2018 Symposium on Radiation Measurements and Applications (SORMA XVII)

June 11th - 14th, 2018

University of Michigan
Ann Arbor, Michigan, USA

Abstract Book

Sponsored By

Department of Energy - National Nuclear Security Administration
Consortium for Verification Technology

Monday June 11th	**5:00-8:00 PM - Conference Registration - Michigan League 2nd Floor Concourse** **6:00-8:00 PM - Opening Reception - Michigan League Vandenberg, Hussey, and Garden**		
	Rackham Auditorium Lydia Mendelssohn Theatre	Hussey	Ballroom
Tuesday June 12th	**7:30-5:00 PM - Conference Registration - Michigan League 2nd Floor Concourse**		
8:30-8:45 am	Welcome!		
8:45-9:45 am	Plenary I - Dark Matter Search and Liquid Xenon Detector Development		
9:45-10:45 am	Plenary II - Modernizing the IAEA verification instrumentation		
10:45-11:00 am	Coffee Break		
11:00-12:00 pm	Plenary III - FRIB: The Path to Scientific Discovery		
12:00-1:30 pm	Lunch Break		
1:30-3:00 pm	Scintillation Detectors I	Particle/Photon Cancer Therapy, and Other Medical Imaging Applications	
3:00-4:00 pm			Poster I - New Radiation Detectors
4:00-5:30 pm	Semiconductor Detectors I	Neutron Facility, Characterization, Detectors and Generators	
6:00-9:00 pm	Conference Reception at the University of Michigan Museum of Art		
Wednesday June 13th	**7:30-5:00 PM - Conference Registration - Michigan League 2nd Floor Concourse**		
8:00-9:30 am	Neutron Detectors II	PET, SPECT and Other Medical Imaging Techniques	
9:30-10:30 am			Poster II - Radiation Measurement Techniques
10:30-12:00 pm	Room-Temperature Semiconductor Detectors	Algorithms and Modelling	
12:00-1:30 pm	Lunch Break		
1:30-3:00 pm	Inorganic Scintillation Detectors	Gamma-Ray Imaging Systems	
3:00-4:00 pm			Poster III - Medical and Environmental Applications
4:00-5:30 pm	Nonproliferation, Safeguards, and Homeland Security	Detector Electronics and Signal Processing	
6:00-9:00 pm	Conference Dinner at the Henry Ford Museum of American Innovation		
Thursday June 14th	**7:30-5:00 PM - Conference Registration - Michigan League 2nd Floor Concourse**		
8:00-9:30 am	Nonproliferation, National and Homeland Security Applications	Unconventional Radiation Detectors and Techniques	
9:30-10:30 am			Poster IV - Physics, Security Applications, and Signal Processing
10:30-12:00 pm	Space and Nuclear Physics Applications	Scintillation Detectors III	
12:00-1:30 pm	Lunch Break		
1:30-3:00 pm	Liquid Detectors for Neutrino Detection and Gas Detectors for Nuclear Physics	Radiation Detection using Mobile/UAVs	
3:00-3:30 pm	Coffee Break		
3:30-5:00 pm	Plastic Scintillators (DNDO projects)	Active Interrogation Techniques	

Greetings from the Chairman

Welcome to the 17th Symposium on Radiation Measurements and Applications (SORMA XVII). While SORMA had traditionally been held every four years, it has been only two years since the previous Symposium was held at the University of California. This increased frequency has largely been due to the step change in the world following the attacks on the U.S. World Trade Center, and the emergence of new international threats demanding our community's attention. Radiation detection and measurement science has always been an active field because of the large number of applications that depend upon our measurements, but the new emphasis on security has added demands on our technologies that were unimaginable more than a decade ago.

The program that you are about to experience is the culmination of dedicated work of a few hardy volunteers. The Organizing Committee has been passionate about ensuring this forum remains open and accessible to all practitioners who are dedicated to our craft. Please join us in gratefully acknowledging the generosity of our Symposium Sponsors who understand the importance of our science and the value of this Symposium. Our exhibitors also would like to invite you to peruse their newest technologies and measurement tools. We have expanded into new spaces to accommodate all of the exhibitors who wished to attend SORMA. We tried to keep the cozy atmosphere while still placing the priority on the scientific program.

The technical program before you is scientifically strong and shows remarkable innovations in critical technology areas, including semiconductors, scintillators, gas-filled detectors, ultra-high resolution devices, electronics, and the concepts that exploit them. The Program Committee has carefully selected these technical papers, split approximately evenly between poster and oral presentations, which span the rich spectrum of our field. The presentation format, oral or poster, was determined solely on the most impactful format to showcase the results. SORMA has always favored poster sessions as the predominant presentation method because of the longer exposure time, personal interaction, and warm hospitality. The presentation format is uncorrelated with assessed relevance, importance, novelty, maturity, or quality. If you want to receive the full benefit from this conference, we encourage you to fully immerse yourself in the poster sessions.

For your social program, we have chosen activities that will follow the successful programs of the past symposia. Please join us as we stroll to the reception Tuesday night at the University of Michigan Museum of Art. Once there, you will be treated with delectable hors d'oeuvres while being guided through the museum's fine exhibits. Our traditional dinner will return Wednesday night to the famous Henry Ford Museum in Dearborn. We have asked that the gift shop remain open for those wishing to bring souvenirs home. On Thursday night, for those of you staying overnight for the MCNPX-Polimi workshop, there are many other sites worth seeing: watching the Detroit Tigers play a professional baseball game under the stars (the Twins are in town this week), taking in wild night life in Windsor, Canada, or even a scenic canoe trip down our local Huron River. We hope you will take full advantage of Michigan hospitality while you are with us.

In closing, we welcome you to this wonderful opportunity to interact with superb colleagues and dear friends. Our community is linked by common interests and pursuits, and you will undoubtedly find the technical presentations by your colleagues to be stimulating and rewarding.

Welcome!

David.

Contents

1 Exhibitors

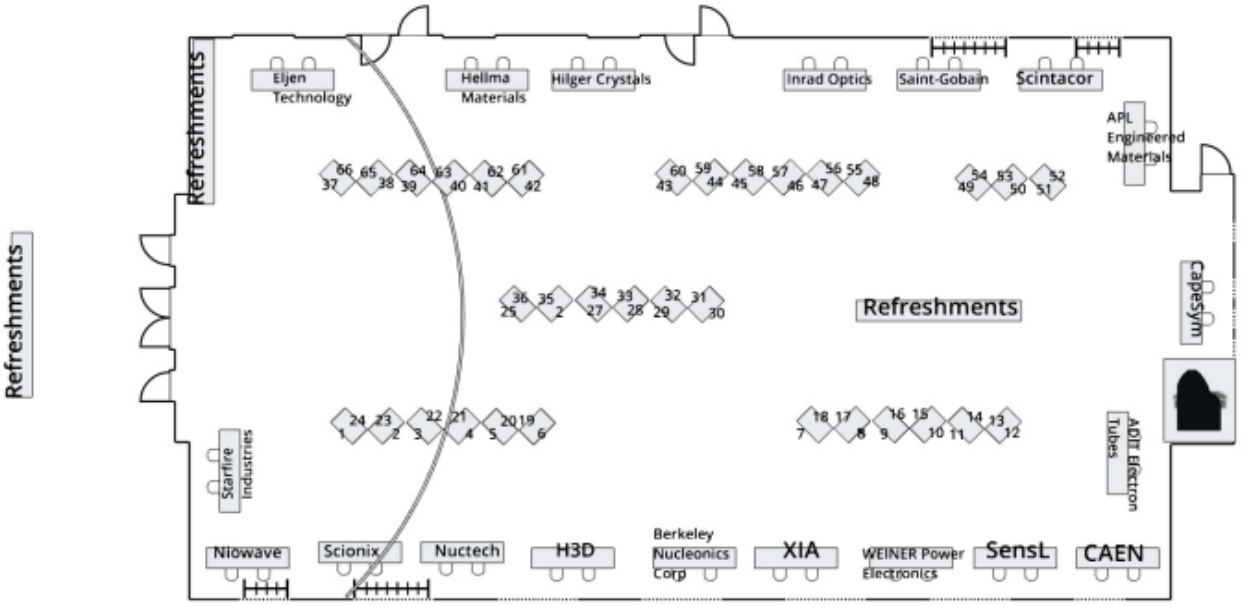
In League Ballroom

ADIT Electron Tubes
APL Engineered Materials
Brekeley Nucleonics Corp
CAEN
CapeSym
Eljen Technology
H3D
Hellma Materials
Hilger Crystals
Inrad Optics
Niowave
Nuctech
Saint-Gobain
Scintacor
Scionix
SensL
Startfire Industries
WIENER Power Electronics
XIA

