^{137}Cs radiation source irradiators and an associated rise in orthovoltage irradiator use for small animal research. With this change in technology, there is a need for standardization of calibration protocol, a thorough investigation of the appropriate dosimetric procedures, and an independent peer review program.

CIRMS Mission: This project is in agreement with CIRMS mission for standardization. It highlights the need for collaboration between industry, science, and medicine.

First Author's Goals: The first author is currently a specialized master's degree student in medical physics. Next fall, she plans to continue her education by pursuing a PhD in medical physics. Her long-term goals are to practice medical physics at an academic center and to become a Clinical Operation Director of Medical Physics. This project has provided her with opportunities to improve her research and leadership skills, and will aid her in achieving her career goal of bridging gaps in knowledge and addressing unmet needs.

References:

Guterman, L. (2015, July 01). Irreproducible life sciences research in U.S. costs $28 billion. Retrieved October 04, 2017, from https://www.sciencenews.org/article/irreproducible-life-sciences-research-us-costs-28-billion

Pedersen, K. H., Kunugi, K. A., Hammer, C. G., Culberson, W. S., & DeWerd, L. A. (2016). Radiation Biology Irradiator Dose Verification Survey. *Radiation Research, 185*(2), 163-168. doi:10.1667/rr14155.1

Seed, T. M., Xiao, S., Manley, N., Nikolich-Zugich, J., Pugh, J., Brink, M. V., …DeWerd, L. A. (2015). An interlaboratory comparison of dosimetry for a multi-institutional radiobiological research project: Observations, problems, solutions and lessons learned. *International Journal of Radiation Biology, 92*(2), 59-70. doi:10.3109/09553002.2015.1106024

CIRMS Student Travel Grant – sponsored by IBA Industrial Inc.

Dosimetry Verification in Radiobiology X-Ray Irradiators
(Poster 4)

Natalie Viscariello, Keith Kunugi, and Larry DeWerd
Medical Radiation Research Center, University of Wisconsin-Madison, USA

Objectives

X-ray cabinet irradiators are often used for radiobiology research. These irradiators may be calibrated using the AAPM TG-61 protocol[1], and TLD measurements may be used for experiment-specific dosimetry. It was found previously that many institutions were not delivering the intended dose when using this technique[2], but it is unclear if these discrepancies stem from differences in measurement setup or calibration. In an effort to encourage reproducibility in radiobiology, a 2013 NIST symposium established a need for traceable and consistent dosimetry measurements[3].

One consideration for accurate dose measurements in these irradiators is their output spectrum; the x-ray beams in these cabinet irradiators may not resemble NIST-matched x-ray beams used for detector calibration. Because detectors, especially TLDs and film, exhibit energy-dependent effects at kilovoltage energies[4-5], characterizing their response in radiobiology irradiators is important for improving accuracy in dose estimates.

This study used a validated EGSnrc model of an x-ray irradiator to investigate changes in spectra in radiobiology beams. This model was then used to determine TLD microcube energy response changes in-phantom. These changes were simulated and measured in 3D-printed murinemorphic phantoms. Characterization of detector response in these phantoms allows for a better estimate of corrections needed for providing accurate dose estimates for radiobiology irradiators.

Methods

3D-printed murinemorphic phantoms were developed from CT image sets of a 25 g lab mouse (Figure 1). TLD-100 microcubes were inserted into voids in the mouse body. These phantoms were used for simulation in EGSnrc and measurement. The resin composition was measured and accounted for in phantom simulations.

Figure 1: A 3D-printed murinemorphic phantom was fabricated. They were printed using Formlabs clear resin with a void for kapton tubes loaded with TLD-100 microcubes.

A previously validated Monte Carlo model[6] of the NIST-matched M-series x-ray beams at the University of Wisconsin Medical Radiation Research Center (UWMRRC) was used. Dose-rate determinations are possible for calibration irradiations at the UWMRRC by using detailed simulation of the irradiation geometry[2] and measured NIST-matched air-kerma rates. The air kerma, dose to water (D_w) in-phantom and dose to TLD (D_{det}) in-phantom were simulated. This allowed for the TLDs to be irradiated to a known dose in-phantom utilizing the M-series beams.

In order to approximate x-ray spectra found in Precision X-ray's XRad 320 cabinet irradiators, two filter packs were built for the UWMRRC x-ray system. These filters were fabricated such that the irradiator's 300 kVp and HVL matched those in the XRad 320 unit. These produced HVLs of 1 mm Cu (F1) and 4 mm Cu (F2). The air-kerma rate was measured using an A3 ion chamber and the F1 and F2 beams were simulated using Monte Carlo. The photon and electron spectra were tallied using FLURZnrc and compared to reference M-series x-ray beams. The D_w and D_{det} in-phantom were simulated as in the M-series beams.
The TLDs were irradiated in M150, M200, M250, ^{60}Co and the two radiobiology beams to the same D_w in-phantom. The absorbed-dose energy dependence ($C_{MC}(X)$), absorbed dose sensitivity (M(X)), and intrinsic energy dependence (η(X)) of the TLDs was investigated by normalizing measured and simulated response to ^{60}Co.

Results

The measured and simulated energy responses of the TLD-100 microcubes in-phantom are shown in Figure 2. The response per dose to water for the beams F1 and F2 were 37% and 18% relative to ^{60}Co, respectively. The simulated ratio of D_w and D_{det} was 35% and 18% when compared to ^{60}Co, respectively. The energy dependence of the microcubes in-phantom is consistent with previous absorbed dose energy response studies[6]. This indicates that the response changes by less than 3% for a radiobiology beam when compared to each respective calibration beam, which is within uncertainty of the TLD measurement.

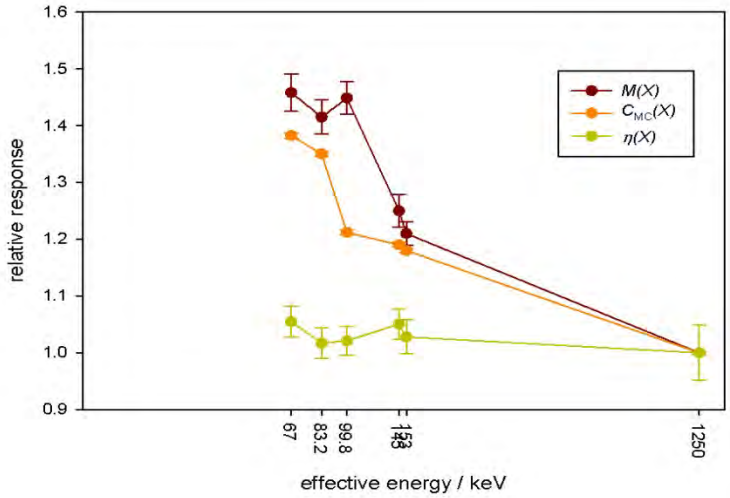


Figure 2: Measured (M(X)), simulated (C_{mc}(X)), and intrinsic energy response (η(X)) in-phantom. The beams are labeled by effective energy, where 83.2 and 152 keV indicate the fabricated x-ray beams.

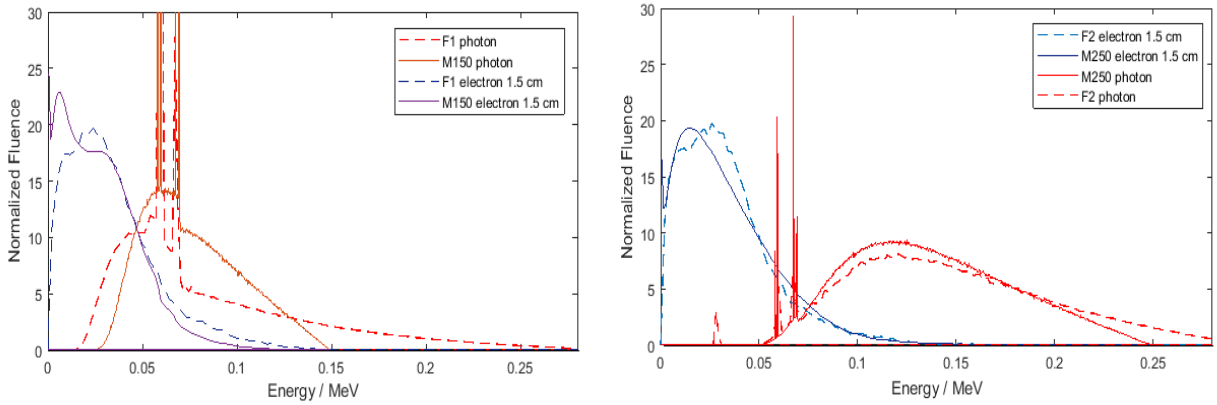


Figure 3: The photon and electron spectra tallied using FLURZnrc. a) The F1 beam with 1 mm Cu HVL is compared to the M150 x-ray beam at UWMRRC. b) The F2 beam is compared to M250.

The tallied photon and electron spectra are shown in Figure 3. The photon spectra in air and the electron spectra at the plane of the TLDs are compared. The HVL and photon spectra for the lightly filtered 300 kVp beam (F1) most closely match the NIST-matched M150 beam, though photons below 50 keV are prevalent in the more lightly filtered F1 beam. In Figure 3b, the M250 and heavily filtered (F2) beam are compared. Despite differences in in-air photon spectra, the electron spectra at depth are similar. Because TLDs are sensitive to the electron spectrum, the TLD response is not expected to vary from the reference beam and the radiobiology beams. This is consistent with the results in Figure 2, where the TLD response for the F1 and F2 are within 2.5% and 3.0% of M150 and M250, respectively.

Conclusions

This study investigated changes in spectra in radiobiology beams. Using Monte Carlo and measurements, the spectra's effect on TLD response in a mouse phantom was determined. This indicates that these mouse phantom spot-checks for the XRad 320 with TLD microcubes require minimal intrinsic energy response

corrections. Additionally, this shows the importance of choosing appropriate calibration beams for detectors in radiobiology beams. Determining the expected detector energy response and calibrating to NIST-matched beams leads to improved accuracy for dose verification measurements.

Relation to CIRMS

This project is part of a larger goal to improve dosimetry tools and establish NIST traceability in radiobiology. The collaboration between biologists and physicists is important for the future of new discoveries and techniques in biology, which fits with the meeting theme of "Radiation technologies for the future." As irradiators in radiobiology become more complex and as experiments require more spatial and dosimetric accuracy, having traceable standards becomes more important. This work is part of the first author's PhD project and the UWMRRC's involvement in providing support for and collaboration with radiation biology.

