Council on Ionizing Radiation Measurements and Standards
23rd Annual Meeting, 2015

"FUNDAMENTALS OF IONIZING RADIATION"

April 27 – 29, 2015

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MEETING FOCUS

The 23rd Annual Meeting of the Council on Ionizing Radiation Measurements and Standards will focus on Fundamentals of Radiation Measurements and Standards.
For more than twenty 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 [diagnostic and therapeutic radiology, nuclear medicine]

- Radiation Protection and Homeland Security [homeland security checkpoint and cargo inspection technology, radiochemistry, waste analysis, personnel dosimetry, electronic dosimeters, bioassay and internal dosimetry environmental dosimetry, first responder needs]

- Industrial Applications and Materials Effects [dosimetry for radiation processing, radiobiology, safety at radiation facilities, food irradiation]

Participants are invited to submit abstracts for poster presentation and possible presentation during the working group sessions.

WORKING 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 were arrived at through dialog at CIRMS meetings and workshops.

CIRMS Medical Subcommittee, which deals with diagnostic and therapeutic uses of ionizing radiation, has found need in four specific areas:

- Radioactivity Standards and Techniques for Nuclear Medicine
- Dose Mapping Systems for 3D Conformal Radiation Therapy and Intensity Modulated Radiation Therapy
- Absorbed Dose Standards for Brachytherapy Sources
- Liquid Based and Micro-Brachytherapy Sources

These reflect current developments in medicine that have come to rely more heavily on the use of radioactive species for diagnostic purposes and treatment. Brachytherapy, for example, is becoming more widely used as an option to treat prostate cancer. Prior to any such internal or to external treatment of cancer, patient dose mapping is needed so that the physician can best treat the targeted or intended area.
The CIRMS Public and Environmental Radiation Protection Subcommittee (PERP), which dealt with radioactivity found in the environment and its possible public health effects, and Occupational Radiation Protection Subcommittee (ORP), which dealt with worker protection in radioactive environments, have been merged into a joint Radiation Protection Subcommittee (RP). Many activities espoused by PERP

were evolving into areas of interest for ORP as well. A new subcommittee devoted to the interests in Homeland Security was formed. Its interests are combined with those in Radiation Protection. Nine Measurement Program Descriptions are defined in these areas:

- Traceability to NIST for Reference, Monitoring and Service Laboratories
- Sorption of Radioactive Elements in Contaminated Soils and Sediments and Urban Structural and Other Materials
- Atom-Counting Measurement Techniques for Environmental and Radiobioassay Monitoring
- Intercomparison Transfer Standards for Neutron Source Calibrations
- Improvements for *In–vivo* and *In-vitro* Radiobioassay Metrology
- Improved Radiation Measurement Infrastructure for Occupational Radiation Protection
- Extension of Calibration Accreditation Criteria to Low Dose Radiations
- Implementation of Support for Personnel Dosimetry Proficiency Testing per ANSI N13.11
- Emergency Radiological Response

These reflect continuing needs to improve upon ways to measure radioactivity, especially in soils, structures and other materials that have been contaminated by hosting activities related to nuclear weapons development. Accurate measurements that will be traceable to national reference standards must be sustained and an understanding of how such radioactivity decays over time is a continuing area of inquiry. Issues of calibration, proficiency testing and the maintenance of a network to monitor dose exposure in occupational settings are covered. The need for a national network capable of responding in the event of terrorist activities involving radiological materials is also addressed.

The CIRMS Industrial Applications and Materials Effects subcommittee (IAME) covers a diverse area generally not related directly to human radiation exposure. In this context, IAME has found need for measurement programs in five areas:

- Radiation Hardness Testing and Mixed-Field Radiation Effects
- Neutron Dosimetry for Reactor Pressure Vessel Surveillance
- Medical Device Sterilization
- Food Irradiation
- Low-Voltage Electron Beam Dosimetry

Terrestrial measurements of the effects (hardening) of types of radiation found in space on electronic materials are essential to satellite operations and communications systems. As nuclear power plants age, radiation effects on their pressure vessels must continue to be monitored. The growing use of irradiation to sterilize medical devices and the emergence of food irradiation demand heightened attention to dosimetry measurements and their traceability to national reference sources.

In an era of constrained government resources, the above point to areas warranting program attention as determined by a consensus of experts from industry, academia and government laboratories and agencies. Adequate resources should be allocated so that the objectives outlined in each area can be accomplished.

The 2015 Needs Report working version is now available online at:
http://www.cirms.org/w

PLENARY AGENDA

Monday, April 27

8:30 am Continental Breakfast/Registration

9:00 am **President's Welcome**
Dr. Kim M. Morehouse, President, CIRMS

9:15 am **Welcome to NIST**
Dr. Lisa R. Karam, Chief
Radiation Physics Division, Physical Measurement Laboratory
National Institute of Standards and Technology, MD

9:30 am **Intro to NEEDS REPORT**
Dr. Walter E. Voit, CIRMS 1st Vice President
University of Texas at Dallas

9:45 am **Keynote Address**
Dr. Robert C. Baumann, Texas Instruments, TX
"Silicon Amnesia and Dementia: Radiation Effects in Microelectronics"

10:15 am **Discussion**

10:30 am Coffee Break

10:45 am **Plenary Session I**
Kevin O'Hara, Sterigenics, USA
"*The Fundamentals of Ionizing Radiation as Applied to Radiation Processing*"

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

CIRMS Student Travel Grant – sponsored by ASTM International

Mitchell Carroll, UT MD Anderson Cancer Center
"*Investigation of PRESAGE as a 3D Dosimetric Tool for Proton Therapy by Measurement of Proton-activated Positron Emission"*

CIRMS Student Travel Grant – sponsored by Hopewell Designs Inc.

Jon Hansen, University of Wisconsin - Madison
"Capacitance Methods to Determine Electrode Area and Air Gap for Windowless Planar Extrapolation Chamber"

CIRMS Student Travel Grant – sponsored by IBA Industrial

Travis Dietz, University of Maryland College Park
"*Improvement of Radiation Grafting of Selective Ligands onto Polymeric Substrates to Produce High-capacity Adsorbents for Harvesting Uranium from Seawater"*

CIRMS Student Travel Grant – sponsored by Radiation Physics Division of NIST

Sameer Taneja, University of Wisconsin – Madison

"A Monte-Carlo Based Spectroscopic Characterization of a Cs-137 Irradiator with Attenuating Material"

11:45 am **Poster Summaries**

12:00 pm **Poster Viewing**

12:45 pm Lunch

1:45 pm **Concurrent Working Group Sessions**: IAME, Medical App, RP/HS
Working Group Session I

3:30 pm Coffee Break

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

5:30 pm Adjourn

Tuesday, April 28

8:30 am Continental Breakfast

9:15 am **President's Welcome**
Dr. Kim M. Morehouse, President, CIRMS

9:30 am **Plenary Session II**
Dr. Michael S. Gordon, IBM T.J. Watson Research Center, NY
"*Challenges in Ultra-low Emissivity Alpha Particle Detection*"

10:00 am **Randall S. Caswell Award for Distinguished Achievement in the Field of Ionizing Radiation Measurements and Standards presented to:**

X. George Xu, PhD *Rensselaer Polytechnic Institute*

10:30 am Coffee Break

10:45 am **Plenary Session III**
Dr. Frédéric Tessier, National Research Council, Canada
"*Resolving the Anomalous Behavior of the NE2575 Ionization Chamber with EGSnrc Simulations*"

11:15 am **Poster Summaries**

11:30 am **Poster Viewing**

12:45 pm Lunch

1:45 pm **Concurrent Working Group Sessions (continued):** IAME, Ma, RP/HS
Working Group Session III

PLENARY AGENDA, CONTINUED

3:30 pm	Coffee Break
3:45 pm	**Working Group Sessions IV**
5:30 pm	Adjourn Day 2
6:15 pm	Bus from Hilton Hotel to Smokey Glen Farm
6:30 pm	Barbecue Dinner at Smokey Glen Farms

Wednesday, April 29

8:30 am	Continental Breakfast
9:15 am	**Welcome Back** Dr. Kim M. Morehouse, President, CIRMS
9:30 am	**Plenary Session IV** Dr. Firas Mourtada, Christiana Care's Helen F. Graham Cancer Center & Research Institute, DE "*Recent Advances in Brachytherapy Dose Calculations Methods— The Need for Standardization is Now More than Ever*"
10:00 am	**Plenary Session V** Dr. Daniel A. Hahn, University of Florida, FL "*Developing Biomarkers of Irradiation of Insects to Facilitate International Trade in Agricultural Commodities*"
10:30 am	Coffee Break
10:45 am	**Closing Address** Paul Wynne, International Irradiation Association, United Kingdom *"Irradiation in a Changing World"*
11:15 am	**Report on Needs in Ionizing Radiation**
12:30 pm	**Closing Remarks/New Officers**
12:45 pm	Lunch
2:30 pm	**ExComm Meeting**
3:30 pm	Adjourn

IAME - INDUSTRIAL APPLICATIONS AND MATERIALS EFFECTS SUBCOMMITTEE

Working Group Sessions

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

Monday, April 27, 2015

Working Group Session I
1:45 – 3:30 pm
What's in the Future for Self-contained Irradiators and their Users?