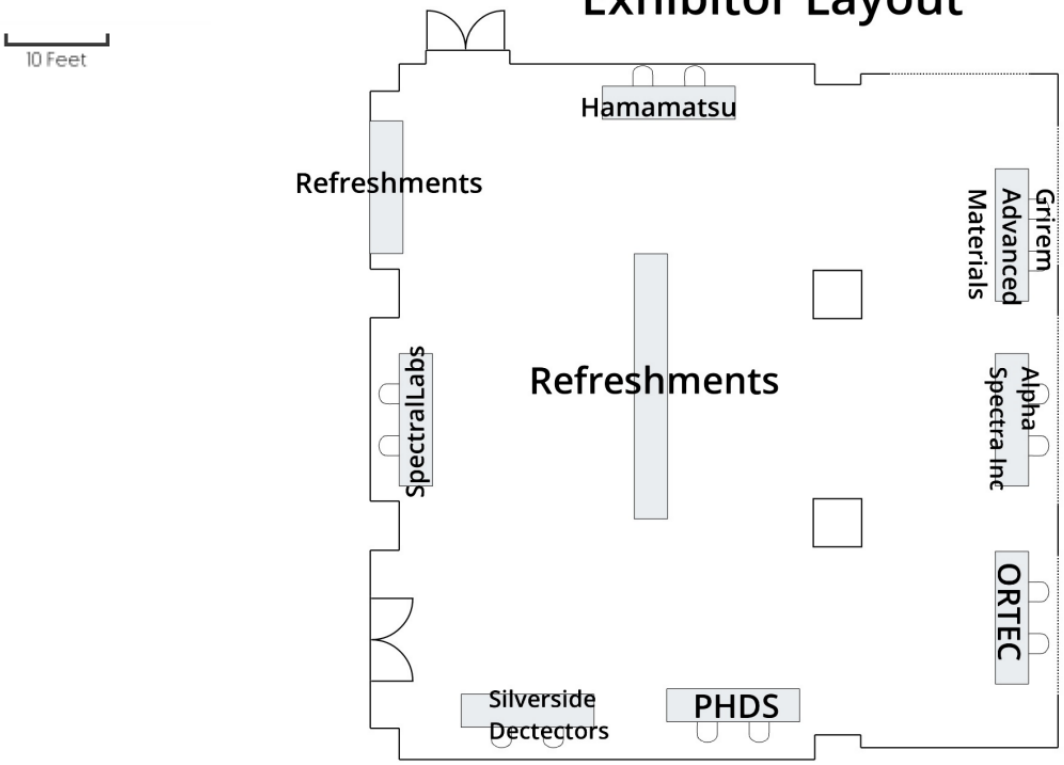
In Michigan Room

Alpha Spectra Inc
Grirem Advanced Materials
Hamamatsu
ORTEC
PHDS
Silverside Detectors
SpectralLabs

SORMA 2018
Exhibitor and Posterboard Layout



SORMA 2018
Exhibitor Layout



2 Social Programs

Monday 6:00 pm - 8:00 pm **Opening Reception - Michigan League**

The Opening Reception will be held at the Michigan League in the Vandenberg and Hussey rooms on the second floor next to the registration table. Buses will pick up attendees staying in off-campus hotels. The League is just a short walk from the Graduate, Bell Tower Hotel, and Residence Inn.

Light refreshments and appetizers will be served. Socializing with new and old friends will be the order of the day. Those interest will also be able to pick up their registration information at the registration table. Buses will return participants to the off-campus hotels after the event until 8:30 pm.

Tuesday 6:00 pm - 8:00 pm **Conference Reception - University of Michigan Museum of Art**

The conference reception will be held at the University of Michigan Museum of Art, which is two blocks away form the Michigan League. A strolling dinner, refreshments, and dessert will be served. Come and plan on spending the full time eating, drinking, and looking at world class art. It should be a fun event. The buses will be available until 9:20 pm for transportation back to the off-campus hotels.

Wednesday 6:30 pm - 9:00 pm **Conference Dinner - Henry Ford Museum of American Innovation**

The conference dinner will be held at the Henry Ford Museum of American Innovation in Dearborn, Michigan. A strolling dinner refreshments, and dessert will be served. Come and plan on spending the full time eating, drinking, and enjoying world class exhibits of American history, industry, and more. Bus transportation will be provided, and will begin departing from the Michigan League immediately after the last session. Buses will return to Ann Arbor with spots at the off-campus hotels and the Michigan League starting at 9:00 pm until 10:15 pm. There will be plenty of free parking for guests who wish to drive themselves.