References

1. CM Ma, CW Coffey, LA DeWerd, C Liu, R Nath "AAPM protocol for 40-300 kV X-ray beam dosimetry in radiotherapy and radiobiology." Med. Phys, 28, 868-893 . 2001
2. K. Pedersen, K. Kunugi, C. Hammer, W. Culberson, L. DeWerd . "Radiation biology irradiator dose verification survey". Radiation Research 185, 163-168. 2016
3. M. Desrosiers, L. DeWerd, J. Deye, P. Lindsay, M.K. Murphy, M. Mitch, F. Macchiarini, S. Stojadinovic, H. Stone "The Importance of Dosimetry Standardization in Radiobiology". Journal of Research of NIST 118:21. 2013
4. A. Nunn, S. Davis, J. Micka, L. DeWerd, "LiF:Mg,Ti TLD response as a function of photon energy for moderately filtered x-ray spectra in the range of 20-250 kVp relative to 60Co". Med Phys, 35,1859-1869. 2008
5. C Hammer, B Rose, J Fagerstrom, W Culberson, L DeWerd "Experimental investigation of Gafchromic EBT3 intrinsic energy dependence with kilovoltage x-rays, 137Cs, and 60Co. Med Phys, 45, 448-459.2017
6. M Lawless. Development of Kilovoltage X-ray Dosimetry Methods and Their Application to Cone Beam Computed Tomography. PhD thesis, University of Wisconsin-Madison, 2016.

Evaluation of a Megavoltage Calibration Service at the Secondary Standards Level (Poster 5)

Autumn E. Walter, Larry DeWerd
Medical Radiation Research Center, University of Wisconsin - Madison

Objective: In 1999 and 2000, the AAPM and IAEA shifted from the use of direct cavity theory to Monte Carlo based determination of absorbed dose-to-water. Thus, the current practice in the United States is to obtain an $N_{D,w}^{^{60}\mathrm{Co}}$ calibration coefficient for a user chamber from an accredited dosimetry calibration laboratory (ADCL). This value is determined in ^{60}Co beam from reference standards that are calibrated with the calorimeter at NIST. When the ionization chamber is used in a linear accelerator, the $N_{D,w}$ values must have a beam quality conversion factor, denoted k_Q, applied to convert to the beam energy being used. An alternative to this calibration process is a direct, megavoltage calibration. Currently, a number of primary laboratories, such as the National Research Council (NRC) Canada, perform such calibrations, which provide both an $N_{D,w}$ and k_Q for the energies available at the primary laboratory. The purpose of this work was to evaluate the feasibility of a megavoltage calibration service at the secondary level in the United States through comparing uncertainties to the NRC service and to the current ^{60}Co calibration service at the UWADCL.

Methods: The NRC Canada's megavoltage calibration service was performed on an Exradin A12 Farmer chamber (Standard Imaging, Middleton, WI), Exradin A28 scanning chamber (Standard Imaging, Middleton, WI), and Wellhofer IC69 Farmer chamber (IBA, Schwarzenbruck, Germany) (Figure 1). The absorbed dose-

to-water calibration coefficient, $N_{D,w}$ was provided for 6, 10, and 25 MV photons. Using the provided %dd(10)$_x$ values of the NRC linear accelerator, quadratic fit equations were determined for each of the chambers to evaluate any uncertainty in extracting $N_{D,w}$ for beam energies not used at the NRC. The %dd(10)$_x$ values of the Varian 21EX Clinac® (Palo Alto, CA) at the UWMRRC were measured and $N_{D,w}$ was determined from the equations. These beam quality specifiers were tracked over time to determine stability of the linear accelerator. Preliminary uncertainty budgets were determined for the potential service at the secondary level, traceable to the NRC.

Figure 1: Exradin A12 Farmer chamber (top), Exradin A28 scanning chamber (middle) and Wellhofer IC69 Farmer chamber (bottom) that were calibrated at the NRC.

Results: Using MATLAB, uncertainties in the quadratic fits (Figure 2) were found to have a range of ±0.25% to ±0.40% for each chamber. For the uncertainty budgets formulated (Tables 1 and 2), the value of 0.40% was used as a conservative estimate. The ^{60}Co $N_{D,w}$ values from the UWMRRC differed from the NRC values by up to 0.60%. The UWMRRC linear accelerator's $\%dd(10)_x$ of 66.9% for the 6 MV beam was found to be 0.45% smaller than the NRC value. Utilizing the UWMRRC $\%dd(10)_x$ in the quadratic fit resulted in a 0.07% difference from the NRC determined $N_{D,w}$.

Figure 2: $N_{D,w}$ data for the A12 (top left), IC69 (top right) and A28 (bottom) chambers from the NRC. The error bars represent the calculated uncertainty in the quadratic fit at each point

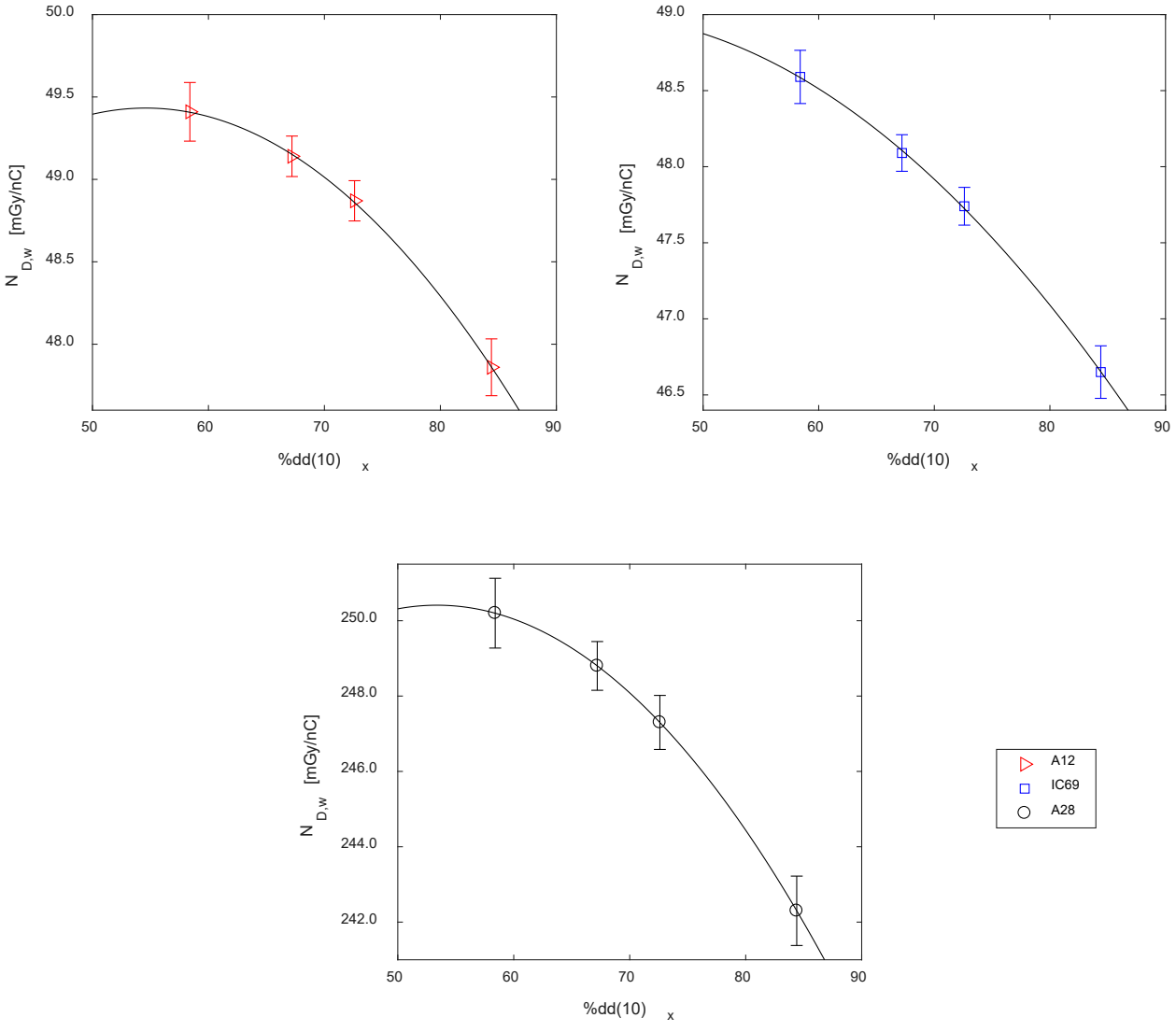


Table 1: Preliminary standard uncertainty budget for the megavoltage calibration service traceable to the NRC Canada.

Quantity	Type A	Type B
Charge	0.05%	0.06%
Timing		0.008%
Air Density		0.10%
Cycle Repeatability		0.17%
Distance from Source		0.03%
Beam Uniformity		0.06%
Standard Electrometer		0.10%
NRC Chamber Calibration		0.35%
NRC Energy Extraction		0.20%
Combined Uncertainty	0.05%	0.47%
Standard Total Uncertainty (k=1)	**0.47%**	
Expanded Uncertainty (k=2)	**0.94%**	

Table 2: Preliminary customer uncertainty budget for the megavoltage calibration service traceable to the NRC Canada.

Quantity	Type A	Type B
Charge	0.05%	0.06%
Timing		0.008%
Air Density		0.10%
Sample Volume Averaging		0.06%
Distance from Source		0.03%
Beam Uniformity		0.06%
Rotation, Tilt, Off-axis		0.06%
Dose Calculation and Conversion		1.1%
k_Q		0.70%
$N_{D,w}$ Fit		0.40%
Combined Uncertainty	0.05%	1.37%
Standard Total Uncertainty (k=1)	**1.37%**	
Expanded Uncertainty (k=2)	**2.75%**	

Conclusion: The low uncertainties in both the quadratic fit and overall standard budget indicate the potential feasibility of installing a megavoltage calibration service at the secondary standards level. Future work will aim to developing a fixturing system that will allow a reproducible calibration set-up, as well as the evaluation of the use of the A12, A28, and IC69 chambers as working standards for the calibration service.

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 investigation of megavoltage calibrations and quality assurance of ionization chambers. This work is important to both the CIRMS mission and the conference theme of "Radiation Technologies for the Future," as it focuses on the development of a new calibration service that can pave the way for future radiation dosimetry and linear accelerator use, with potentially creating a more accurate measurement system. The first author's goal is to become a clinical/academic medical physicist and currently works in a laboratory focused on metrology.

Work towards the Development of a Mailed Audit Protocol for Canada with a Sub-1 % Uncertainty using Alanine
(Poster 6)

Iymad Mansour, Malcolm McEwen
Carleton University, Ottawa, Canada
National Research Council Canada

Objective:

The National Research Council of Canada (NRC) is currently developing a mailed audit system using alanine. Alanine is an amino acid that upon irradiation results in the creation of stable free radicals. The free-radical concentration can be accurately determined using electron paramagnetic resonance (EPR). The long lifetime of these free radicals and an effective atomic number close to that of water makes it an ideal choice as an audit dosimeter compared to other possible dosimeters (e.g., OSL or TLD).

Methods:

A Bruker EMX EPR spectrometer operated at the NRC is used to read out the alanine pellets. The peak-to-peak height of the central part of the EPR spectrum normalized to the mass is proportional to the energy deposited in the alanine pellet. However, alanine is known to be susceptible to environmental conditions, both at irradiation and read-out, and therefore significant effort was put into mitigating such effects.