Round Table Discussion
Emily Craven, Nordion
Mark Desrosiers, NIST/RPD
Mark Driscoll, SUNY ESF
Lonnie Cumberland, NIST/RPD
Ryan Tracey, STERIS
Marshal Cleland, IBA

Working Group Session II
3:45 – 5:15 pm
Industrial Irradiation Challenges and Solutions

3:45 - 4:05	Using Mathematical Modeling to Support Change Control Kim Patton, Becton Dickinson
4:05 - 4:25	Mathematical Modeling as a Tool in Source Replenishments Emily Craven, Nordion
4:25 - 4:45	Standardization of Nuclear Component Off-Carrier Processing Ryan Tracey, STERIS
4:45 - 5:15	Establishing a More Robust Decontamination Dose for Medical Devices James Eidum, Johnson & Johnson

Tuesday, April 28, 2015

Working Group Session III
1:45 – 3:30 pm
The Use of Ionizing Radiation in Synthesis of Advanced Materials

Moderator, Mohamad Al-Sheikhly, University of Maryland

Yuri Berlin, Northwestern University
Christopher Lavelle, Johns Hopkins Applied Physics Laboratory
Dianne L. Poster, NIST

Working Group Session IV
3:45 – 5:15 pm
Pursuing a Radiation Advanced Manufacturing Center

Round Table Discussion
Moderator: Mark Driscoll, SUNY ESF

Mohamad Al-Sheikhly, University of Maryland
Gary Cohen, RadTech
Michael T. Postek, NIST
Mark Driscoll, SUNY ESF

MEDICAL APPLICATIONS SUBCOMMITTEE

Working Group Sessions

Chairs: Regina Fulkerson, Wes Culberson (University of Wisconsin) and Ronnie Minniti (NIST)

Monday, April 27, 2015

Working Group Session I
1:45 – 3:30 pm
Theme: **External Beam**

1:45-2:05	Measurements of Stopping Powers Using Single Electron Counting Malcom McEwan, NRC Canada
2:05-2:25	The Physics of Proton Therapy Wayne Newhauser, LSU, Department of Medical Physics
2:25-2:45	Small Field Dosimetry in Radiotherapy from a Standpoint of Basic Research Guerda Massillon-JL, Universidad Nacional Autonoma de Mexico
2:45-3:30	Questions for speakers and discussion on "current needs" Interactive discussion with audience
3:30-3:45	Break

Working Group Session II
3:45 – 5:15 pm
Theme: **Brachytherapy**

3:45-4:05	End of Life for Brachytherapy Devices Zoubir Ouhib, Lynn Cancer Institute, Boca Raton, FL
4:05-4:25	New NIST Standard for Electronic Brachytherapy Michael Mitch, NIST
4:25-4:45	Addressing the Dosimetry Challenges of Using a Titanium Applicator with a Low Energy Brachytherapy Source Sam Simiele, Univiversity of Wisconsin, Department of Medical Physics
4:45-5:15	Questions for speakers and discussion on "current needs" Interactive discussion with audience

5:15 Adjourn

Tuesday, April 28, 2015

Working Group Session III
1:45 – 3:30 pm
Theme: **Radiation Biology, "Research, Devices & Dosimetry"**

1:45-2:05	Dose is More than a Number: The Growing Need for "Radiobiology Dosimetry Standards" Jim Deye, NIH/NCI (retired)
2:05-2:25	Output Verification of Radiobiological Irradiators Kurt Pedersen, University of Wisconsin, Department of Medical Physics
2:25-2:45	Novel High-throughput Irradiators for In Vitro Radiation Sensitivity Bioassays Bryan Bednarz, University of Wisconsin, Department of Medical Physics
2:45-2:55	Poster Summary: Photon and Electron Beam Dosimetry using Calorimetry at ARPANSA Ganesan Ramanathan, ARPANSA

2:55-3:30 Questions for speakers and discussion on "current needs"
Interactive discussion with audience

3:30-3:45 Break

Working Group Session IV
3:45 – 5:15 pm
Theme: **Frontiers of Medical Physics**

3:45-4:05 Ionization Chamber Construction
Brian Hooten, Standard imaging
4:05-4:25 Stereotactic Radiotherapy for Breast Cancer
Yildrim Mutaf, University of Maryland, Department of Radiation Oncology
4:25-4:45 Commissioning an IRay System for Ocular Stereotaxy using Integrated Tissue Air Ratio
Justin Hanlon, Oraya Therapeutics, Inc.
4:45-4:55 Poster Summary: Evaluation of a Lung Density CT SRM
Heather Chen Mayer, NIST
4:55-5:15 Questions for speakers and discussion on "current needs"
Interactive discussion with audience

5:15 Adjourn

RADIATION PROTECTION/HOMELAND SECURITY SUBCOMMITTEE

Working Group Sessions

Chairs: Chip Starns (ScanTech) and Michael Unterweger (NIST)

Monday, April 27, 2015

Working Group Session I
1:45-:30 pm
Theme: **Checkpoint Screening**

1:45-2:15 Overview of X-Ray Screening Standards for Homeland Security with Attention to Radiation Protection Standards
Larry Hudson, NIST

2:30-3:00 Z_e and ρ_e a Different X-ray CT Feature
Harry Martz, LLNL

3:30-3:45 Break

Working Group Session II
3:45-5:15
Panel Discussion on Future of Checkpoint/Cargo Screening
PANEL: Larry Hudson, Dolan Falconer (ScanTech CEO), Harry Martz

5:15 Adjourn

Tuesday, April 28, 2015

Working Group Session III
1:45-3:30

1:45-2:15 Proposed Trifurcation of the ASTM F792 Checkpoint Standard: the Quality Assurance and Human Perception Test Objects/Test Methods
Ron Tosh

2:30-3:00 Proposed Trifurcation of the ASTM F792 Checkpoint Standard: the Objectively Evaluated Test Article and Test Methods
Jack Glover

Working Group Session IV
3:45-5:15

3:45-4:15 Development of Dosimeter Technology for First Responder Applications
Tom Partington

4:15-5:15
Wrap-up Discussion: Future of the Committee

5:15 Adjourn

Plenary Abstracts

Silicon Amnesia and Dementia: Radiation Effects in Microelectronics

Dr. Robert C. Baumann, Texas Instruments, TX

In the benign terrestrial environment, radiation is often the dominant failure mechanism in qualified microelectronics. Things only get worse in high reliability environments where the radiation exposure is more intense and prolonged! After a review of key radiation mechanisms and various environments, we consider “dementia” caused by permanent degradation induced by absorbed dose and “amnesia” caused by single-event-effect induced malfunctions. We will then look at the radiation sensitivity of microelectronics as a function of commercial scaling, and conclude with the primary mitigation strategies used to harden microelectronics in high-radiation environments.

The Fundamentals of Ionizing Radiation as Applied to Radiation Processing

Kevin O’Hara, Sterigenics, USA

The fundamentals of ionizing radiation as applied to the radiation processing of medical product and food is presented from the contract-service provider’s perspective.
Radiation is considered to be the ideal treatment method for many products. Some polymeric and biological materials, however, do experience unacceptable changes possibly forcing the use of other sterilization modalities (or aseptic processing).
The radiation processing world is getting more and more complex. The radiation-processing challenges of medical implants, other advanced materials and food are presented. The improved understanding of the irradiation processes has led to new processes and improved performance of materials.

Challenges in Ultra-low Emissivity Alpha Particle Detection

Dr. Michael S. Gordon, IBM T.J. Watson Research Center, NY

In the semiconductor industry, to minimize the influence of single event upsets (SEU) caused by alpha particles near transistors, the current alpha particle emissivity requirement for materials is $\varepsilon < 2\ \alpha/\text{khr-cm}^2$ which amounts to $1.4\ \alpha/\text{hr}$ on a 300 mm diameter wafer. This low level exceeds the counter background on most gas proportional or ionization counters. In this talk, I will discuss the effect that counter background, cosmic rays, radon adsorption, and even static charge on insulating samples has on making these measurements. Also, I will show the results of several round-robin alpha-counting experiments, highlighting the large variability of measurements from lab-to-lab in one of the studies. Finally, I will discuss the need for an industry-wide, large-area, ultra-low emissivity standard.

Resolving the Anomalous Behavior of the NE2575 Ionization Chamber with EGSnrc Simulations

Dr. Frédéric Tessier, National Research Council, Canada

In 1993, upon acquiring a Cs-137 irradiator, physicists at the National Research Council of Canada (NRC) noticed that measurements with the large volume 600cc ionization chamber model NE2575 showed an unexpected deviation from the inverse square law, with a discrepancy of up to 4% at 8 meters from the source. Although this anomaly was confirmed experimentally and was well documented, a definitive explanation remained elusive. Twenty years later, we revisit this problem using EGSnrc Monte Carlo simulations to discern the contribution of each chamber component to the anomaly. We show that the observed deviation arises mostly from long photon attenuation paths inside the chamber cylindrical side wall. We propose an empirical correction to address the issue in practice, but also uncover an optimal chamber angle at which the inverse square law behavior is recovered. Our story of the NE2575

chamber anomaly highlights the fundamental role Monte Carlo simulations play in radiation measurement standards today.