3 Instructions for Presenters

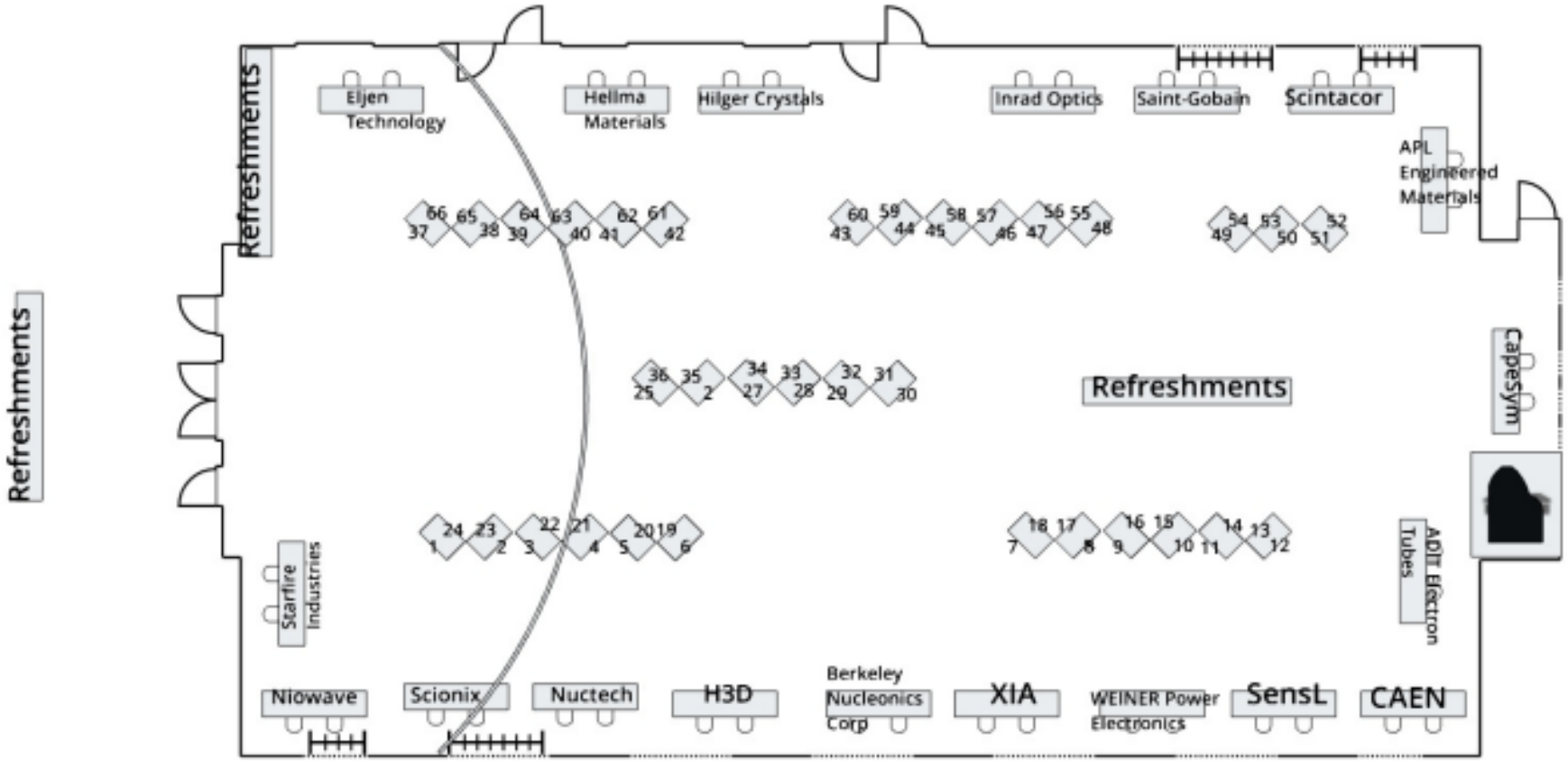
Oral Presentations

- If selected for an oral presentation, your presentation slot will be 15 minutes in length, which includes **presentation and discussion**. Please plan on preparing a **12 minute oral presentation** which leaves time for a **3 minute discussion period**.
- Invited speakers will be given a **20 minute slot for both presentation and discussion** with the presentation length left to the discretion of the speaker (e.g. 16 minute oral presentation and 4 minutes for discussion).
- **Presentation order** within sessions will be specified on the My Papers page and also listed in the program. Please note that presentation order may be changed any time prior to the start of the symposium.
- All technical material must be presented via a University of Michigan laptop. All presentation laptops will be running Windows 10; there will be no Macs available for presentation or testing. All laptops will have Adobe Acrobat Reader XI, Microsoft Office 2016, and Google Chrome. The Kalamazoo Room must be used to test the presentations on an identical laptop **and** to upload the presentation onto the presentation laptop. Please create your presentation keeping in mind the software we are using.
- Lydia Mendelssohn and Rackham (plenary speakers) both have standard 3 x 4 format for their screens. The screen in the Hussey room is widescreen.
- All files should be loaded onto the presentation machine at least one session before your presentation session. The Kalamazoo Room will be setup for this purpose.
- **Backup your presentation** on several forms of media. You may wish to use a USB drive, upload to the cloud, or email yourself the presentation for online access.
- Presenting from personal machines or transparency / overhead projectors will **not** be available.

Poster Presentations

- There will be 4 poster sessions which highlight a group of papers. Authors are **required to be present** near their posters for discussion with symposium attendees during the prescribed times.
- All poster abstracts will be listed in the abstract book. Poster board locations will be identified by your **assigned poster index** and your previously assigned **paper number** (found at My Papers). Please note that poster indexes may be changed any time prior to the start of the symposium.
- All poster boards will be located in the Ballroom of the Michigan League. All Posters **must be put up before the individual poster session** starts, and **must be removed after each poster session**. Please ensure that you post and remove your poster according to the poster session schedule.
  - Posters for Session I can be put up in the **morning of Tuesday, June 12**, and should be **removed by Tuesday evening**.
  - Posters for Session II can be put up in the **morning of Wednesday, June 13**, and should be **removed by Wednesday lunchtime**.
  - Posters for Session III can be put up in the **afternoon of Wednesday, June 13**, and should be **removed by Wednesday evening**.
  - Posters for Session IV can be put up in the **morning of Thursday, June 14**, and should be **removed immediately following lunch on Thursday**.
- Poster boards are 3 feet wide and 4 feet tall (portrait orientation). Pushpins will be provided for affixing materials to poster boards.

SORMA 2018
Exhibitor and Posterboard Layout



4 Bus Schedule

Monday, June 11th

Into campus
Pick up location #1: Hampton Inn
Pick up location #2: Sheraton Hotel
Drop off location : Michigan League
Pick up times: 3:00 pm, 3:40 pm, 4:20 pm, 5:00 pm
Final pick up time: 5:40 pm

To off-campus hotels
Pick up location : Michigan League
Drop off location #1: Sheraton Hotel
Drop off location #2: Hampton Inn
Pick up times: 6:20 pm, 7:00 pm, 7:40 pm, 8:20 pm
Final pick up time: 9:00 pm

Tuesday, June 12th

Into campus
Pick up location #1: Hampton Inn
Pick up location #2: Sheraton Hotel
Drop off location : Michigan League
Pick up times: 7:00 am, 7:10 am, 7:40 am, 7:50 am, 8:20 am
Final pick up time: 8:30 am

To off-campus hotels - ONE WAY
Pick up location : Michigan League
Drop off location #1: Sheraton Hotel
Drop off location #2: Hampton Inn
Final pick up time: 5:30 pm

To University of Michigan Museum of Art
Pick up location : Michigan League
Drop off location #1: University of Michigan Museum of Art
Pick up times: 5:30 pm, 5:45 pm

To off-campus hotels
Pick up location : University of Michigan Museum of Art
Drop off location #1: Sheraton Hotel
Drop off location #2: Hampton Inn
Pick up times: 7:00 pm, 7:20 pm, 7:40 pm, 8:00 pm, 8:20 pm, 8:40 pm, 9:00 pm
Final pick up time: 9:20 pm

Wednesday, June 13th

Into campus
Pick up location #1: Hampton Inn
Pick up location #2: Sheraton Hotel
Drop off location : Michigan League
Pick up times: 7:00 am, 7:10 am, 7:40 am, 7:50 am, 8:20 am
Final pick up time: 8:30 am

To off-campus hotels - ONE WAY
Pick up location : Michigan League
Drop off location #1: Sheraton Hotel
Drop off location #2: Hampton Inn
Final pick up time: 5:30 pm

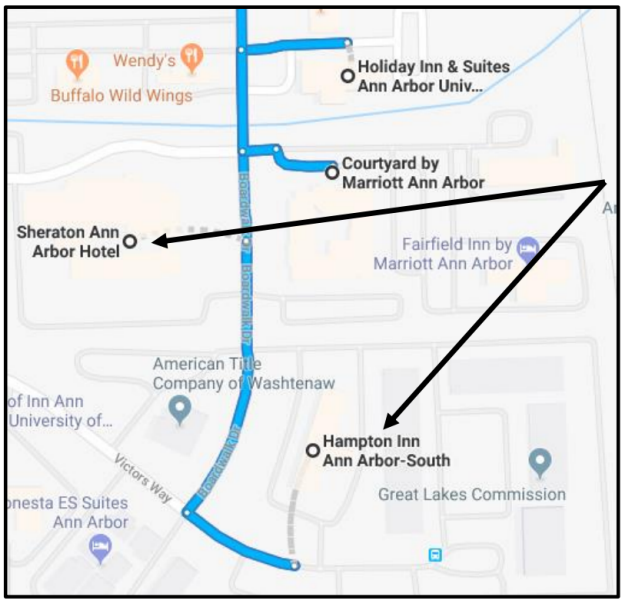
To Henry Ford Museum of American Innovation
Pick up location : Michigan League
Drop off location #1: Henry Ford Museum of American Innovation
Pick up times: 5:30 pm - Multiple buses will depart as filled