There is no “constant" relating alanine signal intensity to dose and therefore to calculate the dose to an alanine dosimeter, a *calibration curve* is generated from reference irradiations in the NRC Co-60 beam. The literature suggests that a 0.5% - 1.0% fit uncertainty associated with the calibration curve is reasonable in the clinically applicable dose range (below 100 Gy). To improve this, a machine learning algorithm, which assesses all possible configurations of a calibration data set, was developed to monitor for trends in fit-related interpolation error. The algorithm serves two purposes:

- Monitor the quality of the calibration set by identifying outlying data points
- Optimize the number of points, as well as the range of the calibration curve so that interpolation uncertainty can be minimized

Finally, to test these developments, a series of trial audits were conducted using an Elekta Precise linac – a 6 MV photon beam was used to deliver doses in the 10-20 Gy range. Five pellets were irradiated at each dose point using a standard AAPM TG-51 geometry.

Results:

To test the repeatability of the spectrometer, a set of five pellets was measured every day for two-weeks. Careful sample control combined with a stable reference sample, permanently fixed within the spectrometer for signal normalization, led to a reduction in the standard deviation on the signal intensity measurement from 0.6% to 0.25%.

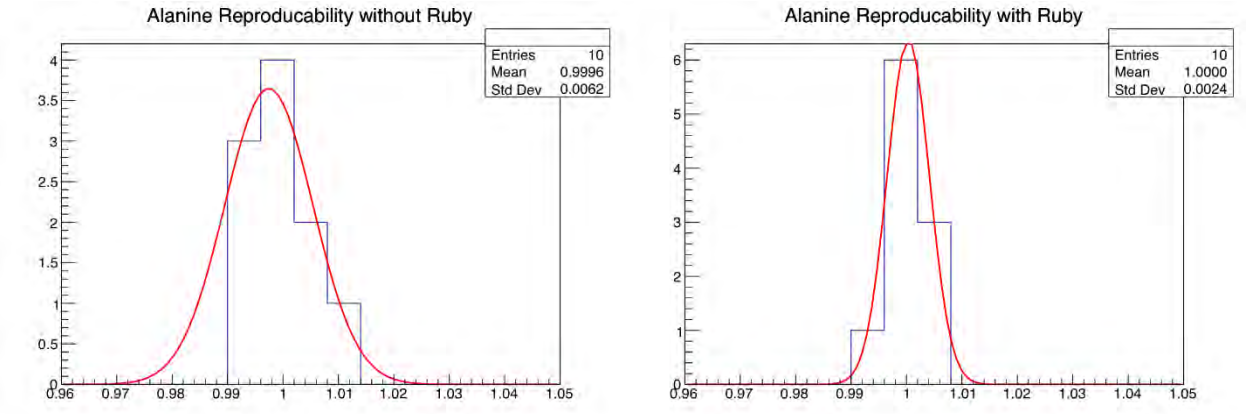


Figure 1: Effect of using reference ruby to normalize alanine signal, normalized to mean, on standard deviation of pellets

To test the machine learning algorithm the starting point was to select a noise free data set. A comprehensive calibration set in the range 15 Gy to 35 kGy, irradiated using Co-60, from the National Physical Laboratory (NPL) was used (above approximately 100 Gy, the alanine EPR spectrum can be considered to be noise-free). Figure 2 shows 100 out of the possible 3876 fits using a three-point calibration. A point within the set was chosen at random, highlighted with the red star, and the fit related error was reduced from over 1% in the least optimal case to less than 0.1% in the optimal. Testing with clinically applicable data suggested an uncertainty estimate of 0.1% on the calibration curve is achievable.

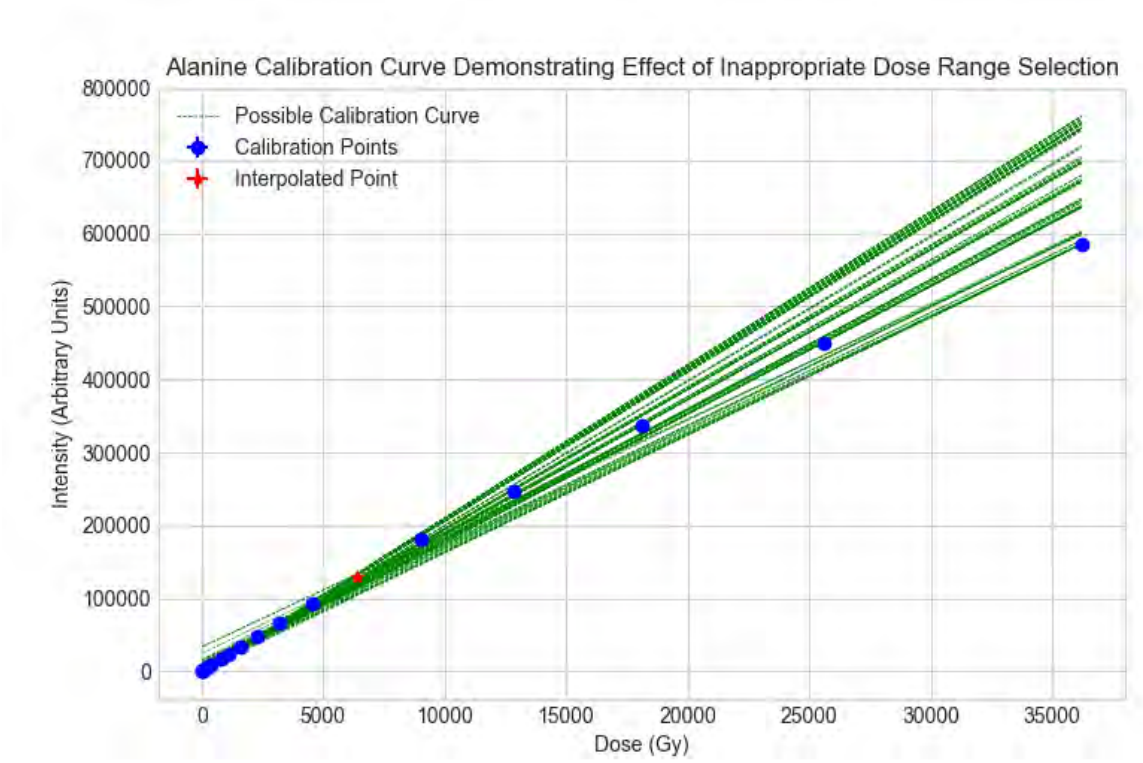


Figure 2: Noise free calibration curve from NPL to test effectiveness of fit interpolation error reduction algorithm. Uncertainty at each point is smaller than symbol size.

The analysis of the trial audits preformed to date are shown in Table 1. At these lower doses background signals can be significant, and therefore a systematic background subtraction procedure was developed and implemented (Figure 3). The rms deviation of the interpolation error of the trials is 0.24% and even for doses down to 7 Gy, the rms deviation and overall uncertainty are not significantly larger. An extrapolation of the data in Table 1 would suggest that a satisfactory uncertainty (< 1 %) can be maintained while reducing the delivered dose below 5 Gy (which is more practical in the clinical setting). More audits will need to be conducted to test this hypothesis.

Table 1: Trial alanine audits using 6 MV linac photon beam

Audit	Dose Delivered (Gy)	Uncertainty Estimate (%)	Dose Interpolated (Gy)	Dose delivered to dose measured difference (%)
1	13.54	0.40	13.55	0.07%
2	7.99	0.55	8.03	0.51%
3	16.95	0.40	16.98	0.18%
4	14.00	0.40	13.99	-0.07%
5	6.80	0.55	6.81	0.15%
6	18.40	0.40	18.37	-0.16%

The uncertainty estimate on the dose interpolation comes from the quadrature sum of:

- The standard uncertainty of five pellets
- Realization of dose (primary standard)
- Alanine readout procedure (such as mass measurement and calibration curve)

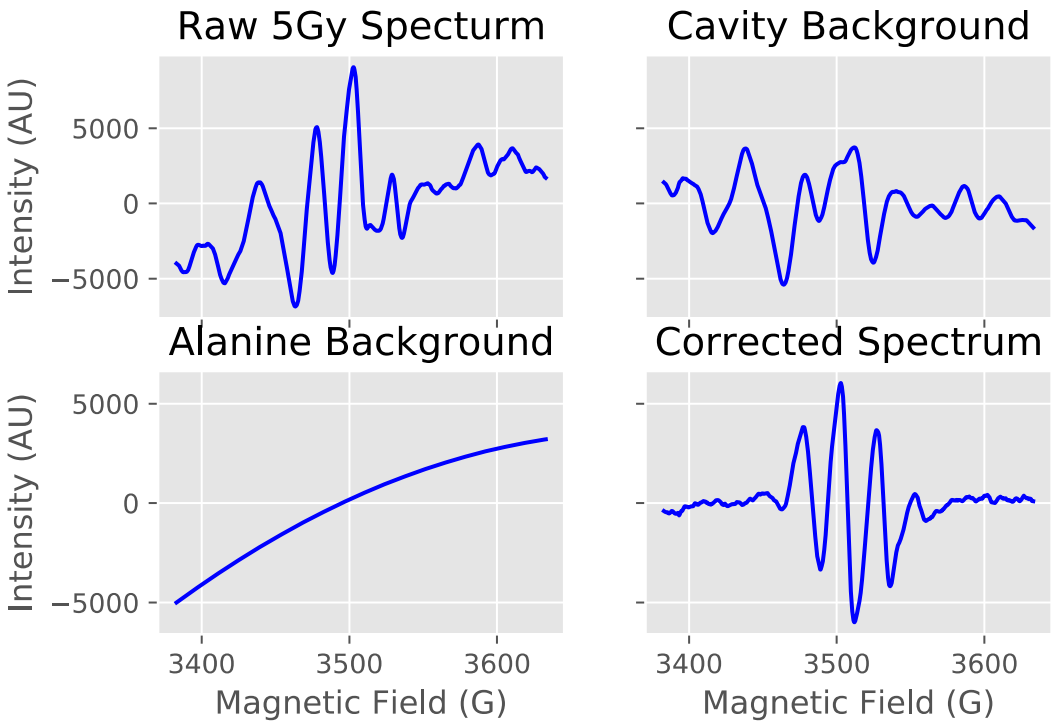


Figure 3: A blank dosimeter is used to measure the background of the EPR cavity and a least squares technique based on a noise free spectrum removes the inherent alanine background to yield the corrected spectrum

Conclusion:

This study has successfully validated alanine as an audit dosimeter by investigating and minimizing the potential sources of inaccuracy associated with alanine dosimetry – environmental sensitivity, determination of the calibration curve and background effects. Initial results indicate that a mailed alanine dosimetry service can have an overall uncertainty below 0.7% at 10 Gy. The next steps for the project is to implement a mailed TG-51 verification, to establish a mailed audit program within Canada.

Relevance to CIRMS mission and first author's career goals:

Air-filled ion chambers have been the workhorses of radiation dosimetry for a century but new technologies such as SRS/SBRT or MRI-linacs have demonstrated their weaknesses. A different kind of dosimetry is needed for the future, something close to unit density and effective atomic number close to that of water. Alanine can do this, and the work thus far on reducing the minimum dose that can be delivered opens up the possibility of using alanine for many of these challenging dosimetric situations.