Recent Advances in Brachytherapy Dose Calculations Methods - The Need for Standardization is Now More than Ever

Dr. Firas Mourtada, Christiana Care's Helen F. Graham Cancer Center & Research Institute, DE

With the recent introduction of heterogeneity correction algorithms for brachytherapy, the Medical Physics community is still unclear on how to commission and implement these into clinical practice. The recently-published AAPM TG-186 report discusses important issues for clinical implementation of these algorithms. A charge of the AAPM-ESTRO-ABG Working Group on MBDCA in Brachytherapy (WGMBDCA) is the development of a set of well-defined test case plans, available as references in the software commissioning process to be performed by clinical end-users. The need for standardization of such tasks is now needed for brachytherapy treatment planning transition from TG43 formalism to MBDCA.

Learning Objectives:
1. Summarize the evolution of clinical treatment planning systems from basic hand calcs up to the new fast model based algorithms, showing the benefits and limitations of each.
2. Describe how standardization of commission tasks will help the community to transition from a TG-43 model to the new heterogeneity corrected dose distribution for brachytherapy
3. Review TG-186 and WGMBDCA guidelines, commission process, and dosimetry benchmarks.

Developing Biomarkers of Irradiation of Insects to Facilitate International Trade in Agricultural Commodities

Dr. Daniel A. Hahn, University of Florida, FL

Ionizing radiation is emerging as an alternative to other treatments, like chemical fumigants, for eliminating insect pests in fresh commodities including fruits and vegetables, thus facilitating trade regionally and internationally. Irradiation can directly kill insects at the time of treatment, but irradiation treatments for phytosanitary treatment must be below 1 kGy and at these low doses irradiated insects do not always die immediately. Instead irradiation can leave live and apparently healthy insects in a commodity that are either unable to move on to the next life stage because metamorphosis is blocked or that may develop into sterile adults. After an irradiation treatment, live insects that are destined for death or sterility may be found alive on a shipment (e.g., so called “wigglers”). Because these insects are destined for death or are alive but unable to reproduce they pose no threat. However, these live insects may show no outward physical signs of irradiation, thus calling into question whether an irradiation treatment has been properly applied. This uncertainty about the efficacy of irradiation treatments could potentially cause inspectors to refuse an imported commodity with substantial economic ramifications for agricultural producers and shippers.
There is a critical need for diagnostic tests to verify whether live insects found during the inspection of a commodity for import or export have been irradiated. We outline current strategies to develop a biomarker of irradiation in insects. Biomarker development has focused largely on detecting DNA damage—the primary cause of death and sterility following irradiation. Promising indicators of irradiation-induced damage to DNA include markers of DNA oxidation and repair such as histone phosphorylation and antibodies to oxidized Guanine nucleotides. Finally, we will discuss key requirements for a successful biomarker of irradiation and future avenues for research.

Irradiation in a Changing World

Paul Wynne, International Irradiation Association, United Kingdom

The first large scale commercial irradiation facilities were established 50 years ago. In North America and Europe investment in gamma facilities reached its peak in the 1980's and 1990's. Today new gamma facilities are essentially being constructed in Asia. Electron beam technology has long complemented gamma but the majority of facilities are in house. After a period of relative stability the scientific, regulatory and commercial environment is changing.

The pace of global change is accelerating and many of the changes are impacting on the irradiation industry. Cobalt supply, transport, safety, security and disposal have become topical issues. The fear of terrorism is a global issue that pervades every aspect of business including the irradiation industry. One consequence of change is that it triggers reactions from regulators. The quest for growth means that we are witnessing a spate of merger and acquisition activity in our industry. This has its own consequences and creates further change for both commercial enterprises and the wider irradiation.

New irradiation equipment suppliers have appeared and a number have established enviable reputations over a relatively short period of time. The potential for X-ray technology as an alternative to gamma is the subject of much debate and strategic investments are being made to evaluate and capitalize of the potential opportunities. We are also seeing the emergence of on-line sterilization with low energy self shielded EB and X ray machines that could take a portion of the traditional irradiation business in-house.

The way in which the irradiation industry responds to the challenges and opportunities will be debated during the course of this conference. We will probably come to recognize that in spite of the globalization the different regions of the world still retain some degree of specificity.

This presentation will highlight some of the key changes that are currently taking place within our industry at the present time.

Students' Abstracts

CIRMS Student Travel Grant – sponsored by ASTM International

1. Investigation of PRESAGE as a 3D Dosimetric Tool for Proton Therapy by Measurement of Proton-activated Positron Emission

Mitchell Carroll[1,2], G. Ibbott[1], J. Adamovics[3]

[1]Department of Radiation Physics, University of Texas MD Anderson Cancer Center, 1515 Holcombe Blvd., Houston, TX 77030 USA
[2]University of Texas at Houston Graduate School of Biomedical Sciences, Houston, TX 77030 USA
[3]Heuris Pharma, LLC, 412 Sunset Rd., Skillman, NJ, 08558 USA

Objectives

Radiotherapy techniques have advanced and radiation dose plans have become significantly more complex over the last decade. In proton therapy, which includes extremely steep dose gradients as a result of the Bragg peak covering the clinically treated volumes, this is especially true. This Bragg peak can be significantly shifted in the patient as a result of even minor density changes in its path which can result in both a significantly over dose to healthy tissue and under dose to the diseased tissue. Early studies have investigated the potential of proton positron activation as a method of noninvasive *in vivo* dosimetry using positron emission tomography (PET) [1]. The cross-section for activation of positron emitters is dependent on the energy of the proton beam which changes with depth in tissue, leading to a shift in areas of maximum positron activity away from the Bragg Peak. Using a separate device for relative dosimetry can lead to dose mapping uncertainties [2]. A 3D dosimeter can allow mapping of proton dose distribution to the PET activity measurement within a single detector and reduce these uncertainties.

Previous studies have tested polymer gels to map positron-emitter activation. Gels rely primarily on ^{15}O emitters which have half-lives of ~2 minutes making rapid readout essential [3]. We have investigated use of the radiochromic polyurethane dosimeter PRESAGE® to correlate the proton dose distribution to the PET activity measurement within a single detector. The applications of this novel dosimeter are being studied as a tool for proton therapy commissioning and treatment verification [4]. The polyurethane in PRESAGE® is primarily composed of carbon (approx. 62% w/o) which has a more manageable half-life of 20 minutes.

Methods

The PRESAGE® formulation used was developed to minimize the sensitivity to proton LET and has similar density and RLSP to tissue [5]. Cylindrical dosimeters were irradiated with 180-MeV energies in a single, wide-beam shot with passive double scattered protons. Irradiations were performed at the M.D. Anderson Proton Therapy Center. Immediately after irradiation, the dosimeters were rushed to a nearby PET/CT for the first stage of imaging on a GE Discovery 690 FX. PET scanning was run for three hours to allow acquisition of the full decay of the activated isotopes. A CT was used for attenuation correction of the PRESAGE®.

Following the PET scan, the dosimeters were analyzed using the Duke Mid field-of-view Optical CT Scanner (DMOS) at a nearby facility. The 3D dose distributions were measured by the radiation induced change in optical density determined by reconstructing corrected projection images of a nonreactive, parallel beam filtered back-projection across 360°. The dose response of PRESAGE® is linear and this optical density change can be converted to dose based on absolute dose measurements. We chose to use relative dose for direct comparison with the PET measurement using the Computational Environment for Radiotherapy Research (CERR) software platform.

Results

PET reconstructions relative to decay time were correlated to the dose measurement of the DMOS to determine time sensitivity of the activation decay. Measurements of the PRESAGE® dosimeter taken with PET/CT and optical-CT are shown in Figure 1. The PET/CT shows the effect of dose as positron emission while the optical-CT measures dose by a change in the optical density in the dosimeter.

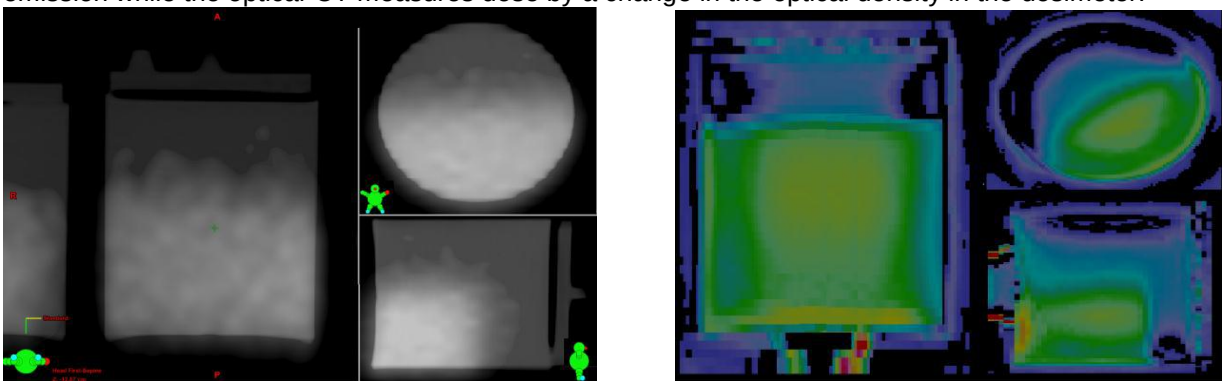

Figure 1: Co-registered PET/CT cross-section with three hour reconstruction (left) and PRESAGE® optical-CT image cross-section (right).

A comparison of the two imaging modalities demonstrates the proton activation geometrically with respect to the beam profile. Previous studies have shown the positron hotspots shifted towards the proximal region of the SOBP compared to the measured dose [5] which was correlated with the results of this irradiation. At the distal-80% of the field, a 1 cm discrepancy between the measured dose and the PET activity was found. An averaged profile along the central axis, along with ion chamber data of the beam, reflects this shift in the activity peak and is shown in Figure 2. Further along the distal region, in which the beam energy has significantly decreased, shows no PET signal as proton energies have fallen below the carbon activation thresholds.