To off-campus hotels
Pick up location : Henry Ford Museum of American Innovation
Drop off location #1: Sheraton Hotel
Drop off location #2: Hampton Inn
Drop off location #3: Michigan League
Pick up times: 9:00 pm - Multiple buses will depart as filled
Final pick up time: 10:15 pm

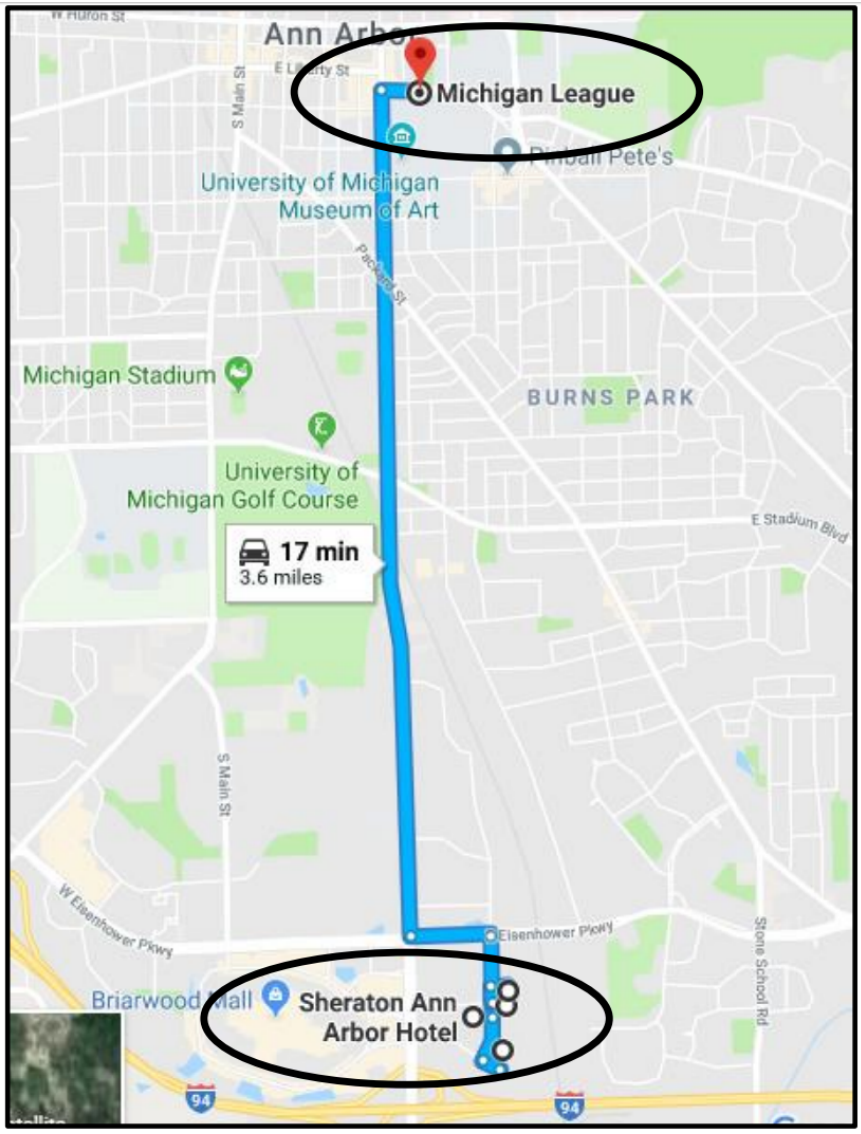
Thursday, June 14th

Into campus
Pick up location #1: Hampton Inn
Pick up location #2: Sheraton Hotel
Drop off location : Michigan League
Pick up times: 7:00 am, 7:10 am, 7:40 am, 7:50 am, 8:20 am
Final pick up time: 8:30 am

To off-campus hotels
Pick up location : Michigan League
Drop off location #1: Sheraton Hotel
Drop off location #2: Hampton Inn
Pick up times: 5:00 pm, 5:20 pm, 5:40 pm
Final pick up time: 6:00 pm