My career goal is to become a clinical medical physicist. Working at Canadas National Metrology Institute has not only forced me to focus on the many sources of uncertainty in radiation therapy dosimetry, it has taught me that an understanding of metrology is essential for clinical medical physics and given me a solid foundation for my career. As a result of this project, I would like to embark on a PhD study furthering the

field of dose modeling calculations. I believe that there are still improvements to be made in treatment delivery and verification and thus advance patient care.

Pushing the limits of EGSnrc: Computing microscopic dose metrics on a macroscopic scale using multiscale modeling
(Poster 7)

Martin Martinov and Rowan M. Thomson
Carleton University, Ottawa, Canada

Purpose

Increasingly, studies in the field of radiotherapy (also X-ray imaging) are considering microscopic dose metrics. These studies aim to improve our understanding of the biological effects of existing treatments, and contribute to the development of novel treatment techniques, e.g., gold nanoparticles (GNPs) for radiosensitization in radiotherapy. In many studies, Monte Carlo (MC) simulations of radiation transport are used to investigate energy deposition on cellular and subcellular length scales. However, there is often a need to consider macroscopic (~cm) volumes of interest (e.g., tumor and surrounding tissues), and modeling microscopic cellular detail within these macroscopic volumes presents a challenge for MC simulations. This motivates the development of multiscale MC models that can simultaneously model cellular and subcellular components of interest (e.g., nucleus) while considering different depths/positions within a macroscopic volume. This work considers the application of EGSnrc, a fast and well-tested macroscopic MC code, to the problem of efficient multiscale modeling to advance radiation dosimetry.

Methods

Diverse simulations at μm and nm length scales are carried out using a custom version of the EGSnrc user-code egs_chamber, modified with new geometries and scoring algorithms. Sensitivity to choices of transport parameters, models and algorithms are investigated using a variety of different scenarios. Two such scenarios that use EGSnrc at short length scales are presented here, along with published results for comparison, as well as multiscale modelling results.

Single cell: The cell is modelled as two concentric spheres (radii: 4 μm nucleus, 5 μm cytoplasm). Isotropic sources emitting monoenergetic electrons are distributed throughout the nucleus, the cell or on the surface of the cell. Dose per becquerel per second (the S-value [mGy/Bq/s]) is scored in either the whole cell or only the nucleus.

GNPs within a micro-cavity: A microscopic cavity containing gold is modelled as either a homogeneous gold/tissue mixture or tissue containing discrete 50 nm diameter GNPs. The ratio of dose scored to the tissue containing the GNPs (but not dose to the GNPs themselves) over the dose scored to the homogeneous mixture is computed.

Multiscale model: Multiscale modeling with EGSnrc is investigated using a simulation relevant for GNP dose-enhanced radiotherapy (Figure 1). Photons are incident on a macroscopic cylindrical phantom. The phantom bulk consists of a gold-tissue mixture with over 100 microscopic scoring regions inserted along the central axis. Each scoring region consists of a 100 μm radius sphere filled with a lattice of cells; cells are modelled as concentric spheres with nucleus and cytoplasm compartments (radii 5 and 7.35 μm, respectively). The scoring region contains a small non-scoring buffer along the boundary to ensure local scatter conditions. Three potential intracellular GNP distributions are considered: GNPs concentrated in (a) the perinuclear region, (b) a single endosome, or (c) four endosomes. The total gold mass in the cell is the same in all three cases, with GNPs discretely modelled in a hexagonal lattice.

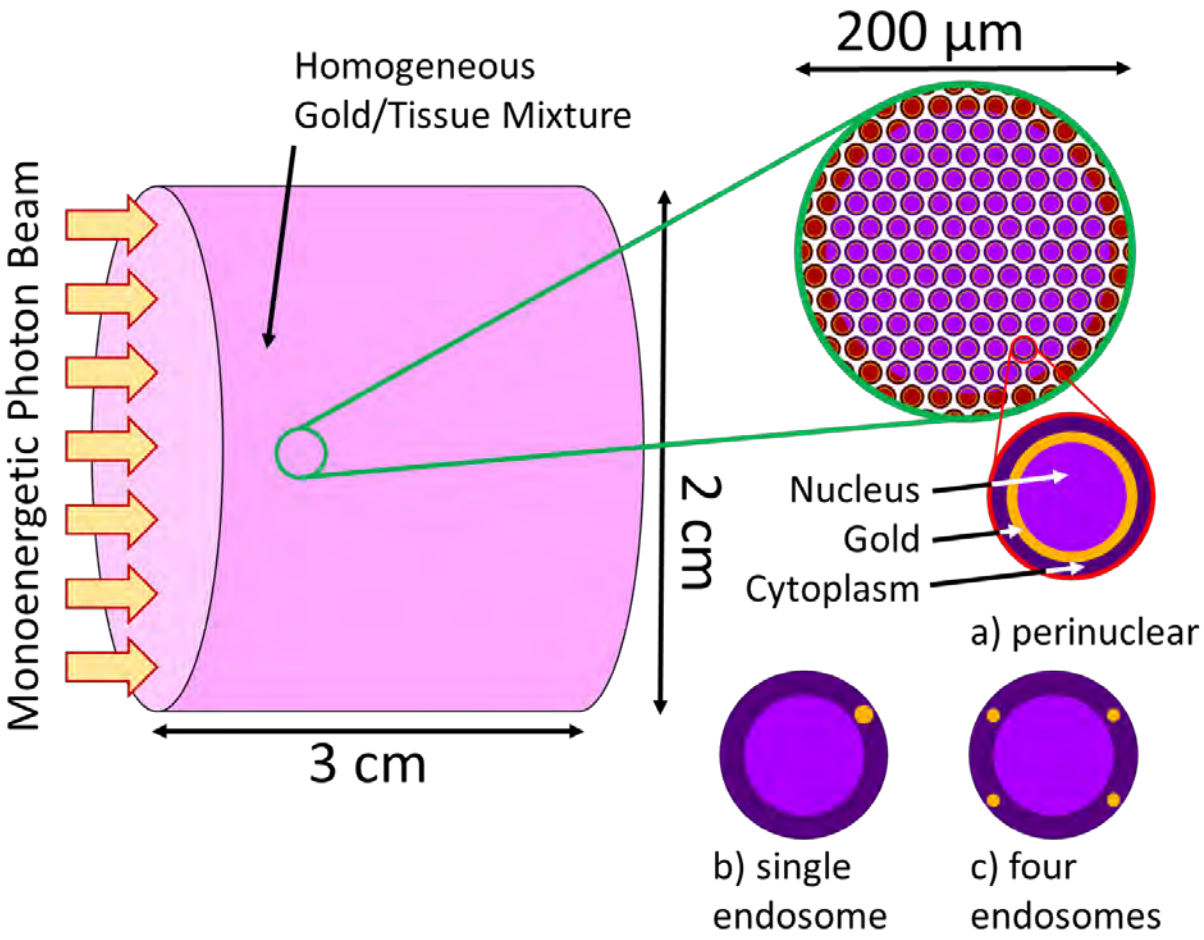


Figure 1 – Multiscale model: phantom with microscopic scoring regions comprised of cells for (a-c) different intracellular GNP configurations

Results

Single Cell simulation results, presented in Figure 2 (labels read [target volume ← electron source]), shows S-value calculations alongside those performed by Sefl *et al*[1] (Geant4DNA). Dose ratios when using different models to simulate **GNPs within a micro-cavity** are presented in Table 1 alongside those published by Koger & Kirkby[2] (PENELOPE) for three different concentrations of gold (units of mg of gold per gram of tissue [mg/g]). The agreement found across a wide range of simulation parameters with different Monte Carlo codes demonstrates EGSnrc's ability to accurately score in microscopic cavities, even when modeling geometries on the nanometer length scale.

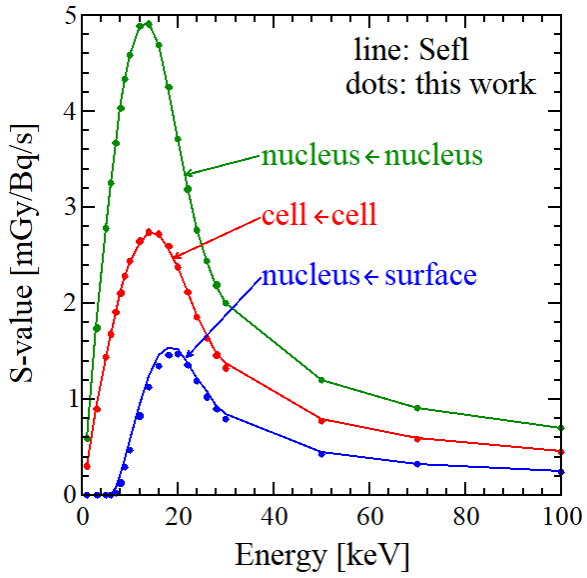


Figure 2 – Single cell S-values

Table 1 – Ratio of dose (tissue with GNPs/gold-tissue mixture) within a micro-cavity

Gold Concentration (mg/g)	Energy (keV)	Koger & Kirkby	This work
5	20	0.920 (07)	0.920 (03)
	30	0.945 (07)	0.947 (05)
	50	0.967 (10)	0.973 (09)
10	20	0.887 (07)	0.883 (02)
	30	0.929 (07)	0.926 (04)
	50	0.960 (10)	0.966 (08)
20	20	0.866 (07)	0.847 (02)
	30	0.920 (08)	0.906 (03)
	50	0.971 (10)	0.942 (06)

Figure 3 shows the nucleus Dose Enhancement Factor (DEF, the ratio of dose scored to tissue in the presence of GNPs over dose scored in the absence of gold) as a function of depth in the **multiscale model** (Figure 1) for a 20 keV beam and a concentration of 10 mg/g. Shaded regions, representing a 10% variation in local gold concentration, demonstrate additional expected variation in DEF due to the heterogeneous nature of GNP uptake. DEFs are highest when GNPs are in the perinuclear region. DEFs vary greatly with intracellular GNP distribution, from as low as 1.1-0.4 when gold is distributed in four endosomes, to as high as 2.2-0.7 when GNPs aggregate in the perinuclear region. Intracellular GNP distribution also affects the depth at which DEF drops below unity (2.2 cm for model (a), 0.4 cm for (b) and (c)). The multiscale model (containing ~1.5×10^6 cells) results agree with those when modelling cells throughout the cylindrical phantom (~5.8×10^9 cells), but simulations are 100 times faster. Thus, these simulations are much more efficient, making diverse calculations in this complex parameter space possible.