Comparisons of the spatial distributions between the measured dose and PET signal are perhaps the most relevant for *in vivo* verification. A lateral axis profile comparison shows another cross-section of relative uniformly measured dose which demonstrates the positrons activity across a monoenergetic profile (Figure 3).

PET measurements showed minor improvements in stability for scans beyond 60 minutes with all additional durations agreeing to within 2%.

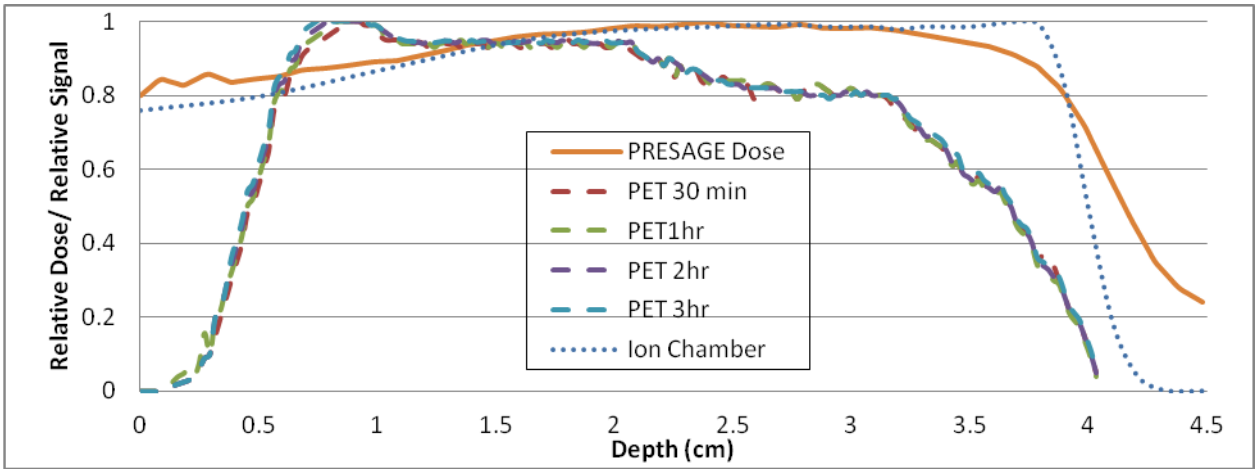

Figure 2: DMOS measured relative dose and PET activity along the PRESAGE® central axis.

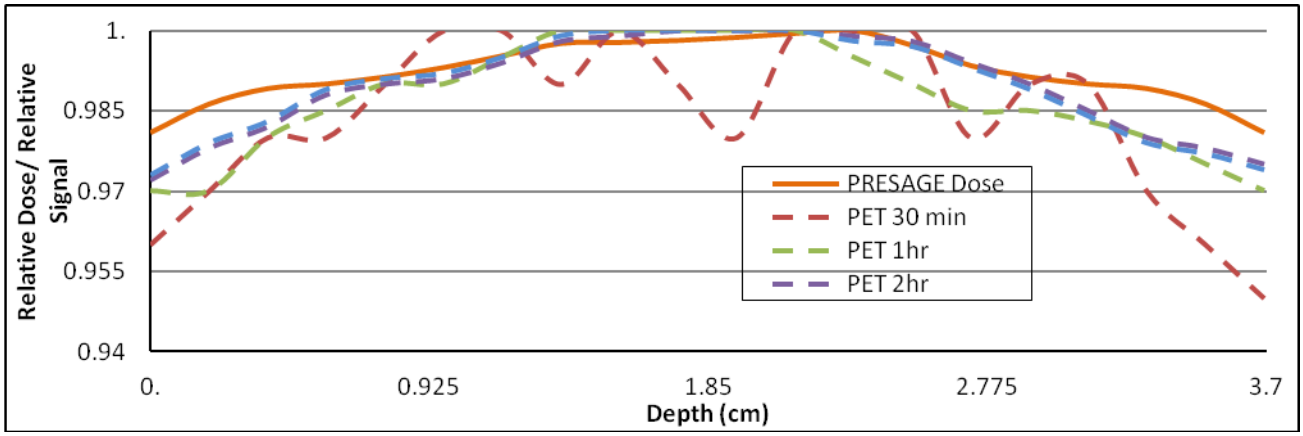

Figure 3: DMOS measured relative dose and PET activity comparison along the PRESAGE® lateral axis.

Discussion

PET activation offers a unique opportunity for *in vivo* dosimetry and treatment verification of complex proton treatment plans and PRESAGE® offers the unique potential to accurately and realistically correlate the dosimetric and PET activation information. This correlation showed good agreement until the distal end of the beam. With further study, a potential methodology for the correction of this PET activity shift would allow for an accurate and available tool for nearly any proton dose verification and demonstrates the feasibility of proton activated positron emission as an *in vivo* dosimetric tool.

Relation to CIRMS

The focus of CIRMS has been, in large part, the measurement of radiation in its application to medical therapies. My graduate research has been adapting PRESAGE® to be fully compatible to proton therapy and developing it as a tool for remote and in-house dose verification. As proton therapy is still a relatively new tool in the clinical setting, conventional radiation detectors are still not fully suited to provide accurate verification of treatment plan delivery. CIRMS is still setting the fundamentals that will be used in proton clinics according to fifth triennial report on "Needs in Ionizing Radiation Measurements and Standards" which stated the goal as "harmonizing protocols for proton beam dose determinations." In this I believe PRESAGE® will find a use, and to some degree, positron emission dosimetry will be further examined as a potential tool.

Support by grant 5RO1CA100835

References:

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CIRMS Student Travel Grant – sponsored by Hopewell Design Inc.

2. Capacitance Methods to Determine Electrode Area and Air Gap for Windowless Planar Extrapolation Chamber

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Objectives:

Ophthalmic applicators and episcleral plaques are commonly used to treat malignant and benign diseases of the eye. Planar extrapolation chambers have been employed by standards laboratories to determine the dose rate from a planar brachytherapy source. For this research project, a planar extrapolation chamber has been constructed to test the efficacy of a windowless design. During future work, a windowless, convex chamber is proposed to calibrate concave episcleral plaques. For the planar chamber, capacitance measurements are used to determine the effective area of the collecting electrode instead of conventional methods of using machining specifications or a scanning electron microscope (SEM). Furthermore, capacitance measurements are proposed as a non-contact technique to accurately determine the initial air gap between the collecting electrode and the applicator source.

Methods:

Conventionally, planar extrapolation chambers feature a Mylar entrance window. The air gap between the entrance and collecting electrode is varied incrementally, and the reading is extrapolated toward a zero offset

to determine the surface dose rate. For this work, the effectiveness of a windowless extrapolation chamber is explored where the metal source itself serves as the biased electrode. Using a NIST calibrated Tracerlab RA-1 $^{90}Sr/^{90}Y$ planar source, measurements with a windowless, planar system are carried out to characterize the accuracy of the system. A correction factor is calculated with Monte Carlo methods to adjust for the effective point of measurement difference at which the dose rate is specified with and without the entrance window present. The established calibration procedures from IRD-P-09 for the NIST planar extrapolation chamber are utilized whenever applicable. A non-radioactive metal applicator is used during capacitance measurements to determine the effective area of the collecting electrode. For varying gap width, a change in voltage is induced from 0 to 10 V, and the generated charge is collected using an electrometer. From these values, the capacitance is calculated. Assuming an ideal parallel plate capacitor, the effective area of the collecting electrode is directly related to the slope of the line for measured plate separation as a function of inverse capacitance. The formulation is not dependent on the true gap width, as long as the offset does not vary between measurements. Additionally, since the windowless chamber does not feature a stationary entrance electrode, the initial air gap must be determined before each source calibration measurement. Capacitance measurements are proposed to determine the initial gap width through a non-contact technique. Since the radioactive source inherently induces charge deposition in the measurement setup, care must be taken to isolate the displacement current attributable strictly to capacitance discharge upon a change in voltage. Starting with a stable current read at 5 V, the bias is quickly increased at the onset of a 30 s charge measurement. This charge reading is recorded, and a subsequent 30 s charge measurement is taken upon stabilization to determine the expected steady state reading at the new bias setting. The capacitance is then calculated as the difference between charge readings and the initial change in voltage.

Results:

Thus far, Monte Carlo simulations have been completed to quantify the expected reduction in dose rate caused by the presence of the 0.006 mm thick Mylar entrance window for the NIST extrapolation chamber. The correction factor was found to be $k_{foil} = 0.928 \pm 0.006$. Thus, the surface dose rate measured by the windowless, planar extrapolation chamber is expected to be 7.8% higher than the decay corrected dose rate given by the NIST calibration for the same source. Additionally, capacitance measurements were completed to quantify the surface area of the collecting electrode for the windowless, planar extrapolation chamber. Under this formulation, the effective area of the collecting electrode was found as 12.58 mm^2 with 1.21% uncertainty given by the population standard deviation after six trials. This result agreed closely with the expected value of 12.57 mm^2 from the manufacturer. The capacitance measurement technique can potentially be used to calculate the effective area of the convex electrode during future work. Finally, the measured capacitance of the planar extrapolation system was used to determine the actual gap width for the windowless chamber at the beginning of calibration measurements. The technique has been shown to achieve accuracy in the initial gap offset to within 0.013 mm, which is considered satisfactory for the calibration procedure. The capacitance technique for determining gap separation avoids any physical contact between the source and electrode, reducing stress to the source surface. Also, it reduces the number of measurements needed to determine the original offset, since previous techniques iterated between several readings at different plate separations. Measurements of the NIST calibrated ophthalmic applicator are ongoing to further test the effectiveness of the windowless, planar extrapolation chamber.