Bus Stop Locations



Michigan League
911 N University Ave,
Ann Arbor, MI 48104

5 Program View of Papers

Time	Session Title - Location - Chair
Tuesday June 12th	
8:30-8:45 am	**Welcome! - Rackham Auditorium - David Wehe**
8:45-9:45 am	**Plenary I - Dark Matter Search and Liquid Xenon Detector Development - Rackham Auditorium - David Wehe** * **0495** - Imaging Liquid Xenon Detectors for the Search of Dark Matter Weakly Interacting Massive Particles - *Elena Aprile* (USA)
9:45-10:45 am	**Plenary II - Modernizing the IAEA verification instrumentation - Rackham Auditorium - Zhong He** * **0497** - Modernizing the IAEA verification instrumentation: Lessons from experience and vision to the future - *Alain LeBrun* (France)
10:45-11:00 am	**Coffee Break - Lobby -**
11:00-12:00 pm	**Plenary III - FRIB: The Path to Scientific Discovery - Rackham Auditorium - David Wehe** * **0494** - FRIB: The Path to Scientific Discovery - *Witold Nazarewicz* (USA)
12:00-1:30 pm	**Lunch Break - On Own -**
1:30-3:00 pm	**Scintillation Detectors I - Mendelssohn - David Wehe** * **0071** - Advances in Scintillation Materials - *Kanai Shah* (USA) **0032** - Organic Spectroscopic Scintillators based on Quantum Dot Nanocomposites - *Qibing Pei* (United States) **0136** - Plastic scintillators produced in one day with efficient pulse shape discrimination and thermal neutron capture. - *Alan Sellinger* (USA) **0407** - Physical and Scintillation Degradation of Plastic Scintillators - *Matthew Loyd* (United States) **0332** - Characterization of the light output anisotropy of stilbene crystals - *Robert Weldon* (United States) **0409** - Charge drift in organic liquids at room temperature - *Marc Bergevin* (USA)
1:30-3:00 pm	**Particle/Photon Cancer Therapy, and Other Medical Imaging Applications - Hussey - Ling-Jian Meng** * **0047** - Current and future needs for in vivo imaging and dose verification in proton beam radiotherapy. - *Jerimy Polf* (United States) **0080** - Precision imaging of 4.4 MeV gamma rays using a 3-D position sensitive Compton camera - *Jun Kataoka* (Japan) **0085** - Detection Systems for Range Monitoring in Proton Therapy: Needs and Challenges - *Guntram Pausch* (Germany) **0240** - Neutron and charged particle trackers: scintillating fiber devices for particle therapy applications - *Ilaria Mattei* (Italy) **0128** - Monte Carlo code application to the study of 3D neutrons distribution in a radiotherapy bunker and validation with experimental measurements - *belen juste* (Spain) **0101** - High-Resolution Compton Tomography for Small Animal Molecular Imaging - *Ross Barnowski* (USA)
3:00-4:00 pm	**Poster I - New Radiation Detectors - Ballroom - Mark Hammig** **0043** - 1 - Scintillation properties of Eu-doped BaFBr crystal - *Takayuki Yanagida* (Japan) **0091** - 2 - Scintillation properties of Eu-doped SrF_2 translucent ceramic - *Takumi Kato* (Japan) **0092** - 3 - X-ray induced luminescence properties of Ce-doped $Ca_3Sc_2Si_3O_{12}$ single crystal - *Takumi Kato* (Japan) **0109** - 4 - Crystal growth, crystal structure, optical and scintillation properties of self-activated Cs4YbI6 - *Yuntao Wu* (United States) **0110** - 5 - Improvement of europium doped strontium iodide scintillating crystals by aliovalent codoping - *Yuntao Wu* (United States) **0117** - 6 - Comparative study of scintillation properties of CsBr:Tl transparent ceramic and single crystal - *Hiromi Kimura* (Japan) **0119** - 7 - Scintillation characteristics of a heterogeneous composite detector in shards geometry - *Tingshiuan Wu* (United States) **0120** - 8 - Development of two-dimensional quantum confinement material $(C_6H_5C_2H_4NH_3)_2Pb_{1-x}Sr_xBr_4$ for scintillation detectors - *Masaki Akatsuka* (Japan) **0121** - 9 - Comparative study of Ce-doped $Tb_3Al_5O_{12}$ crystal scintillators with different Ce-concentrations - *Daisuke Nakauchi* (Japan) **0122** - 10 - Comparative study of Eu-doped $SrAl_2O_4$ crystal and translucent ceramic for X- and gamma- ray measurements - *Daisuke Nakauchi* (Japan) **0123** - 11 - Auger-free luminescence characteristics of $Cs(Ca_{1-x}Mg_x)Cl_3$ - *Keisuke Takahashi* (Japan) **0124** - 12 - Development of liquid scintillators based on mixed-organic solvents containing ^6Li for neutron detection - *Sae Arai* (Japan) **0176** - 13 - Radiochromic properties of organic films based on a diarylethene molecule - *Masanori Koshimizu* (Japan) **0304** - 14 - New Scintillating Bolometer Crystals for Rare Particle Detection - *Joshua Tower* (United States) **0328** - 15 - Monte Carlo simulation of CLYC-PVT composite scintillators for gamma/neutron detection - *Frank Ruta* (United States) **0398** - 16 - Characterization of a 13 CLYC Crystal - *Eric Becker* (United States) **0426** - 17 - Position sensitive scintillation detector using polymer-based plastics and pulse shape analysis - *Michael Aspinall* (United Kingdom) **0471** - 18 - Evaluation of PVT Scintillators for Fast Neutron Imaging - *Ibrahim oksuz* (United states) **0040** - 19 - Cherenkov Detectors for Gamma and Neutron Detection - *Hattan Natto* (US) **0149** - 20 - Tensile, flexural, and light output measurements of selected organic scintillators for evaluation of their potential as structural materials - *Caleb Redding* (United States of America) **0178** - 21 - Effect of Li^+ codoping on $(Lu_{0.75}Y_{0.25})_3Al_5O_{12}:Pr^{3+}$ single crystal scintillators - *Camera Foster* (United States) **0195** - 22 - Sensitivity and Linearity of Optical Fiber Type Neutron Detector Using a Small Piece of ^6Li-Based Scintillator - *Akihisa Ishikawa* (Japan) **0268** - 23 - Development of a compact high-sensitivity $SrI_2(Eu)$-based detector module - *Ivan Khodyuk* (United States) **0308** - 24 - Pulse Shape Discrimination in Organic Scintillators The Role of Intersystem Crossing - *Angela Di Fulvio* (United States) **0394** - 25 - Growth and scintillation properties of Cs_2LiYCl_6 crystals doped with different Ce_{3+} concentration - *Guohao Ren* (China)

Time	Session Title - Location - Chair
Tuesday June 12th	
3:00-4:00 pm	**Poster I - New Radiation Detectors - Ballroom - Mark Hammig** **0418** - 26 - Temperature Response and Radiation Damage Effects on Potassium Strontium Iodide - *Callie Goetz* (USA) **0335** - 27 - Alkali-Free Ce-Doped and Co-Doped Fluorophosphate Glasses for Future HEP Experiments - *Chen Hu* (United States) **0274** - 28 - Picosecond absorption spectroscopy of self-trapped excitons and Ce excited states in $La_{(1-x)}Ce_xBr_3$ for x = 0.004% to 100% - *Peiyun Li* (United States) **0273** - 29 - High photoluminescence quantum yield and fast radiative lifetime from Cs_4PbBr_6 with $CsPbBr_3$ nano-inclusions prospects and issues as a scintillator - *Junwei Xu* (United States) **0165** - 30 - Crystal growth and scintillation performance of Cs_2_HfCl_6 - *Stephanie Lam* (USA) **0377** - 31 - Picosecond absorption spectroscopy of excited BaBrCl with Eu and Au dopants - *Richard Williams* (US) **0087** - 32 - Scintillation properties and alpha-ray detection capabilities of thin-film plastic scintillators - *Masanori Koshimizu* (Japan) **0197** - 33 - Growth and Characterization of Cesium Hafnium Bromochloride Free of Cracking and Coring - *Cordell Delzer* (USA) **0148** - 34 - Optimizing europium concentration in Cs_4SrI_6 and Cs_4CaI_6 Scintillators - *Daniel Rutstrom* (United States) **0421** - 35 - Optical Properties and Emission Mechanism in TLYC Scintillator - *Lakshmi Soundara Pandian* (USA) **0046** - 36 - Structural characterization of La_2O_3 and Nb_2O_5 doped CeO_2 simulant for UO_2 towards solid-state direct-conversion neutron detectors - *Christopher Shaver* (United States) **0053** - 37 - Evaluation of LiCAF for neutron spectroscopy using SiPMs and portable electronics - *Mike Ford* (USA) **0074** - 38 - Advancements in Gd-based neutron detection: γ-γ quasi-coincidence approach - *Jonathan Dumazert* (France) **0126** - 39 - Basic study on a LiF-Eu:CaF_2 mixed power neutron scintillator - *Kenichi Watanabe* (Japan) **0174** - 40 - Component Characterization for a Compact, Optically Segmented Neutron Double Scatter Camera - *Andrew Druetzler* (United States) **0266** - 41 - DEVELOPMENT OF A SOLID-STATE POSITION SENSITIVE NEUTRON DETECTOR PROTOTYPE BASED ON ^{6}Li - GLASS SCINTILLATOR AND DIGITAL SIPM ARRAYS - *Shashank Kumar* (Germany) **0391** - 42 - The potential of real-time, fast neutron and γ radiography to low-mass, solid-phase media - *Mauro Licata* (United Kingdom) **0466** - 43 - Development of hot pressed lithium indium selenide for use as a ceramic radiation detector - *Joseph Bell* (United States of America) **0130** - 44 - Thin-Film Neutron Detector Based on CdTe and Li-6 Layers - *Alvin Compaan* (United States) **0155** - 45 - Hot pressed UO_3 as candidate material for direct conversion solid-state neutron detector - *Seth Lawson* (United States) **0106** - 46 - Design and construction of sandwich pixelated detector prototype for dual-particle spectroscopic radiography - *Kristofer Ogren* (USA) **0318** - 47 - Low-cost, high quality growth and characterization of $MAPbBr_3$ perovskite single crystals - *Jeremy Tisdale* (United States) **0406** - 48 - Gamma spectrum acquisition with Halide Perovskite - *Lei Pan* (United States) **0443** - 49 - Spectroscopic Radiation Detection Using Methylammonium Lead Iodide Perovskite Single Crystals Grown from Solution - *Suneel Joglekar* (USA) **0322** - 50 - Methylammonium lead bromide: a low-cost organometallic semiconductor for radiation detection - *Travis Smith* (United States) **0244** - 51 - Development of large area Neganov-Luke phonon amplified light detectors for dark matter experiments - *Jin A Jeon* (Republic of Korea) **0279** - 52 - Compact phonon-scintillation detection system for rare event searches at low temperatures - *Hyelim Kim* (Korea) **0281** - 53 - Silicon carbide stability for alpha particle detection at high temperature: A comparative approach - *Yusuf Abubakar* (United Kingdom) **0311** - 54 - Discriminating nuclear recoils from alpha particles using acoustic signatures in γ / β -blind tensioned metastable fluid detectors - *Brian Archambault* (United States) **0373** - 55 - The realization of high uniformity drift electric field with a compact field cage - *Zhujun Fang* (China) **0453** - 56 - Commissioning run of the Solenoid Spectrometer for Nuclear Astrophysics (SSNAP) at Notre Dame - *Jacob Allen* (United States) **0458** - 57 - The Neutron Induced Fission Fragment Tracking Experiment: Precise Measurements of Fission Cross Section Ratios in a Time Projection Chamber - *Nicholas Walsh* (US) **0177** - 58 - Simulation and fabrication of a scCVD diamond as a radiation detector and vacuum window - *Xin Tong* (Canada) **0077** - 59 - Operation of Microhexcavity Plasma Panels Detectors in Geiger and Avalanche Mode - *Nicholas Ristow* (US) **0339** - 60 - Diamond detectors for directly-imaged, high-speed proton radiography - *Levi Neukirch* (United States) **0288** - 61 - Aramid-based nanocomposites for portable ionizing radiation detection - *Drew Vecchio* (United States) **0438** - 62 - Ultrafast Waveguiding Quantum Dot Scintillation Detector - *Katherine Dropiewski* (United States of America) **0397** - 63 - Material defect study of thallium lead iodide ($TlPbI_3$) crystals for radiation detector applications - *Ge Yang* (United States) **0470** - 64 - Using the Formation Mechanism of 2-D Superlattices from PbSe Nanocrystals and Nanocrystal Attachment to Improve Charge Carrier Transport of Semiconductors - *Brandon Davis* (United States) **0491** - 65 - A New Semiconductor Radiation Detector $CsPbBr_3$ - *Duck Young Chung* (USA)
4:00-5:30 pm	**Semiconductor Detectors I - Mendelssohn - Alan Janos** * **0349** - High performance CdZnTe for security applications - requirements for high volume production and experience Curve effects for improved cost competitiveness. - *jason mackenzie* (Canada) **0058** - Temperature based gamma-ray event reconstruction in 3-D position-sensitive CdZnTe detectors - *Jiawei Xia* (United States) **0051** - Halide Perovskite for New Generation X-ray and ray Detectors - *Haotong Wei* (USA) **0267** - $^6LiInSe_2$ Semiconductor Neutron Detector - *Joshua Tower* (United States) **0163** - Resonant two-photon mapping of defect states in TlBr during aging under applied voltage - *Drew Onken* (United States) **0192** - The p-type point contact germanium detectors in CDEX experiments - *LIPING JIA* (China)