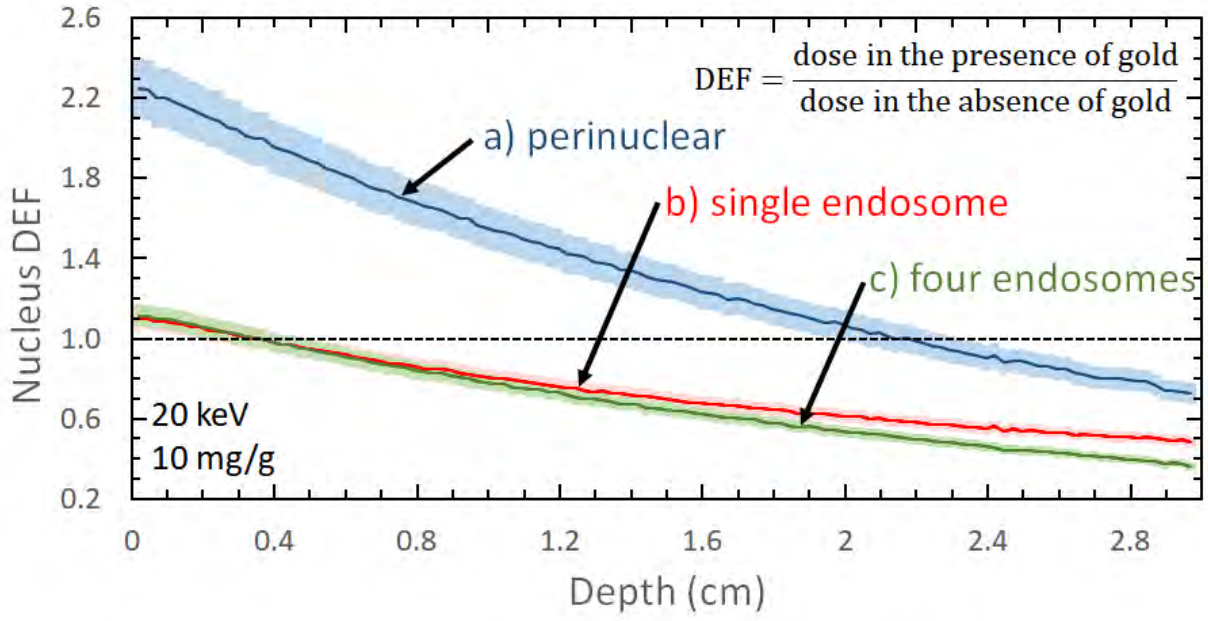


Figure 3 – Multiscale GNP simulations: Nuclear dose enhancement factor versus depth in cylinder

Conclusion

Monte Carlo simulations are of fundamental importance for all aspects of radiation dosimetry, from measurements in standards laboratories to developing new treatment approaches. The EGSnrc MC code for radiation transport, maintained within Canada's primary ionizing radiation standards laboratory at the National Research Council, is a standard code within the field. This study demonstrates agreement between EGSnrc and results with other MC codes for simulations involving cells and nanometer components, and the potential of EGSnrc for multiscale simulations involving scoring in micron-sized geometries, thus enabling further research and applications with this important and widely-used code system.

My PhD work is focused on the field of GNP dose-enhanced radiotherapy, thus validation of EGSnrc at nanometer length scales and demonstration of the efficiency of multiscale modeling are central to my research.

References

[1] M Šefl, et al., *Applied Radiation and Isotopes* 104 (2015): 113-123.

[2] B Koger & C Kirkby, *Physics in Medicine and Biology* 61 (2016): 2014.

Mapping the Effective Dose of Radiation in a Hemispherical Lunar Habitat
(Poster 8)

Joshua Smith, Zi-Wei Lin
Thomas Harriot College of Arts and Sciences, East Carolina University

Purpose: The purpose of this research is to get a detailed map of the effective dose for a hemispherical dome on the Moon. This is to see how the geometry of the dome affects the distribution of the radiation and in turn this information can be used to design habitats to minimize the radiation exposure to astronauts.
Objective: Ionizing radiation is a relatively large threat when it comes to space missions, especially long term missions and missions that take astronauts outside of Earth's magnetosphere. One effective way to mitigate astronauts' exposure to ionizing radiation is to use thick shielding to attenuate the harmful protons and heavy ions that would be bombarding the astronauts on a long-term mission. The goal of this study is to map the effective dose of radiation inside of a hemispherical dome made of lunar regolith on the surface of the Moon to see which areas of the dome are the least and most irradiated with respect to height and radius. The dose is also mapped outside the dome. It is already known that, inside a spherical or hemispherical geometry, the effective dose rate goes down as you get further from the center of the dome and towards the inner wall of the dome, when albedo radiation can be neglected. To map the radiation, the hemispherical dome was modeled in a Geant4 simulation using the 1977 GCR (Galactic Cosmic Rays) environment and the 1989 SPE environment.

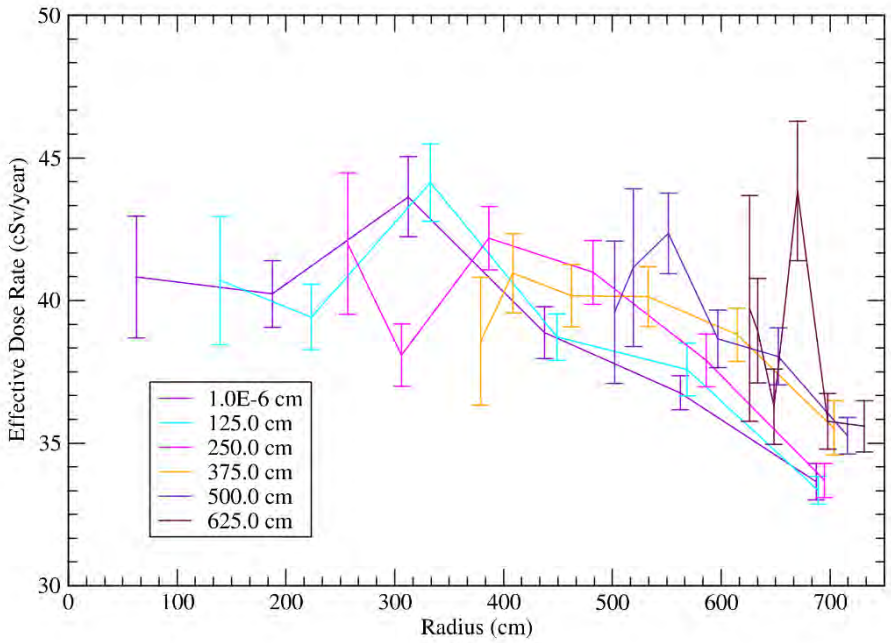
Methods: This study focuses on one dome with an inner radius of 750cm and a thickness of 50cm, composed of lunar regolith with a density of 2.0 g/cm^3. This dome is modeled on a flat lunar regolith ground as to simulate the secondary particles coming from the surface due to incoming radiation interacting with the ground. This particle data from Geant4 simulations were used to map out where each particle traveled, and then used to calculate the effective dose of radiation at any physical location. Pre-existing fluence to effective dose conversion coefficient tables were used to convert our particle fluences to an effective dose. The effective dose rate was tallied for different horizontal rings at different heights to generate our 3-D map. The data were then normalized to fit its respective environment.

Results: Although the error for the data inside of the dome is sometimes large, there are still some insights that can be obtained from these maps. Each of the lines on the graphs represents a height above the lunar surface, while the radius is the distance from the center of the dome at the surface to the midpoint of the ring the dose was measured in. For the 50cm GCR data inside the dome, we see a general trend of decreasing effective dose with the radius at a given height, consistent with previous findings. For the 50cm SPE data inside the dome, the percentage decrease is bigger, again consistent with previous findings. We also see that the effective dose at the same radius is typically larger at larger heights inside the dome for both the GCR and SPE environment; this is related to the lunar albedo radiation (i.e. back-scattered particles coming from the lunar ground), which 3-D distribution has not been studied in previous works.
For the 50cm GCR data outside of the dome, there is an increase of 38% of the effective dose rate for the region nearest to the dome from 0cm to 625cm, and the difference decreases (as expected) as the distance from the center increases. For the SPE 50cm data outside the dome, the difference between the smallest radius rings for the 625cm height and the 0cm height is 30%, and as the radius increases, the difference gradually gets smaller. The large decrease towards the outer wall at the same height, and the increase of effective dose with height at the same radius, can be both understood from the shielding effect of the dome structure on radiation along certain directions.

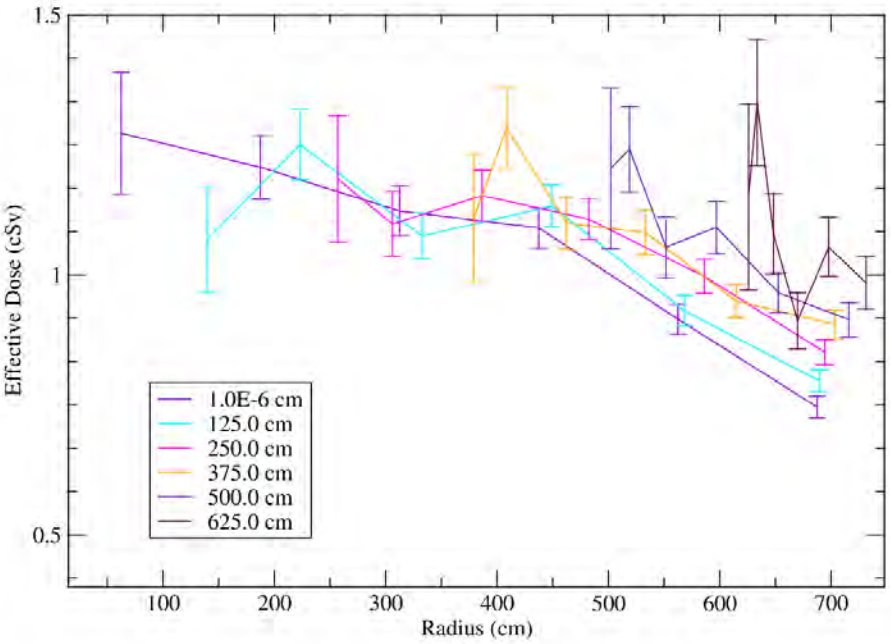
Conclusion: This study has mapped the effective dose rate for the 1977 GCR environment and the effective dose for the 1989 SPE environment using a Geant4 simulation. The doses were mapped for 6 different heights at 6 different radii each both inside and outside of a 50cm thick dome made of lunar regolith of interior radius 750cm. The study found that there is a significant decrease in effective dose near the inner wall of the dome as height decreases. There was also a decrease in effective dose outside the dome close to the wall as height decreases for all heights less than or equal to 664cm. Future work would consist of simulating more particles as to decrease the error as well as mapping results using different materials for the dome wall and different dome thicknesses to expand upon the work done here.

Relevance to the CIRMS mission and first author's goals: This project is used Monte-Carlo code Geant4 to map out the effective dose inside and outside of a hemispherical lunar habitat dome. This fits with the mission of CIRMS in that it is mapping the dose of ionizing radiation in 3 dimensions, which also fits well with the "Radiation Technologies for the Future" focus of the upcoming meeting. The first author is aiming to get into graduate school for physics and eventually becoming a physics professor. He is currently working on his undergraduate degrees in physics and mathematics at East Carolina University. The last author is a physics professor at East Carolina University and one of his previous studies is what this study is expanding upon.