CIRMS Student Travel Grant – sponsored by the Ionizing Radiation Division of IBA

3. Improvement of Radiation Grafting of Selective Ligands onto Polymeric Substrates to Produce High-capacity Adsorbents for Harvesting Uranium from Seawater

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[1] Catholic University of America

There exists 1000 times more uranium in the world's oceans than exists in terrestrial ores, enough to satisfy our current nuclear energy needs for centuries to come, however a method of extracting this uranium efficiently and effectively remains to be found as the low concentration of uranium (3.3 parts per billion on average) and the presence of other solutes at much higher concentrations in seawater presents a unique chemical challenge. It is argued that the most viable method for extraction is through the development of adsorbents composed of fabrics grafted with monomers which can selectively and economically extract this uranium. A number of chemical monomers have been known to exist which can extract uranium ions from aqueous solutions, an example of which includes amidoxime groups which were purported to be the best candidate for use in recovery of uranium from seawater based on studies performed in the 1980's. These amidoxime groups however required post-irradiation chemical treatments and required long exposure times to seawater in order for these fabrics to extract suitable amounts of uranium. This work seeks to improve upon the production and extraction efficiency of the previous work by testing ligands which had not been explored in the studies performed in the 1980's nor have been developed since then. By properly functionalizing these monomers and using radiation to graft them to polymeric substrates, this work seeks to create a new series of fabrics that have high capacity and selectivity for the extraction of uranium from seawater.

Initially, potential monomers and their chemical analogs are chosen and tested based on their previous association with their ability to bind to uranium. These monomers are first tested by adsorbing them in activated carbon and rotating them in spiked water or natural seawater for a defined period of time. Following the adsorption period, the uranium concentration difference between the water sample both before and after the extraction period is determined using different characterization techniques including a spectrophotometric method and the use of both an ICP-MS and ICP-AES. If the candidate monomer shows promise with the activated carbon test, either the original monomer or an analog of the monomer containing additional functional groups suitable for polymerization is grafted to a Nylon-6 or other polymer substrate using radiation ideally in an aqueous medium to limit the amount of chemical waste produced by the production of the fabric. Once the substrate has been successful grafted, the fabric is then used to extract uranium from samples of both spiked water and actual seawater.

So far 18 candidate monomers have been tested from which three monomers have been selected for further study based on their performance, (bis[2-(methacryloxy)ethyl] phosphate (B2MP), diallyl oxalate (DAOx), and 2-(5-bromo-2-pyridylazo)-5-(diethylamino)phenol (Br-PADAP). In the case of B2MP, the main problem has been the limited solubility of B2MP in water, which has made it difficult to graft the monomer in aqueous solution. Several approaches have been tried in order to overcome this difficulty, including addition of a small volume fraction of an alcohol, rapid stirring to maintain the B2MP in suspension, and the use of food-grade surfactants. At 120% grafting density, the highest uranium loading of 10 mg U/g adsorbent was obtained upon testing 15-mg samples of adsorbent fabric with 10 mL of 10 mg/L U in seawater, and when the volume of the solution was raised to 100 mL the observed loading increased to 44 mg/g U. In the case of DAOx, low grafting densities in aqueous media have been the main difficulty. A dramatic increase in grafting densities however (to 100% and above) has been recently achieved through the addition of Mohr's salt [$(NH_4)_2Fe(SO_4)_2$] as a homopolymerization inhibitor. At that grafting density, a uranium loading of 3 mg U/g adsorbent was observed using 14-mg samples of adsorbent fabric with 10 mL of 10 mg/L U in seawater. In the case of Br-PADAP, recently obtained results with this ligand sorbed on activated carbon are indicative of high selectivity and high loading. Thus, a uranium loading of 6 mg U/g adsorbent was observed using 15-mg samples of adsorbent fabric with 10 mL of 10 mg/L U in seawater. When the concentration of uranium was

lowered to 0.2 mg/L and the volume was kept constant at 10 mL, the observed loading fell to 0.1 mg U/g adsorbent, but when the volume of the 0.2-mg/L U solution was increased to 100 mL the observed volume increased to 0.7 mg U/g adsorbent, indicating that the falloff of the observed loading with concentration was largely due to depletion of the test solution with respect to uranium, and that higher loadings can be expected if the volume of the dilute U solution in seawater is further increased. However, the absence of double bonds from Br-PADAP has prevented it from being radiolytically grafted onto a polymeric support. Future efforts with this monomer will focus on synthesizing derivatives of Br-PADAP with suitable functional groups to allow for grafting.

The use of ionizing radiation as an efficient mechanism for generating adsorbent fabrics is directly related to the CIRMS mission of advancing the use of ionizing radiation in industrial and manufacturing processes. Successfully achieving the goal of this project will also serve the continuation of the nuclear industry through creation of a new, more economical, and cleaner way of harvesting uranium which is directly related to my career goal of advancing the peaceful use of nuclear energy. This work is currently being performed in collaboration with Oak Ridge National Laboratory and Dr. Gary Gill at Pacific Northwest National Laboratory who are assisting in the testing of the extraction efficiency of our fabrics in real seawater, as well as with Dr. Lonnie Cumberland, Dr. Fred Bateman, and Dr. Lisa Karam of the National Institute of Standards and Technology who are providing access to the linear accelerator and fixed irradiation sources as well as assisting with the irradiations.

CIRMS Student Travel Grant – sponsored by the Ionizing Radiation Division of NIST

4. A Monte-Carlo Based Spectroscopic Characterization of a 137Cs Irradiator with Attenuating Material

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Medical Radiation Research Center

Objectives: ^{137}Cs irradiators are often used for calibration of health physics and radiation protection instrumentations, including ion chambers, Geiger-Mueller (GM) counters, and scintillators that are used as survey meters. Although ionization chambers have a relatively flat energy dependence, GM and scintillator survey meters show more substantial energy-dependent variations in response. The primary air-kerma rate standard at the National Institute for Standards and Technology (NIST) for the calibration of these irradiators is a variety of spherical graphite ionization chambers with very little energy-dependent effects, but the response of survey meters may be affected by the spectral changes caused by the addition of lead attenuators that are used to modulate the exposure rate. Effects of the changes in energy spectrum on detector response are not currently accounted for. This study uses an experimentally validated irradiator geometry modeled in the MCNP5 (Monte Carlo N-Particle 5, Los Alamos, New Mexico) transport code to characterize the effects of attenuation on the energy spectrum of the primary beam.

Methods: This study utilized a Hopewell Designs (Alpharetta, Georgia) dual-source G-10 model ^{137}Cs irradiator which houses a 416 Ci and a 5 Ci ^{137}Cs sources. The irradiator geometry for the 416 Ci source was modeled in MCNP5 and validated by comparing measured and simulated percent depth dose (PDD) and cross-field profiles. PDDs were measured using an A12 farmer-type ionization chamber and a custom-built water tank with a 1/16-inch acrylic entrance window and chamber positioning software.
PDDs were measured in half-centimeter increments and normalized to a depth of 2.25 cm. The water tank was modeled in MCNP5 and an energy deposition tally was used in cells centered on the detector position. Field profiles were measured using EBT3 film in a custom-made acrylic phantom providing 3.14 cm of buildup and 9.60 cm of backscatter acrylic. A single 120 minute irradiation was performed, giving an estimated dose of 1.10 Gy to film. An optical density profile was used for analysis and was normalized to an optical density value obtained by averaging over the center of the field. The phantom was modeled in MCNP5 and a modified flux tally across a water-equivalent tally cell was performed. The geometry of the model was validated with no attenuators placed in front of the beam path.

The validated irradiator geometry was used to investigate spectral changes due to the addition of lead attenuators in the primary beam path. The Hopewell G-10 irradiator has four attenuators including a 2x, 4x, 10x, and 100x with lead thicknesses of 0.635 cm, 1.22 cm, 2.22 cm, and 4.32 cm, respectively, which

provide attenuation in combinations from 0x to 8000x. MCNP5 was used to tally the spectra in 4 cm x 4 cm x 4 cm cube at a distance of 100 cm from the source with various amounts of attenuation. The average energy and the relative intensity of the 662 keV peak of the simulated spectra were analyzed.

Results: Simulated and measured PDDs and profiles agreed within 1.2%, which was within the uncertainties of both experimental and MCNP5 data sets. An MCNP5 simulated spectral tally showed that the average energy and corresponding uncertainty for 0x, 2x, 4x, 10x, and 100x attenuation was 582 keV (0.11%), 626 keV (0.18%), 637 keV (0.26%), 646 keV (0.49%), and 652 keV (1.69%)**,** respectively. The intensity of the 662 keV peak, normalized to the intensity of the 662 keV peak from the no attenuation simulation was 47.2%, 25.3%, 7.3%, and 0.6% for 2x, 4x, 10x, and 100x attenuation, respectively.