Time	Session Title - Location - Chair
Tuesday June 12th	
4:00-5:30 pm	**Neutron Facility, Characterization, Detectors and Generators - Hussey - Mark Wrobel** **0152** - New Neutron Beam Facilities Developments at the Penn State Breazeale Reactor (PSBR) - *Kenan Unlu* (USA) **0049** - Fission Neutron Angular Correlation Measurements and MCNP6.2 Simulations - *Madison Andrews* (USA) **0170** - Fabrication and experimental evaluation of microstructured ^{6}Li silicate fiber arrays for high spatial resolution neutron imaging - *Michael Moore* (USA) **0431** - Experimental and Predicted Performances of the Micro-Layered Fast-Neutron Detector - *Priyarshini Ghosh* (United States) **0129** - Inverse Problem Approach for the underwater localization of Fukushima Daiichi fuel debris with fission chambers - *Jonathan Dumazert* (France) **0313** - Niowave Neutron Interrogation System - *Valeriia Starovoitova* (USA)
6:00-9:00 pm	**Conference Reception - University of Michigan Museum of Art -**

Time	Session Title - Location - Chair
Wednesday June 13th	
7:30-5:00 pm	**Conference Registration - 2nd Floor Concourse -**
8:00-9:30 am	**Neutron Detectors II - Mendelssohn - Donny Hornback** **0401** - Single-photon detection performance for neutron imager development - *Erik Brubaker* (USA) **0305** - Characterization of Deuterated-stilbene (stilbene-d_{12}) for Neutron Spectroscopy - *Angela Di Fulvio* (United States) **0473** - Directional fast neutron detection based on neutron time projection chamber and plastic scintillation detectors - *Yidong Fu* (China) **0326** - Demonstration of coded-aperture fast neutron imaging based on Timepix detector - *Clement LYNDE* (France) **0035** - A comparative study of scintillators for ultracold neutron detection - *Zhehui Wang* (USA) **0449** - Improved Manufacturing and Performance of the Microstructured Semiconductor Neutron Detector - *Taylor Ochs* (United States)
8:00-9:30 am	**PET, SPECT and Other Medical Imaging Techniques - Hussey - Kanai Shah** * **0493** - Trends and opportunities in nuclear medicine imaging - *Todd Peterson* (US) **0324** - The Hybrid Cerenkov-Charge Induction Readout TlBr Detector - *Gerard Arino Estrada* (USA) **0414** - Development of a MR insert PET detector using strip-line signal readout - *Heejong Kim* (US) **0341** - System Modeling and Evaluation of a Prototype Inverted-Compound Eye - *Xiaochun Lai* (USA) **0461** - A Broadband X-ray Fluorescence Emission Tomography Imaging System Utilizing Small-Pixel Ultra-High Resolution CdTe Detectors - *Jonathan George* (United States) **0371** - Edge-illuminated semiconductor x-ray and gamma-ray detectors for medical imaging - *William Barber* (US)
9:30-10:30 am	**Poster II - Radiation Measurement Techniques - Ballroom - Shaun Clarke** **0444** - 1 - Experimental Validation of a Scintillator-Based, Cosmic-ray Muon Tomography Proof-of-Concept System for Dry Nuclear Fuel Storage Cask Monitoring - *can liao* (United States) **0379** - 2 - Shielding a Monoenergetic Photon Source for Nonproliferation Applications Analysis - *Cameron Miller* (United States) **0162** - 3 - Characterization of Rotating Scatter Mask Designs for Novel Applications in Photon Detection - *Robert Olesen* (USA) **0068** - 4 - FRAMv5.2 Estimation of Plutonium and Uranium Isotopics using Digitized 3-D Position-Sensitive CdZnTe Detectors - *David Goodman* (United States) **0167** - 5 - Measurement and Analysis of Beta-ray Spectra at CANDU Reactors - *Faraz Bohra* (Canada) **0234** - 6 - Study, fabrication and test of a special cooling system for targets submitted to intense ion beams - *Vittoria Capirossi* (Italia) **0245** - 7 - Double Photon Emission Coincidence Imaging with GAGG-SiPM Compton Camera - *Mizuki Uenomachi* (Japan) **0254** - 8 - Design of a photoneutron source for Bragg edge transmission imaging - *LU LU* (China) **0269** - 9 - Gamma-Ray Yield Measurement of ^{12}C(p,p')^{12}C at E_p=19.5 - 30 MeV: Preliminary Results from NaI(Tl) - *Felicia Sutanto* (USA) **0289** - 10 - Production and Detection of Radioxenon for Nuclear Explosion Monitoring - *Valeriia Starovoitova* (USA) **0321** - 11 - Elemental and Structural Characterization of Scale Deposition in Oil Pipes using X-Ray Microfluorescence and Computed Microtomography - *Davi Oliveira* (Brazil) **0329** - 12 - EMISSION AND TRANSMISSION TOMOGRAPHY SYSTEM APPLIED TO ANALYSE INDUSTRIAL PROCESS INSIDE CHEMICAL REACTORS. - *Carlos Henrique Mesquita* (Brazil) **0353** - 13 - Standoff Enrichment Analysis of UF_6 Cylinders - *Bonnie Canion* (USA) **0392** - 14 - Transfer of the Oak Ridge Enge Split-Pole Spectrograph to Notre Dame - *Dan Bardayan* (United States) **0432** - 15 - Non-destructive Inspection of laminated joints of pipe in polymeric composite material reinforced by fiberglass - *Cintia Ferreira* (Brazil) **0433** - 16 - Evaluation of root canal retreatment quality through of microCT - *Thais Santos* (Brazil) **0190** - 17 - Autonomous UAV-Based Radiation Inspection and Mapping of Radiological Contamination - *John Bird* (United States) **0314** - 18 - Continuous and Unattended Spectroscopic Operation and Analysis with the Mirion Data Analyst - *James Zickefoose* (USA) **0338** - 19 - Artificial Neural Network Algorithms for Classification and Recovery of Piled-up Pulses in Active Interrogation of Special Nuclear Material - *Angela Di Fulvio* (United States) **0159** - 20 - Effects of Clutter During Radiation Measurements - *Michael Willis* (United States) **0456** - 21 - Detector Characterization for Quantitative Spectral Radiography of Uranium Powder Samples - *Benjamin McDonald* (USA)