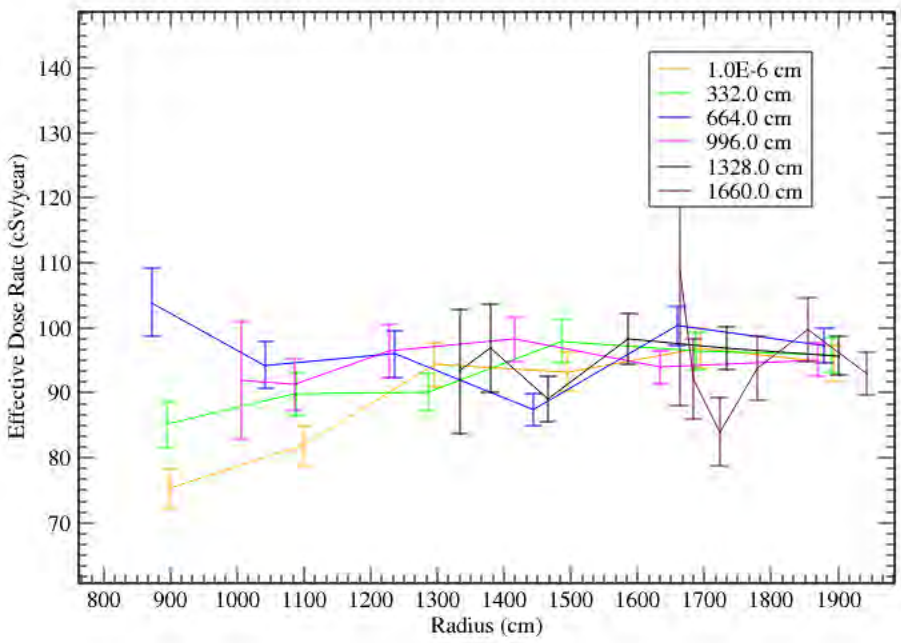
GCR 50cm Inside Dome Effective Dose Map



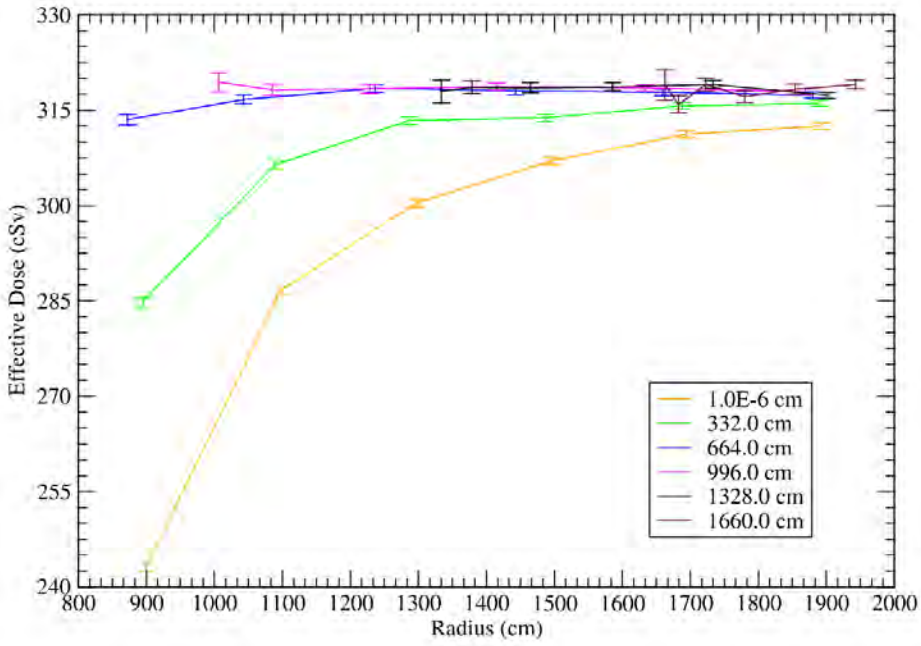
SPE 50cm Inside Dome Effective Dose Map



GCR 50cm Outside Dome Effective Dose Map



SPE 50cm Outside Dome Effective Dose Map



Validation of the NCI-ALMANAC Potential to Identify Radiation Modifiers (Poster 9)

Sadhana Lolla
Poolesville High School, Maryland

Objective: Radiotherapy is regarded as one of the most important methods of treatment for primary tumors. The use of radioprotectors and radiosensitizers has the potential to improve radiation treatment as protectors reduce injury to normal cells from radiation, and sensitizers increase the sensitivity of tumor cells to radiation. The goal of this study was to test whether a combinatorial drug sceening strategy could be used to identify novel radiosensitizers and radioprotectors by analyzing various drugs' interactions with commonly known radiomimetics. The NCI-ALMANAC was used to analyze the drug pairs. The NCI-ALMANAC (A Large Matrix of Anti-Neoplastic Agent Combinations) is a database compiled by the NCI that displays the growth-inhibitory activity of different combinations of over 100 FDA- approved small-molecule oncology drugs against the NCI-60, a panel of 60 human tumor cell lines. Over 100 drugs were compared when combined with five radiomimetics: bleomycin, doxorubicin, daunorubicin, topotecan, and etoposide.

Materials and Methods:

NCI-ALMANAC Database

The database was compiled by testing each single agent at 5 concentrations, chosen based on clinical relevance. This data was then compared to the percentage of growth when the cell lines were exposed to the drug pairs, where one agent was tested at five concentrations and the other agent was tested at three concentrations. The cell lines were exposed to the drug pair for 48 hours. The formula used to calculate the growth percentage limited the calculations to be lower than the control. If the growth percentage increased by more than 50% between adjacent doses of either drug, the data for the corresponding drug pair was removed.

Identification of radiomimetics and compilation of verified radiation modifiers through PubMed:

A PubMed search was conducted with the terms "radiomimetic" and "DSBs" to find well-known radiomimetic drugs. The term radiomimetic was defined as a drug that mimics radiation by inducing DNA DSBs. The following drugs were used in at least three studies: bleomycin, neocarzinostatin (not included in the NCI-ALMANAC), doxorubicin, etoposide, daunorubicin, and topotecan.

Radiosensitizers and radioprotectors that have been verified by at least three studies were identified by conducting a PubMed search with the terms "radiosensitizer" and "radioprotector." The radiosensitizers included erlotinib, gefitinib, arsenic trioxide, cabazitaxel, cisplatin, hydroxyurea, rapamycin, paclitaxel, docetaxel, and celecoxib. The only radioprotector was amifostine.

Identification of radiosensitizers and radioprotectors through NCI-ALMANAC:

Each radiomimetic was selected as the "Primary Drug" in the NCI-ALMANAC database. The heat map showing the combination of the radiomimetic with 100 other drugs was analyzed using the Drug Pair ComboScore, provided by the NCI-ALMANAC as a measure of each drug pair's growth-inhibitory effect on each cell line. The ComboScore was calculated by the following formula: (Holbeck et al. 2017)

$$Y_i^{A_p B_q} = 100 \times \frac{T_1^{A_p B_q} - T_0}{T_1^0 - T_0}$$

As the ComboScore increased, the growth inhibitory effect of the drug pair increased, so the combined effect of the first and second agents killed more cells than the first agent alone. If the ComboScore was below 0, the growth-inhibitory effect of the drug pair decreased, so the first and second agents killed fewer cells than the first agent alone. If the ComboScore was between -50 and 50, the drug pair was regarded as having no interaction.

If the heatmap showed that the drug sensitized over 50% of the cell lines to the radiomimetic (the ComboScore was more than 50), the graphs of the drug pair's effect on the tumor growth were analyzed to determine if the drugs had a synergistic effect or if one of the drugs inhibited the growth of the tumor, independent of the radiomimetic. This would create an illusion of radiosensitization when there was no synergy between the drugs. The same was done if the drug protected over 50% of the cell lines from the radiomimetic.

The above process was completed for the five radiomimetics. If a drug sensitized the cell lines to at least three of the five radiomimetics, it was classified as a radiosensitizer. If a drug protected the cell lines against three of the five radiomimetics, it was classified as a radioprotector.

Results:

The drug-drug interactions documented in the NCI-ALMANAC showed that the following drugs sensitized drugs to the radiomimetics: Romidepsin, Valrubicin, Daunorubicin, Procarbazine, Celecoxib, Erlotinib, Gefitinib. The radioprotectors were fulvestrant, an antiestrogen receptor which protected over 75% of cell lines, and mitotane. Only three of these drugs were included in the initial list of radiosensitizers: celecoxib, erlotinib, and gefitinib. After searching through the PubMed literature, it was determined that valrubicin, daunorubicin, and procarbazine had never been used as radiosensitizers. Additionally, well-known radiosensitizers such as cabazitaxel and cisplatin did not exhibit sensitizing effects when combined with any of the five radiomimetics, while radiosensitizers such as arsenic trioxide showed a protective effect when combined with one or more of the radiomimetics. Amifostine, an FDA-approved radioprotector, appeared to have a slight sensitizing effect when combined with bleomycin.

Figure 1: NCI ALMANAC heatmap displaying interactions between amifostine and bleomycin. As the shade of red darkens, the sensitizing effect increases.

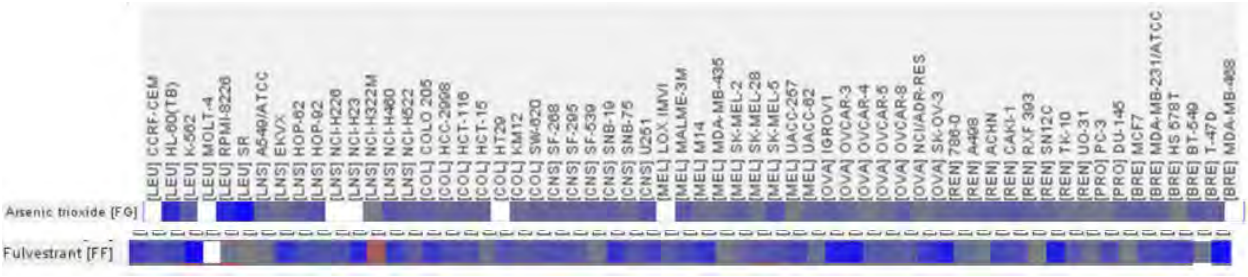


Figure 2: NCI ALMANAC heatmap displaying interactions between bleomycin and fulvestrant. As the shade of blue darkens, the protective effect increases. 75% of the cell lines are protected by fulvestrant against bleomycin.

Figure 3: NCI ALMANAC heatmap displaying interactions between etoposide and arsenic trioxide. As the shade of blue darkens, the protective effect increases.

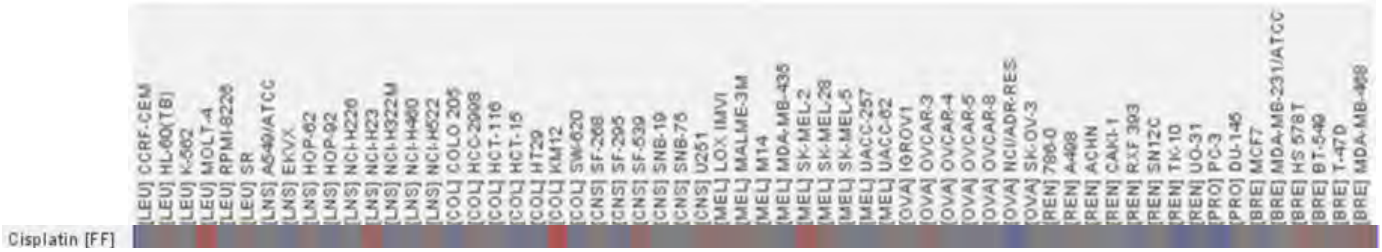


Figure 4: NCI ALMANAC heatmap displaying interactions between cisplatin and doxorubicin. As the shade of red darkens, the sensitizing effect increases.