Conclusions: This study successfully used MCNP5 and a validated ^{137}Cs irradiator geometry to characterize the effects of increasing attenuation on the energy spectrum through analysis of average energy and 662 keV peak intensity. The aim of future work will be to determine the impacts of these spectral deviations on the response of ionization chambers and various types of survey meters.

Students' Poster Abstracts

5. Development of a Novel Method to Measure Perfluorinated Compounds in Paper and Textiles

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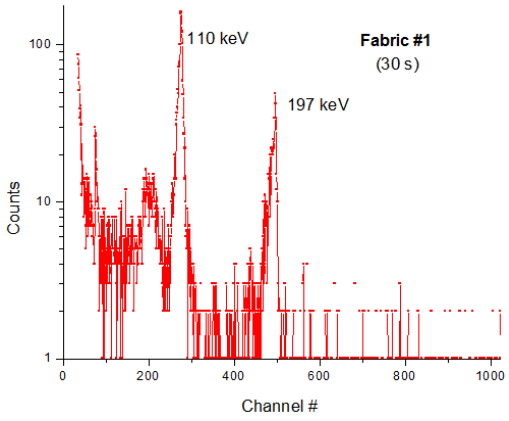

Figure 1: A typical PIGE spectrum of a PFC-treated fabric. Two ^{19}F peaks are identified.

Particle Induced Gamma-ray Emission (PIGE) spectroscopy is an established ion beam analysis technique for the determination of total fluorine concentrations in the surfaces of various solids, typically sediments and minerals. PIGE utilizes a beam of accelerated protons to excite ^{19}F nuclei on the surface of a sample. As these nuclei de-excite, they emit characteristic gamma-rays that can be used to identify, and to quantify, the total fluorine content. The purpose of this study is to develop a PIGE methodology for rapidly and non-destructively measuring the application of per- and polyfluorinated compounds (PFCs) to commercial paper and textile products.

PFCs are a broad class of man-made compounds containing mostly carbon-carbon and carbon-fluorine bonds. These compounds are widely used industrially as surfactants and coatings that provide water and stain resistance to surfaces. However, current methods available to measure these compounds, such as liquid chromatography-tandem mass spectrometry (LC-MS/MS), are costly and time-consuming. PIGE offers a non-destructive and rapid measurement technique that can be used to test the distribution of these compounds across a surface. This technique would introduce a novel capability for the monitoring of

industrial application of PFCs to consumer products. An example of PIGE analysis on a commercial clothing fabric is shown in Figure 1.

In this study, samples were irradiated with ~10 nA beam of 3.4 MeV protons at the Hope College Ion Beam Analysis Laboratory. A typical fun time was ~3 minutes. The samples were run in air rather than *in vacuo*, by extracting the ion beam through a thin Kapton® window. A total of fifteen papers and nine textile samples were tested for this study, although the sample throughput of in-air PIGE analyses could easily exceed 20 samples per hour. Pieces of each paper and fabric samples were obtained from commercially available consumer products, and were mounted within 2 mm of the exit foil of the beamline. Two solid-state detectors, both a cadmium telluride and a high-purity germanium detector, were used for the gamma-ray analyses. The 110 keV and 197 keV gamma rays from each irradiation were integrated, background substracted, and summed to provide a quantity of counts per microCoulomb of beam delivered. This measurable signal can be converted to an absolute concentration in the surface of the sample by the use of external standards.

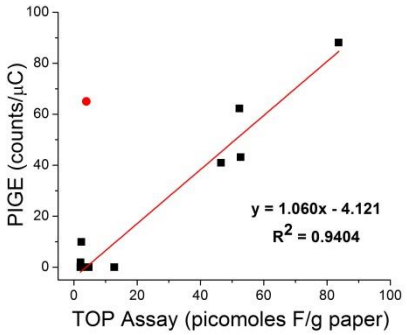

Figure 2: Comparison of PIGE results with the TOP assay on a

The results found with PIGE were compared with results obtained by LC-MS/MS analysis and a total oxidizable precursor (TOP) assay developed at Oregon State University. A comparison of the results, shown in Figure 2, reveals that PIGE is an effective tool to determine the presence or absence of PFCs applied to these consumer products. In order to develop a repeatable technique for taking measurements using PIGE, absolute concentrations determined by external reference standards, precise estimated of the limits of detection, and the volatilization rate of the PFCs from the surface were also explored. Current tests are being performed to develop a method to quantify these results.

Because of the industrial benefits of being able to not only test for the presence or absence of PFCs, but also to provide a quantitative measure of the uniformity of PFC application, we believe that members of CIRMS will be interested in this novel measurement technique. For me, participation in this research has been very rewarding. I am an undergraduate physics major and I plan to attend graduate school. Because of this project, I have developed an interest in nuclear and ion beam physics and hope to attend graduate school in one of those areas. I intend to use this conference participation opportunity to learn more about the graduate research opportunities and post-graduate job opportunities in the field.

This work is supported by funding from the National Science Foundation (NSF-RUI 1306074), the Department of Energy (DE-SC0007352), and the Hope College Department of Physics Guess Research Fund.

6. The Need for Standardization of Dosimetry in Experimental Radiation Biology

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University of Wisconsin - Madison

Significant interest in standardized dosimetry for radiobiological irradiators has developed over the last decade, tied to establishing dosimetry reporting criteria in the field of radiation biology. This interest arose due to concerns that dosimetry in the field of radiobiology was not being properly addressed. At a recent symposium held at NIST, “The importance of standardization of dosimetry in radiobiology,” a set of 12 criteria necessary for adequate reporting of irradiation methodologies was developed by the authors of the conference proceedings.

Based on those criteria, a review of the dosimetry methodology in various peer-reviewed publications revealed that none of the surveyed publications satisfied all 12 criteria. The inadequate reporting of dosimetry methods in the literature raises concerns about the accuracy of the dose delivered to animal test subjects and the resulting experimental results. That concern motivates an investigation into the accuracy of dose delivery in radiation biology studies.

The University of Wisconsin Medical Radiation Research Center (UWMRRC) performed an irradiator output verification study of 12 radiation biology laboratories using polymethyl methacrylate (PMMA) mouse phantoms and thermoluminescent dosimeters (TLDs). The laboratories housing each of these irradiators were asked to deliver specific doses to individual mouse phantoms. Simultaneously, mouse phantoms at the UWMRRC were irradiated with NIST-traceable reference beams representative of the subject laboratories’ beam energies. An air kerma to absorbed dose to water conversion factor was determined for each of the beam energies used through Monte Carlo simulation. By using the known air-kerma rate of the reference beams and the conversion factor, the required irradiation time to deliver the target dose was determined. The irradiated mouse phantoms were returned from the various laboratories to the UWMRRC and the TLDs were processed, comparing their measured output to the calibration phantom TLDs.

Of the seven facilities using radionuclide irradiators, four delivered an output within 5% of the target dose. The dose discrepancies for the other three irradiators ranged from 8.7% to 13.5%. Of the five facilities using x-ray irradiators, only one delivered an output within 5% of the target dose. The dose discrepancies for the other four irradiators ranged from 16% to 42%. These results demonstrate the need for standardization of dose determination and additional oversight of radiobiology investigations.

The mouse-phantom spot-checks were funded in part by the National Institute for Allergy and Infectious Diseases.

7. Development of a Small Energy Electron Accelerator for Surface Treatments and Coatings

Nuttapong Phantkankum

Kent State University

Treatment with ionizing radiation can modify the physical, chemical or biological properties of materials. By using this method one can obtain many beneficial effects such as the reduction of contaminants in surface treatment and the development of new coating materials. Electron Beam Accelerators are durable and reliable equipment for these applications.

This project focuses on designing and building an electron accelerator using a 125 keV electron gun, high voltage cables, and a power supply obtained through a donation to KSU. The emitter connects to a high voltage power supply via a high voltage power cable. The emitter is a hermetically sealed vacuum unit that produces an electron beam, and a heated tungsten filament in the emitter releases electrons. Then a high

voltage accelerates the electrons making an electron beam aimed at a window in the emitter enclosure. After that, the electrons pass from the inside of the emitter, through a thin foil, then into the air, and to a sample.

The work described here consisted of the mechanical and radiation physics design for the overall unit including the beam exposure volume, the platform mechanism to move samples in and out of the beam exposure volume, the radiation shielding, and the safety devices.

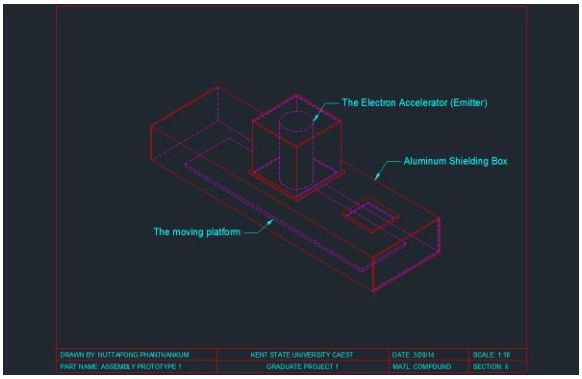

Figure 1 the unit prototype.

The accelerator enclosure is a 1.27 cm thick, 80 cm wide, and 260 cm long aluminum box as shown in figure 1. The platform mechanism consists of an aluminum sample plate on top of a platform; the sample plate is moved by a screw connected to a stepper motor, and the platform is 63.5 cm wide, 185.4 cm long, and it rests on four adjustable legs rising from 12.7 to 25.4 cm from the floor. The speed of the platform can be continuously changed from 0 to 25.4 cm/s.