Time	Session Title - Location - Chair
Wednesday June 13th	
9:30-10:30 am	**Poster II - Radiation Measurement Techniques - Ballroom - Shaun Clarke** **0082** - 23 - Gamma-Ray Spectroscopy via Measurement of Angular Distribution of Compton Scattering - *Andrew Wilhelm* (USA) **0166** - 24 - Optimization of a $LaBr_3$(Ce) spectrometer for high rate gamma-ray spectrometry at CANDU reactors - *Andre Laranjeiro* (Canada) **0229** - 25 - A neural network approach for identification of gamma emitting radionuclides with silicon photomultipliers - *Seungho Jhung* (Republic of Korea) **0337** - 26 - A Comparison of Machine Learning Methods for Automated Gamma-ray Spectroscopy - *Mark Kamuda* (United States of America) **0467** - 27 - Quantification of the Systematic Uncertainty in Measuring a Chance Coincidence Background - *Jaime Gomez* (United States) **0448** - 28 - Optical and Scintillation Properties of Ultrafast Inorganic Scintillators for GHz Hard X-Ray Imaging - *Chen Hu* (United States) **0376** - 29 - Correlation between pulse shape and pulse height in gamma events at the same energy - prospects for improving resolution - *Sergii Gridin* (USA) **0352** - 30 - Design of a prototype radioxenon detection system using stilbene and CdZnTe - *Harish Gadey* (United States of America) **0331** - 31 - Image quality characterization using Presampled-MTF for a neutron imaging system composed of ^{6}Li loaded ZnS detector and CCD camera at different flux locations of the UFTR - *Surafel Woldegiorgis* (United States) **0206** - 32 - Development of a high frame rate neutron imaging method for two-phase flows - *Chad Lani* (United States) **0248** - 33 - Passive neutron measurement by neutron coincidence counting using neutron/gamma discriminating plastic scintillators - *Clement LYNDE* (France) **0270** - 34 - A Monte-Carlo simulation method for the research of self-powered neutron detectors - *Tongyuan Cui* (China) **0285** - 35 - Investigation of A Model Based Reconstruction Technique for Neutron Tomography at the PULSTAR Reactor - *Arka Datta* (United States) **0334** - 36 - Pulse Height Spectra Analysis of an Energy Tuning Assembly - *James Bevins* (US) **0388** - 37 - Pre-deployment characterization of large fast neutron detectors for high performance computing fault characterization - *Elinor Mullin* (United States) **0408** - 38 - Experimental plan for the verification of a neutron imaging technique incorporating compressed sensing in the collimator design - *Nuraslinda Anuar* (United States) **0419** - 39 - Neutron flux measurements in the beam ports of the University of Florida Training Reactor after the HEU to LEU fuel conversion - *Jyothier Kumar Nimmagadda* (United States) **0423** - 40 - Design and development of an External Fast Neutron Beam Facility at The Ohio State University Research Reactor - *Andrew Zapp* (USA) **0044** - 41 - Neutron and gamma-ray Pulse shape discrimination of $LiAlO_2$ and $LiGaO_2$ crystals - *Takayuki Yanagida* (Japan) **0486** - 42 - Thermal Neutron Detectors for Radiation Sensing Using UAVs - *Matthew Carver* (United States) **0366** - 43 - A review of the prompt neutron nu-bar value for ^{252}Cf spontaneous fission - *RAMKUMAR VENKATARAMAN* (United States of America) **0365** - 44 - The Specific (α n) Production Rate for ^{234}U in UF_6 - *RAMKUMAR VENKATARAMAN* (United States of America) **0359** - 45 - Applications of C^{7}LYC Scintillators in Fast Neutron Spectroscopy* - *Partha Chowdhury* (USA) **0161** - 46 - Quantifying the determinants of leakage multiplication for large uranium objects using Monte Carlo simulations - *Matthew Tweardy* (United States) **0142** - 47 - Measurement of neutron and gamma-ray cross-correlation functions with ^{4}He detectors - *Yinong Liang* (United States) **0306** - 48 - Multiplicity Detection of Low-Fluence Neutron Sources using CTMFDs - *Tom Grimes* (United States) **0367** - 49 - Development of an Ir transition edge sensor for near infrared single photon counting - *Yoshitaka Miura* (Japan) **0230** - 50 - Beta Radionuclide Identification Algorithm by Using a Phoswich Detector - *Kim Jinhwan* (Republic of Korea) **0356** - 51 - Progress towards ultrafast detectors for GHz hard X-ray imaging - *Junqi Xie* (US) **0464** - 52 - Simulated Spectral Responses of Thin Planar-Type Radiation Detectors by Tracking Primary Electrons from the Gamma-ray Interaction - *JAEHYO KIM* (South Korea) **0439** - 53 - SiPM-based Compact Time-of-Flight Detector Using Cherenkov Glass - *Mark Bourne* (United States) **0469** - 54 - A New, Versatile, High-performance Digital Pulse Processor with Application to Neutron/Gamma-Ray Pulse-Shape Discrimination in Scintillator Detectors - *Andreas Ruben* (United States) **0479** - 55 - Prototype Design of Pulse Digitalization Base for Photomultiplier Tube with Single Cable - *Tao Xue* (China) **0372** - 56 - Temperature dependence of neutron detectors using $LiCaAlF_6$ scintillators - *Noriaki Kawaguchi* (JAPAN) **0052** - 57 - Flexible silicon-based alpha particle detector - *David Jenkins* (United Kingdom) **0395** - 58 - Time resolved nuclear spectroscopy - exploring new dimension in scintillation characterization - *Weronika Wolszczak* (The Netherlands) **0056** - 59 - Engineering of well conditions to improve the responsivity of p-on-n SiPM for blue light detection - *Kyung Taek Lim* (Republic of Korea) **0179** - 60 - Low Energy Light Yield of Fast Plastic Scintillators - *Thibault Laplace* (USA) **0381** - 61 - Development and Evaluation of $CeBr_3$ and GAGG array with SiPMs for Compton and PET imager - *Kenji SHIMAZOE* (Japan)
10:30-12:00 pm	**Room-Temperature Semiconductor Detectors - Mendelssohn - Mac Black** * **0422** - Development of position-sensitive virtual Frisch-grid CdZnTe detectors - *Aleksey Bolotnikov* (US) * **0424** - Study of the impact of CZT detector characteristics on imaging performance - *Guillaume MONTEMONT* (France) **0347** - Development and Performance of the A400 RIID - *Christopher Wahl* (United States) **0172** - Performance and longevity of pixelated TlBr arrays - *Paul Bennett* (usa) **0294** - Stable Thallium Bromide Detectors for PRD and SPRD Applications - *Amlan Datta* (United States)