Conclusion:

It can be concluded that the NCI-ALMANAC cannot be reliably used as a resource to identify radiation modifiers without further research. The discrepancies between the NCI-ALMANAC data and the published literature may be because the NCI-ALMANAC is a short-term assay, so the cell lines were only exposed to the drug pair for 72 hours. If the cells were exposed to the same drugs for a longer period of time and the clonogenic cell survival assay were used to assess the outcome, the

results may have more similarities to previous studies. The aim of future work will be to investigate the potential of the NCI-ALMANAC to identify other drug interactions that are not radiation modifiers.

Relevance to CIRMS Mission and author's goals:

This work is the result of an internship done by the author at the National Cancer Institute. This work relates to the CIRMS mission because radiation modifiers have the potential to improve radiation treatment in the future by limiting the side effects and accelerating the process. The author aims to work in the field of radiotherapy in the future and is currently attending the SMCS (Science, Math, and Computer Science) magnet program at Poolesville High School.

Other Submitted Abstracts

A Solid State Organic Radiation Detector
(Poster 10)

Michael Bardash
RDS

Most solid state radiation detectors that provide an active electronic signal are diode base detectors made from a variety of crystalline semiconductor materials. The responsivity of these devices is often a function of the radiation quality making it difficult to use the devices directly as dosimeters. We present a completely organic electronic sensor that has the same chemical concentration and density as biological materials. This makes the sensor radiation cross section of the device equivalent to the cross section of human tissue, and thus it is well suited for dosimetric applications. The sensors are constructed on PEN (polyethylene naphthalate) substrates. The active region is constructed from PEDOT (Poly(3,4-ethylenedioxythiophene) and is isolated using pentacene field effect transistors. The construction, and electrical properties of the sensors are described. Radiation responsivity is measured in all regions of the devices, and the results are presented. The sensors response to x-rays/gamma radiation and beta radiation is presented. Initial indication support the concept that these types of devices can measure dose independent of radiation quality.
The work is primarily undertaken by RDS, in partnership with the Center for Unusual Electronics (CUE) and John Kymissis at Columbia University Department of Electrical Engineering and the Sandia National Laboratories research scientists, Graham Yelton, Jason Harper, and Mark Rodrigues.

Radionuclides in Food - Where Metrology Matters
(Poster 11)

William Cunningham
Food and Drug Administration, Center for Food Safety and Applied Nutrition, Office of Regulatory Science

Metrology has an important role in the U.S. Food and Drug Administration (FDA) radionuclide in food monitoring program. It is a fundamental component of laboratory operations and a core reason we report analytical results with confidence. Once results are reported, however, metrology is also quite invisible. When results can be trusted, risk managers are free to focus solely on overarching issues of food safety, communications staff can address concerns raised by media, the public, and various authorities, and risk assessors can address any follow up technical questions that are raised.

In the context of radiological analyses of food, there is also a dichotomy associated with metrology. At very low radioactivity levels, which are central to food safety decisions, a significant health risk can occur only when contamination levels remain elevated and large amounts of the affected food are consumed both on an on-going basis and over an extended period of time (months/years). Since this type of exposure is extremely unlikely, only negligible amounts of radioactivity would typically be ingested, even in times of emergency response. Exposures would therefore be so low that health would not be jeopardized even if there were large errors in analytical measurements. It would seem, then, that metrology would be of little importance, but this is not the case. Metrology is the foundation on which results are reliable and food safety can be confirmed. It therefore has an impact on the agency's reputation, in general.

A Canadian Radionuclide Calibrator Service to Help Ensure Traceability to National Standards (Poster 12)

Islam El Gamal (1), G. Mawko (2,3), R. Galea (1)
(1) National Research Council Canada
(2) Nova Scotia Health Authority
(3) Dalhousie University

Purpose: To demonstrate the impact of a service in Canada which provides traceability of radioisotopes to Canadian national standards for radionuclide calibrators.

Methods: Clients host a transfer instrument which has been calibrated and hence traceable to national standards at the National Research Council (NRC) of Canada for participation in a local comparison. The transfer instrument is allowed to equilibrate at the measurement site, preferably a centralized nuclear pharmacy. The radionuclides produced are then measured in the calibration geometry for the comparison before being shipped off to the individual radionuclide calibrator sites. NRC offers alternatives to this method and is open to custom service configurations that work for an individual application or organization.

Results: The Nuclear Medicine departments in the Nova Scotia Health Authority (NSHA) participated in hosting a transfer instrument from NRC in 2016 and 2017. The 2016 comparison only covered Tc-99m whilst the 2017 comparison was expanded to include I-131 and F-18 for a number of chambers. For the Tc-99m comparison two calibration geometries, a serum vial and a syringe, were evaluated. The results indicate a marked improvement from 2016 where 4 chambers were not within the recommended 10 % of the calibrated activity to all chambers being within 10 % of the calibrated activity. Additionally the 2017 comparison showed that all of the chambers were within 5 % of the calibrated activity. Every effort is made to ensure the service is quick and unintrusive allowing clinical activities to run unaffected during the comparison.

Conclusions: The service has been offered to the province of Manitoba and Nova Scotia with both provinces intending to periodically repeat the exercise. Both provinces have centralized nuclear pharmacies which facilitated the greatest coverage of their Nuclear Medicine departments. The service is voluntary and reports are issued directly to clients who can make an independent assessment of what action, if any, is required should a radionuclide calibrator be found to perform poorly in a comparison. The authors encourage all nuclear medicine departments and any industrial, academic or commercial enterprises which utilize radionuclide calibrators to participate in a comparison with NRC to establish traceability to Canadian national standards.

The Effect of Fringing Fields on Free Air Chamber Collection Volume (Poster 13)

Irene Hnatiw
Walt Whitman High School, Bethesda, MD
Paul Bergstrom Dosimetry Group, Radiation Physics Division Physical Measurement Laboratory

Free Air chambers are the instruments used to realize the primary standard for air kerma (kinetic energy released per unit mass) for low and medium-energy x rays. Measurements using these chambers are of the charge collected, q, or of the current i. These measurements are converted to air kerma through correction factors that are dependent on the geometry of the chamber and on physical data. We focus on the factor Veff, which is the effective volume, or ion collection volume, of the air chamber. The effective volume changes from its nominal value when the electric field in the chamber fringes, and thus the fringing effect should be accounted for. We model the electric field in NIST's Lamperti free air chamber using the COMSOL Multiphysics code with models of increasing sophistication to examine the assumptions made in NBS Handbook 64.

CDC'S Rapid Radionuclide Screen – Improvements, New Methods, and Plans for the Future (Poster 14)

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

CDC has been developing a series of urine radionuclide screening and quantitative methods (Bioassay) to monitor and assess potential internal radiological contamination in people. 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 analytical methods, (e.g. through automation). HPGe gamma spectrometry capability has been extended to a total of six detectors, all of which are now automated. 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 are also developing new methods to increase the number of priority radionuclides addressed as well as we have automated half of our Gross Gamma screening method detectors. We intend to continue method development and improvement in the future, eventually extending our capabilities to rapidly analyze for all priority radionuclides.

CDC has reported extensively on methods, instrumentation and procedures toward this end, but we are continually working to improve these methods so we can provide higher quality data more quickly in the incident response. Here we report our recent improvements, new methods and future plans.

Bluetooth Devices Connectivity using 802.15 Pan Irda Infrared Milimeter Waves Range (2.4 – 6 GHZ) (Poster 15)

Nisha Mithal
Alphabet Mountain View, CA

ANN artificial neural networks recover your reproducible sound and vision clarity as its low carbon energy using silicon wave the effect it produces near bomb devices is extremely affective to sensory nerves and site versioning of 32 feet. Net is useful for all societies across the world fighting against nuclear weapons its basically Cognitive Sciences integrated Computer Science seismic activity detection using its waves in Bluetooth. Devices as they are short haul waves for long distance communication. It works in a flexible environment adaptable to DARPA techniques as well battery market goes bigger and better in 2018. Advances in battery technologies hold the keys to continuing progress in portable electronics, robotics, military and telecommunication applications, as well as distributed power grids. by: Kevin Clemens Electronics & Test, December 26, 2017 Advances in battery technology, primarily through the application of lithium-ion battery chemistries, has made a mark in several distinct market segments, namely: Portable electronics (cell phones and tablets) Military and telecommunications & Medical devices.

On the Impact of ICRU Report 90 Recommendations on k_Q Factors for High-energy Photon Beams (Poster 16)

Bryan R. Muir and Ernesto Mainegra-Hing
Measurement Science and Standards, National Research Council of Canada, Ottawa, Canada

Purpose: To assess the impact of the International Commission of Radiation Units and Measurements (ICRU) report 90 recommendations on the beam-quality conversion factor, kQ, as well as beam quality specifiers used for clinical reference dosimetry of megavoltage linac photon beams.

Methods: The ICRU recently published report 90, which recommends changes to key dosimetry data that will affect reference and clinical dosimetry. The central parameter for clinical reference dosimetry is the beam quality conversion factor, kQ, and reference dosimetry protocols are now recommending Monte Carlo calculations of these factors. Electron stopping powers are required as an input to Monte Carlo simulations and the recommendations of ICRU-90 include changes to these stopping powers for water and graphite, which could impact calculated kQ factors. In this work, the absorbed dose to water and the absorbed dose to the air in two ionization chambers representative of those typically used for linac photon reference dosimetry, a graphite- and a plastic-walled chamber, are calculated at the reference depth in a water phantom using Monte Carlo simulations. Depth-dose calculations in water are also performed to investigate changes in beam quality specifiers. The calculations are performed in a cobalt-60 beam and MV photon beams with nominal energy between 6 MV and 25 MV using the EGSnrc simulation toolkit. Inputs to the calculations use stopping-power data for graphite and water from the original ICRU-37 report and the new proposed values from the recently published ICRU-90 report. Calculated kQ factors are compared using the two different recommendations for key dosimetry data and to measured kQ factors.

Results: Less than about 0.1 % impacts from ICRU-90 recommendations on the beam quality specifiers, the photon component of the percentage depth-dose at 10 cm, %dd (10)x, and the tissue-phantom ratio at 20 cm and 10 cm, TPR20,10, are observed. Although using different recommendations for key dosimetric data affect water-to-air stopping-power ratios and ion chamber perturbation corrections by up to 0.6 % and 0.4 %, respectively, we observe little difference (less than or equal to 0.14 %) in calculated kQ factors. This is contradictory to the predictions in ICRU-90 that suggest differences up to 0.5 % in high-energy photon beams. A slightly better agreement with experimental values is obtained when using ICRU-90 recommendations.

Conclusion: Users of the addendum to the TG-51 protocol for reference dosimetry of high-energy photon beams, which recommends Monte Carlo calculated kQ factors, can rest assured that the recommendations of ICRU report 90 on basic data have little impact on this central dosimetric parameter.