Safety considerations include four doors, one used for the sample compartment and the others to get access and service different parts of the unit, all with limit switches to shut off the operation of the accelerator when any one of the doors is opened. Radiation detectors will shut down the system when radiation exposure is exceeding the maximum thresholds. The heat generated by the electrons going through the window foil will be removed by a cooling system. The temperature of the window foil as well as of the sample platform will also be measured as part of the safety considerations of the whole unit.

PENELOPE Monte Carlo Code simulations were performed to determine the appropriate material for the accelerator enclosure, the amount of shielding material, and the dose received by a sample under different operation conditions of the unit.

Figure 2a shows the geometry used to obtain the dose received by a dosimeter when it moves through the electron beam exposure area with a speed v_y. The dosimeter has “width” a, “length” b, and “thickness” d, and moving with constant velocity v_y along the direction of the y axis. To calculate the dose to the dosimeter, we have simulated an ideal experiment with a static electron beam, with the line source at the positive z axis, and an ideal planar dosimeter with its thickness d equal to the actual dosimeter. By using PENELOPE we obtained the energy collected by a detector 1 having the same length as the one of the dosimeter, but its width equal to the width of the electron beam footprint at its center. Then we calculated the dose by assuming that the dosimeter collected all this energy measured by this detector when it moved from the left side to the right side of the electron beam footprint, as shown in figure 2b.

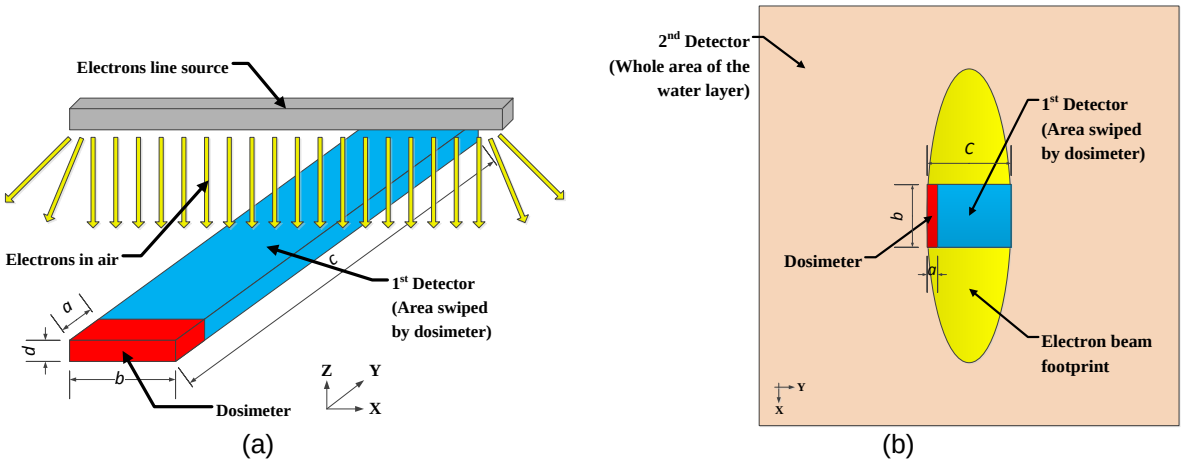

Figure2. a) Schematic diagram of the geometry used to simulate the irradiation of a dosimeter, with the beam at its central position. b) Diagram showing the dosimeter and the area covered when it moves relative to the static beam, with the velocity v_y.

The results of all the simulations show that:

- The 0.25-inch aluminum can absorb all electron penetration,
- At the edge of the emitter enclosure there is no dose, so designing of the unit prototype is safe.
- If we use an air gap of about 5 cm, a beam current of 12.6 mA, and a sample speed of 0.51 m/s, we obtained a dose at the detector of 2.75 kGy in good agreement with the manufacturer data sheet.

The unit will be built under the design and simulation conditions to get safely appropriate doses. The all unit enclosure will be built by using aluminum. The electron-emitter support will be built by using stainless steel inside the enclosure to ensure that it can support the 16 kilograms weight of the emitter. A controller will be provided to control the platform that can move the sample to the beam exposure area, its speed, and also controls the power supply to get an appropriate high voltage and beam current from the electron emitter. A diagram of the design will be presented as well as initial dose measurements of radiation once the unit construction is finished.

Other Submitted Abstracts

8. Practical Implications of Dose and Dose-rate Effects

Anthony J. Berejka

Ionicorp+

With the initiation of commercial X-ray processing at Sterigenics in New Jersey since 2002 to decontaminate mail for the US Postal Service and at Synergy Health in Daniken, Switzerland to sterilize medical devices since 2014, the consequences of dose and dose-rate effects have significant practical implications. The one order of magnitude higher dose-rate for electrically generated X-rays versus radioactive sourced cobalt-60 gamma rays not only results in greater production through-put, but in medical device sterilization means significantly less deleterious effects on plastics.

X-rays have significantly lower dose-rates than electron beams (EB) from commercial, high current accelerators. This has resulted in the auto-catalytic polymerization of a monomer used as an impregnant in a thick (16cm) piece of wood. Studies involving the use of low-energy EB units have shown dose-rate effects on the polymerization-crosslinking of monomers and oligomers used in EB curable adhesives and coatings.

The much greater depth of X-ray penetration than EB has resulted in X-rays being used in product development to cure composite materials at ambient temperatures. X-ray penetration enables formed products to be cured while they are still being constrained in a mold.

Another area that requires more current research is the effect of dose-rate on cell death, whether from gamma sources, EB or X-rays. Ionizing radiation is used not only for medical device sterilization, but now in the emerging market for low-energy EB of the decontamination of surfaces of materials used for food and medicinal packaging.

Radiobiology has long held that a continuous dose will lead to cell death at lower dose exposure than incremental dosing. With the development of radio-fluorescing biological materials, direct indicators of cell death could be used in lieu of dosimetry. Commercially relevant studies have not been done in this area. In terms of bio-burden kill, one would suspect that products and materials are being greatly over exposed or over dosed. Studies at the cellular level could confirm or challenge this opinion.

9. Evaluation of a Lung Density CT Standard Reference Material

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[1]NIST, [2]Accumetra, [3]Mt. Sinai Hospital

We have developed a 5-density (0.06 g/cc to 0.23 g/cc) suite of polyurethane foams as a CT lung density reference (SRM-2088)) with SI traceable physical densities, and have evaluated it in a clinical measurement setting free from physiological noise. The SRM was measured inside an anthropomorphic chest phantom in a clinical 64-row scanner, to assess the mean HU value and its distribution. Two tube current settings (200 mA and 50 mA) were used to represent high- and low-dose CT clinically, with back-to-back repeat scans, and for each scan the image reconstruction was performed at slice thicknesses of 0.625 mm and 1.25 mm. A volume histogram was generated for the entire suite, and was fitted to a function with 5 Gaussian peaks, each reporting a centroid (mean HU) and standard deviation (SD in HU) as a measure of the accuracy and precision of the measurement. Statistical analysis was performed using the two levels of mA and recon slice thickness as factors to study the effect on the centroid and the SD. The analysis showed that neither dose nor thickness has significant effect on the centroid, but both have significant effect on the SD. At 200 mA, the observed average SD is about half of that at 50 mA. With the thickness doubled, the SD decreased by a factor of 1.17, providing a parameter relating spatial resolution and noise. The SD is more than 3 times

higher when compared to the SRM in-air measurement (without the attenuation and scattering from the chest wall) performed earlier, whereas for the centroid excellent agreement was observed. The study provides the underlying uncertainty assessment for these standard references in the lung density range in a set of scanning conditions, forming the basis for estimating the sensitivity to changes in lung density in a clinical setting.

10. CDC's Analytical Methods to Rapidly Respond to a Radiological or Nuclear Incident: Overview, Recent Improvements and Future Directions

Robert L. Jones and David Saunders

Centers for Disease Control and Prevention (CDC), National Center for Environmental Health, Division of Laboratory Sciences, Inorganic and Radiation Analytical Toxicology Branch

In its Public Health role, and for response to a radiological emergency, CDC has been developing urine radionuclide screening and quantitative analytical methods to assess potential internal radiological contamination in people. There are twenty-two priority radionuclides considered primary threat agents that might be used in a radiological incident (e.g. detonation of a dirty bomb or radiological dispersal device (RDD)). Rapid radioisotope identification and quantification for these priority radionuclides is a critical need in determining who has been contaminated and the degree of exposure, thus providing critical information for medical management, treatment and follow-up. CDC has reported extensively on methods, instrumentation and procedures toward this end, but we continually strive to improve these processes so we can provide higher quality data more quickly for critical medical decisions. Here we report our overall analytical methods, recent improvements and future method development plans.

Efforts to enhance our capabilities and capacities include improving existing methods, largely through automation as well as method refinements. HPGe gamma spectrometry capability has been extended to a total of six detectors, all of which are now automated. This automation includes sample changers with computer automated batch analysis routines to automatically load samples, acquire and analyze data, produce reports and export data files for input to our LIMS. We have developed/implemented method improvements, specifically for Sr-90, 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 beginning the process of implementing the second level of automation of our rapid Gross Gamma screening method. All of our analytical methods are or will be CLIA compliant (a clinical laboratory requirement). We intend to continue method development and improvements in the future, eventually extending our capabilities to analyze for all 22 priority radionuclides.