Sensitive Volumes of Solid State Dosimeters used in Small Field Dosimetry (Poster 17)

Ganesan Ramanathan [1,2]
[1] *Ex-Senior Radiation Scientist, Australian Radiation Protection and Nuclear Safety Agency Yallambie, Victoria, Australia*
[2] *Present address: Emeritus Professor, Department of Medical Physics Bharathiar University, Coimbatore, India*

Semi-conductor devices such as diode and diamond have been found to be highly suitable for small field dosimetry due to their small size, high sensitivity and resolution (Pedro Andreo et al. 2017). The IAEA-AAPM international working group published a formalism involving the use of a series of correction factors to accurately convert the measure of a detector to absorbed dose to water (IAEA TRS-483 2017). Several investigators have evaluated the correction factors both by experiment and by Monte Carlo simulations (Hamza Benmakhlouf et al. 2014). The published experimental data showed disagreement with the MC calculated results and it was attributed to the use of incorrect sensitive volumes (Andreo, 2016). While experimental measurements and realistic Monte Carlo simulations have used the sensitive volumes of these detectors based on manufacturers' blue prints treating the entire volumes of the silicon and diamond as sensitive volumes. In reality, to collect the charge carriers produced in these detectors manufacturers have used metal contacts and in solid state physics it is well known that when a metallic contact is made between these crystals, a Schottky junction is formed and the depletion

volumes created at the junction are the real sensitive volumes (S.M. Sze et al. 2007). It is difficult to estimate the depletion volumes theoretically based on the properties such as resistivity of silicon and diamond crystals.

An experimental method is proposed in this paper to arrive at the depletion volumes of silicon and diamond detectors. The method is based on the theoretical sensitivity equivalence of a standard ionization chamber and these detectors. It is well known that when equal volumes of ionization chambers and solid state detectors are considered the solid state detectors are having higher sensitivities by a factor of ~ 18000 times based on the ratio of densities of air and silicon/diamond and the energy required to produce charge carriers in both types of detectors.

Measurements have been made at 6 MV photon beam at 100 cm SSD and 10 cm depth in a water phantom. Standard reference chamber NE 2571 (Farmer chamber) of known volume 0.6 cc was used. The chamber was calibrated against the Australian primary standard graphite calorimeter held at ARPANSA (Ganesan Ramanathan et al. 2014). The solid state detectors used under the same geometrical conditions are PTW 60017 electron diode and PTW 60019 micro-diamond. The integrated charges for 100 MU were recorded for both the ionization chamber and the solid-state detectors with PTW Unidose electrometer. The sensitive volumes of solid-state detectors were derived using the sensitivity equivalence with the charges measured with the chamber and the detectors. Densities of air in the chamber (1.205×10^{-3} g.cm^{-3}), silicon in the diode (2.330 g.cm^{-3}) and diamond (3.510 g.cm^{-3}) were used in the calculations. Energy required to produce ion pairs in air (33.94 eV) and electron-hole pairs in the solid-state detectors (3.4 eV) were also used in conjunction with the densities. The calculated volumes by this method will improve the accuracy in small field measurements.

REFERENCES

1. Pedro Andreo and Hamza Benmakhlouf, Role of the density, density effect and mean excitation energy in solid -state detectors for small photon fields, Phys.Med.Biol.,62 (2017) 1518-1532.

2. H Benmakhlouf, J Sempau, P Andreo, Output correction factors for nine small field detectors in 6 MV radiation therapy photon beams: a PENELOPE Monte Carlo Study Medical Physics 41 (4) 2014.

3. Pedro Andreo, Hugo Palmans, Maria Marteinsdottir, Hamza Benmakhlouf and Asa Carisson-Tedgren, On the Monte Carlo Simulation of small field micro-diamond detectors for megavoltage photon dosimetry, Phys.Med.Biol.61 (2016) L1-L10.

4. S.M.Sze and Kwok.K.Ng, Physics of Semiconductor Devices 3rd Edition 2007.

5. Ganesan Ramanathan, Peter Harty, Tracy Wright, Jessica Lye, Duncan Butler, David Webb and Huntley R. The Australian Primary standard for absorbed dose to water (Graphite calorimeter) ARPANSA Technical Report TR-166, June 2014.

Deployable Retrospective Non-Resonant Electron Spin Resonance Dosimetry (Poster 18)

Pragya R. Shrestha1,2, Robert Gougelet 2,3, Kin P. Cheung 2, Jason T. Ryan 2, Lonnie T. Cumberland 4 and Jason P. Campbell 2

1. *Theiss Research, La Jolla, CA, USA 2. National Institute of Standards and Technology, Engineering Physics Division, Gaithersburg, MD, USA 3. Global Resonance Technologies LLC, Washington DC, USA 4. National Institute of Standards and Technology, Radiation Physics Division, Gaithersburg, MD, USA*

Introduction: If an improvised nuclear device were detonated in a major US urban area, it would likely be without notice and directly impact hundreds of thousands to millions of victims. Medical care would be severely limited due to direct loss of first responder and healthcare worker lives, loss of communications, and loss of hospital and auxiliary care infrastructure. This work details the Emergency Response Dosimetry System (ERDS) which provides rapid self-assessment of an

individual’s received dose at 2 Gy +/- 0.5 Gy sensitivity levels. This single measurement, available in less than two minutes, provides a means to rapidly sort victims to prioritize those who require additional screening and triage the timely administration of life saving medical countermeasures. Historically, effective mass casualty retrospective dosimetry has been limited due to inherent material or environmental variabilities, cost, and logistical issues. In this submission, we detail a deployable non-resonant ESR-based sensor which rapidly derives a retrospective dose received in an alanine dosimeter embedded in personal identification cards. The ERDS system provides a strong foundation for a cost effective and operational retrospective dosimetry public health countermeasure.

Methods: The embedding of an alanine dosimeter within the thickness of an identification card structure provides the public with a ubiquitous means of personal transfer dosimetry. Self-assessment involves the insertion of the identification card/alanine structure into a non-resonant electron spin resonance probe. The non-resonant transmission line probe is designed such that the identification card is inserted between the signal line and ground plane of the microwave transmission line. This probe interfaces with a highly sensitive X-band continuous wave microwave detection bridge. This experimental setup is complemented by a compact permanent magnet and coil structure used to measure the density of radiation induced free radicals in the alanine dosimeter and relate that density to a received dose. Dose is derived from a comparison of the amplitudes of the central peak in the alanine electron spin resonance spectrum to those measured in calibrated identification cards.

Results: The non-resonant ESR-based sensor can reliably detect 2 Â± 0.5 Gy in less than 2 min. The system described in the methods section allows for a more sensitive, compact and user-friendly system compared to the conventional ESR tool. Since the derived dose is linked to the personal identification card, demographic data can seamlessly be integrated into response plans, providing a crucial data point which will help bring order to an otherwise chaotic situation. ERDS does not require operational expertise to acquire reliable and accurate results. This leads to self-assessment with little oversight, allowing the trained medical staff to focus on treatment of patients most in need.

Conclusion: Alanine dosimeters embedded in an identification card and a highly sensitive compact non-resonant ESR sensor is an effective tool for rapidly sorting individuals’ received dose in the aftermath of a nuclear event. This combination allows for accurate and reliable detection of 2 Â± 0.5 Gy within 2 min and facilitates an extremely effective and rapid emergency response.

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- present: Zhichao Lin, FDA

CIRMS Award for Distinguished Achievement in the Field of Ionizing Radiation Measurements and Standards

2000 **Randall S. Caswell,** National Institute of Standards and Technology (retired)

Randall S. Caswell Award for Distinguished Achievement in the Field of Ionizing Radiation Measurements and Standards:

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)

Student Travel Grant Recipients

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

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:

27th Annual Meeting CIRMS 2019
April 8-10*, 2019

*** 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 2018 Corporate Sponsorship

Benefits to all corporation members/sponsors:

- Company branding through Sponsors List on CIRMS website and on all announcements and mailings
- Editorial position on the CIRMS "Needs Report" Panel
- Can be elected to the Executive Committee
- Up to six 2018 individual employee memberships to CIRMS
- Free tabletop display and/or poster space at CIRMS 2019 Annual Meeting (April 8-10, 2019)

Corporate Sponsor ($1000 per year)

- Company branding through Sponsors List
- Editorial position on the CIRMS "Needs Report" Panel
- Can be elected to the Executive Committee
- Two free individual employee memberships to CIRMS

Bronze Sponsor ($2000 per year)

- Benefits of Corporate Sponsorship
- Free registration to CIRMS meeting
- Extra support and branding through one of the following:
  - Named Sponsorship of *Student Travel Grant*
  - Names and Logos on CIRMS Bags
  - Names and Logos on CIRMS Portfolio
  - Names and Logos on CIRMS Flash Drives
  - Names and Logos on CIRMS Lanyards

Silver Sponsor ($3000 per year)

- Benefits of Bronze Sponsorship
- Named Sponsorship of Coffee Break or second Bronze perk
- One additional free registration to CIRMS meeting (total: 2)
- Two additional free individual employee memberships (total: 4)

Gold Sponsor ($5000 per year)

- Benefits of Silver Sponsorship
- Named Sponsorship of Smokey Glen Farm BBQ Happy Hour or Dessert
- One additional free registration to CIRMS meeting (total: 3)
- Two additional free individual employee memberships (total: 6)

Platinum Sponsor (>$10,000 per year)

- Benefits of Gold Sponsorship
- Sponsor for Smokey Glen Farm BBQ Dinner (or Gala dinner at a different venue)
- Free CIRMS conference registrations for up to 10 people from your organization
- Free individual employee memberships for up to 20 people from your organization

Council on Ionizing Radiation Measurements and Standards
P.O. Box 262333 Plano, TX 75026 Phone: 301-591-8776 Fax: 972-883-7202
www.cirms.org

CIRMS Membership Application

Instructions

Complete this form and print it. Fax to 972-883-7202 or mail the completed form and send your payment to: CIRMS, P.O. Box 262333, Plano, TX 75026.

Membership Class

Select which membership class:

____ **Corporate Sponsor $1,000.00**
____ **Corporate Sponsor Bronze $2,000.00**
____ **Corporate Sponsor Silver $3,000.00**
____ **Corporate Sponsor Gold $5,000.00**
____ **Corporate Sponsor Platinum $10,000.00**
____ **Government / Non-Profit Organization Sponsors $750.00**
____ **Individual Member $50.00**
____ **Student Member $25.00**

Member Information

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

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: _____
Representative 5 Name: _____
Phone: _____
Email: _____
Representative 6 Name: _____
Phone: _____
Email: _____

Council on Ionizing Radiation Measurements and Standards
P.O. Box 262333 Plano, TX 750026 Phone: 301-591-8776 Fax: 972-883-7202
www.cirms.org

Areas Of Interest

	Rep 1	Rep 2	Rep 3	Rep 4	Rep 5	Rep 6
Homeland Security	☐	☐	☐	☐	☐	☐
Industrial Applications & Materials Effects (IAME)	☐	☐	☐	☐	☐	☐
Medical Applications (MED)	☐	☐	☐	☐	☐	☐
Radiation Protection (RP)	☐	☐	☐	☐	☐	☐

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: _____