11. Small Field Dosimetry in Radiotherapy from a Standpoint of Basic Research

Guerda Massillon-JL

Instituto de Fisica, Universidad Nacional Autonoma de Mexico

The electrons generated by photons during their interaction with the matter produce significant ionization through electron-electron Coulomb interactions along their track. The absorbed dose deposited along these tracks is defined as the product of the electron fluence generated and the linear energy transfer, LET, or the restricted mass stopping power averaged over the electron energy spectrum. However, from a standpoint of basic research, in high-ionization density radiation fields, i.e. high LET, where very low-energy electron fluences exist, the physical processes of radiation interaction with matter are not well understood. This is due to the complexities of the interaction process of the electrons with energy below 1 keV caused by quantum and optical phenomena at the atomic level. Besides that, there exists a lack of information about electron cross sections at energy in the sub-keV range and consequently, the determination of the absorbed dose in these radiation fields is challenging. The physical concept of small radiation fields in radiation therapy is strongly correlated to the high-ionization density problem caused by the variation of the electron fluence in the lateral direction and the short range of the electrons generated in the field. Thus, a precise knowledge of

the dosimetric characteristics of the dosimeter used in small radiotherapy field is of great interest. In this talk, I will present a brief description of our research project related to reference dosimetry in small radiotherapy fields and some results obtained in the last few years. Work partially supported by PAPIIT-UNAM grant IN105813, and Conacyt grant 127409.

12. Identification of Irradiated Spices by Electron Paramagnetic Resonance Spectroscopy

Kim M. Morehouse[a] and Marc F. Desrosiers[b]

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The Food Safety Modernization Act requires food facilities conduct hazard assessments and if a hazard is reasonably likely to occur they must put in place preventive measures to control the hazard. Pathogens are reasonably likely to occur in some spices and manufactures may choose to irradiate their products to control this hazard. Currently, there are no reliable methods to determine if a product has been irradiated for verification of compliance with the Act. The use of Electron Paramagnetic Resonance (EPR) to detect irradiated spices was demonstrated in the early 1990's (EN 1787:2001 Detection of irradiated food containing cellulose by ESR spectroscopy). However, the stability of the radiation-induced radical and its spectral characteristics varied across the broad selection of spices and was considered a limitation to the use of this technique. We have recently reexamined this technique to determine EPR could be used to ensure that products that have been labeled as irradiated have indeed been irradiated. This paper will present data on the EPR spectra for over 30 spices. We have investigated the resultant spectra, including its stability with time. Most of the irradiated spices analyzed display an EPR Spectrum that is assigned to a relatively cellulosic radical. Several spices demonstrated a more complex radical spectrum, such as garlic powder and onion powder, which appears to originate from other components. The stable radical found in garlic or onion powder, the radical is stable for over 6 months. For black pepper, the spectrum is multi-component with complexities at early times (day one vs day seven). For most of the spices that were analyzed it was easy to differentiate the irradiated spice from the non-irradiated spice up to 90 days post irradiation treatment.

13. Development of Dosimeter Technology for First Responder Applications

Tom Partington

Technical and Operations Manager, Tracerco Limited (Johnson Matthey Inc.)

The development of a new personal dosimeter for first responder applications is presented. The dosimeter incorporates several new innovations including a novel handheld mode.

Dosimeters conventionally record personal dose (Hp(10)) and should be calibrated on an ISO standard water phantom to simulate the users body. Once the dosimeter is removed from the body an error is introduced and measurement accuracy is compromised. Occasionally, in times of urgency and in the absence of more appropriate equipment, dosimeters have been used in the hand. For first responders a handheld device may be required for source location searches, checking around corners or simply for more convenient area surveys. Similar errors are induced in personal radiation detectors that are calibrated as handheld instruments then worn on the user's belt. This paper presents on/off body data for a range of common dosimeters and personal radiation detectors and discusses the importance of calibration method on measurement accuracy.

New developments in information communications and the benefits for first responders are discussed. Modern display technology means that “pop up” messages that relate to procedures can be associated with alarms to help the user to respond correctly to a radiation incident. Wireless connectivity to mobile devices presents new opportunities for response team monitoring. On-board GPS is now well proven standard technology and can be used to give genuine benefits to response planning.

14. PNNL-NIST Pilot Interlaboratory Comparison of ^{252}Cf Neutron Reference Fields

Roman Kim Piper[1] and AK Thompson[2]

[1] Pacific Northwest National Laboratory, Richland, WA
[2] National Institute of Standards and Technology, Gaithersburg, MD

Measurement Program Description (MPD) C.3.4 of the 5th Council on Ionizing Radiation Measurements and Standards (CIRMS) Report on Needs in Ionizing Radiation seeks to develop and promulgate protocols for the use of thermoluminescent dosimeters (TLD) as interlaboratory comparison standards for neutron calibrations. Two studies were conducted to compare the results of passive personnel radiation dosimetry response from irradiations using D2O-moderated and unmoderated californium-252 (Cf-252) sources used at the Pacific Northwest National Laboratory (PNNL) and the National Institute of Standards and Technology (NIST). It was anticipated that respective lithium fluoride (enriched in lithium-6) albedo dosimeter response per delivered neutron personal dose equivalent, *Hp(10),* would be different between PNNL and NIST due to the differences of the respective source encapsulation and moderating sphere configurations. This was demonstrated by the initial measurement phase of the D2O-moderated Cf-252 source measurements. To validate this outcome and further analyze the proportional components involved, Monte Carlo simulation of the test configuration was performed. The outcome of the simulation was in good agreement with the empirical data and revealed that differences were due, in part, to the respective average personal dose equivalent per source neutron as a result of source configuration differences. These differences also result in facility-specific energy deposition in the dosimeter sensitive element per source neutron. These two conditions are additive for the detection method and geometry specifications of this particular comparison. Evaluation of the unmoderated Cf-252 reference fields resulted in empirical differences that were not replicated by Monte Carlo simulations, indicating potential problems in the initial test approach or simulation design. This poster provides details and results of these two studies to date.

15. Photon Beam and Electron Beam Dosimetry using Calorimetry at ARPANSA

Ganesan Ramanathan, PD Harty, DJ Butler, T. Wright, J. Lye, C. Oliver, DW Webb

Australian Radiation Protection and Nuclear Safety Agency,
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The Australian absorbed-dose-to-water primary standard is a graphite calorimeter based on Domen design procured from the Austrian Research Centres (ARCS, Seibersdorf) in 1991. It was established as the primary standard for ^{60}Co gamma rays in 1997[1].
In 2009 ARPANSA installed an Elekta Synergy Linear Accelerator (linac) and in 2010 the ^{60}Co source was replaced with an Eldorado 78 treatment head containing a new ^{60}Co source. In June 2014, an ARPANSA Technical report [2] was published giving details of the calorimeter geometry, modes of operation, analysis, conversion from absorbed-dose-to-graphite to absorbed-dose-to-water, and the calibration of secondary standard chambers. The report also describes the establishment of the calorimeter on the new ^{60}Co source and the linac beams.
ARPANSA undertook international comparisons of absorbed dose at ^{60}Co in 2010 [3] and linac beams in 2012 [4]. Ratios of the ARPANSA measured dose to water to that measured by the Bureau International des Poids et Mesures (BIPM) were 0.9973 at ^{60}Co, 0.9965 at 6 MV, 0.9924 at 10 MV and 0.9932 at 18 MV, with

a combined standard uncertainty of 5.3 parts in 10^3, 5.5 parts in 10^3, 6.0 parts in 10^3 and 5.9 parts in 10^3 respectively. This talk gives additional information describing the ARPANSA calorimeter and method of realising the absorbed dose for these comparisons.
For electron beam calorimetry, ARPANSA has two options. One is to use the photon calorimeter with provision to add build-up plates required to position the centre of the core at the desired reference depths. This calorimeter with vacuum gaps between the core, jacket and shield is suited for measurements at lower dose-rates. But, the fixed depth existing between the entrance Mylar window to the centre of the core limits its use in the measurement of lower energy (<10 MeV) beams. The other option is to use another graphite calorimeter (procured from the National Physical Laboratory, UK) which does not have a vacuum gaps between the core and the surround, but requires higher dose-rates for measurement. This talk includes the basic methodology of calorimetry, results of graphite absorbed dose measured at 10 MeV and 15 MeV, and preliminary comparison of absorbed dose to water for a Roos chamber based on the calorimeter with calibrations done at NPL on the same chamber.
The absolute dose rate of the Imaging and Medical Beamline (IMBL) on the Australian Synchrotron was measured with a similar graphite calorimeter [5]. The calorimetry results were compared to measurements from the existing free-air chamber, to provide a robust determination of the absolute dose in the synchrotron beam and to provide confidence in the first implementation of a graphite calorimeter on a synchrotron medical beam line. A brief outline of this measurement and the results are also presented.

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16. Use of PENELOPE Monte Carlo Code to Design a 125 Kev Electron Accelerator Irradiator and Determine its Shielding Requirements

Nuttapong Phantkankum and **Roberto M. Uribe**

Kent State University

The Monte Carlo code PENELOPE has been used in order to calculate the shielding requirements and the dose delivered to a dosimeter, for a low energy electron accelerator that is being assembled at KSU using parts from a donated Advanced Electron Beam 125 keV electron accelerator.

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