Time	Session Title - Location - Chair
Wednesday June 13th	
10:30-12:00 pm	**Algorithms and Modeling - Hussey - Sara Pozzi** * **0065** - Event-by-Event Fission Modeling with FREYA - *Ramona Vogt* (USA) **0067** - First Steps Toward Validating Computed Muon Tomography with the CRIPT Detector - *Evan Rand* (Canada) **0143** - Alpha and beta detection capabilities of an environmental continuous air monitoring system - *Eric Becker* (United States) **0301** - Bayesian unfolding of elementary particle spectra in mixed beta-gamma fields - *Andrei Hanu* (Canada) **0361** - Machine learning n/γ discrimination in CLYC scintillators* - *Partha Chowdhury* (USA) **0375** - Quantifiaction of systematic uncertainties from experimental environments - *Keegan Kelly* (United States)
12:00-1:30 pm	**Lunch Break - On Own -**
1:30-3:00 pm	**Inorganic Scintillation Detectors - Mendelssohn - Igor Jovanovic** **0108** - Zero-dimensional Cs4EuX6 (X=Br, I) All-Inorganic Perovskite Single Crystals for Gamma-ray Spectroscopy - *Yuntao Wu* (United States) **0164** - High-performance composite scintillators for gamma/neutron detection - *Stephanie Lam* (USA) **0460** - $KSr_{1.3}Ba_{0.7}I_5$(Eu): A New Ultra-high Light Yield Scintillator with 2.2% Energy Resolution - *Luis Stand* (United States) **0150** - Identification of internal radioactive contaminants in elpasolites (CLYC, CLLB, CLLBC) and other inorganic scintillators - *Richard Woolf* (USA) **0476** - Radiation Hardness and Scintillation properties for Ce:GAGG and Ce:La-GPS Crystals - *Shunsuke Kurosawa* (Japan) **0327** - Low-cost, Multi-mode Detector Solutions - *Urmila Shirwadkar* (USA)
1:30-3:00 pm	**Gamma-Ray Imaging Systems - Hussey - Kai Vetter** * **0459** - 3D Gamma-ray Mapping from the Ground to the Air - *Andrew Haefner* (United States) **0185** - Rotating Scatter Mask Optimization for Gamma Source Direction Identification - *Darren Holland* (United States) **0292** - Use of Pencil Beam Backscatter Radiography to Image Buried Root Structures - *James Baciak* (USA) **0102** - Hard X-ray imaging using monolithic active pixel sensors (MAPS) - *Xuan Li* (USA) **0370** - Development of assembly method of scintillator arrays consisting of Eu:SrI_2 - *Masao Yoshino* (Japan) **0446** - Activity quantification of caesium-137 sources in environmental media using the GRI Compton camera - *Thomas Woodroof* (United Kingdom)
3:00-4:00 pm	**Poster III - Medical and Environmental Applications - Ballroom - Patricia Schuster** **0054** - 1 - Radiation shielding analysis for the A-BNCT facility - *EUNJOONG LEE* (Republic of Korea) **0072** - 2 - TBI Commissioning Using Radiocromic Film And Ionization Chamber - *Priscila Marins* (Brasil) **0201** - 3 - Optimization of Gamma-ray Detectors in Neutron-Induced Gamma-ray Spectroscopy for Geophysical Applications - *Jihye Jeon* (Republic of Korea) **0221** - 4 - The development and optimization design for X-ray laser - *Tsung Ter Kuo* (Taiwan ROC) **0226** - 5 - Radiation Hardened Charge-Sensitive Amplifier Survived up to 2 Mrad by proposed Layout techniques and Size Optimization - *CHANGYEOP LEE* (Republic of Korea) **0277** - 6 - Measurement of the Spatio-Spectral Distribution of Secondary Neutrons with ^{4}He Gas Scintillation Detectors at a Proton Therapy Facility - *Sasmit Gokhale* (USA) **0282** - 7 - Instrumentation for a High-Altitude Dosimeter using PSD Plastic Scintillator - *Scott MacEwan* (Canada) **0296** - 8 - Impact of channel configurations on bandwidth of a cross-strip electrode with multiple ASICs - *Sheng Yang* (United States) **0346** - 9 - Niowave Uranium Target Assembly - *Valeriia Starovoitova* (USA) **0430** - 10 - Nondestructive Assessment of Transportation Fuel Cask using Time-Tagged Neutron Interrogations - *Zhihua Liu* (United States) **0249** - 11 - A new positron-gamma phoswich detector based on wavelength discrimination - *MUHAMMAD NASIR Ullah* (South Korea) **0220** - 12 - Characterization of Thin TlBr Detectors for Intense Radiation Fields - *Mitsuhiro Nogami* (Japan) **0238** - 13 - Ruggedized HPGe detectors for in-situ gamma spectroscopy - *Vlad Marian* (France) **0265** - 14 - Development and image quality of indirect X-ray CMOS flat panel detector with novel readout method for medical applications - *Bo Kyung Cha* (Republic of Korea) **0084** - 15 - Imaging of plutonium particles using an EMCCD-camera-based alpha-particle imaging system - *Yuki Morishita* (Japan) **0086** - 16 - Image denoising with conditional generative adversarial networks (cGAN) in low dose chest radiography - *HEE JOUNG KIM* (South Korea) **0134** - 17 - The research of bi-modal imaging method with a photoneutron source - *Yigang Yang* (China) **0242** - 18 - Performance Estimation of Gamma Electron Vertex Imaging (GEVI) System for Proton Therapy Monitoring - *Han rim Lee* (Republic of Korea) **0243** - 19 - Sparse-view virtual monochromatic CT imaging using a dictionary-learning based reconstruction algorithm - *GUNA KIM* (Republic of korea) **0255** - 20 - X-ray imaging quality of the CMOS X-ray flat panel detector in different modes of dental CT system - *Changwoo Seo* (Republic of Korea) **0262** - 21 - Performance evaluation of a prototype mobile C-arm CT system with high-resolution X-ray flat panel detector - *Bo Kyung Cha* (Republic of Korea) **0276** - 22 - Study of 3D Fast Compton Camera Image Reconstruction Method by Algebraic Spatial Sampling - *Zhiyang Yao* (China) **0280** - 23 - Triple-interaction events selection for prompt gamma emission reconstruction during proton therapy - *Haijian Chen* (USA) **0284** - 24 - Image Reconstruction for Rotational Modulation Collimator (RMC) Using Non Local Means (NLM) Denoising Filter - *sohyeon park* (Republic of Korea) **0435** - 25 - Performance of the Gamma Ray Industrial Process Tomography used for Characterization of the Vesicular Igneous Rock - *Alexandre Franca Velo* (Brazil) **0441** - 26 - DIGITAL ROCK ANALYSIS USING MICROCT AND FLUID FLOW SIMULATIONS IN COQUINA SAMPLE - *Olga Araujo* (Brazil) **0462** - 27 - Fruit PET: 3-D imaging of carbon distribution in fruit using OpenPET - *Keisuke Kurita* (Japan)

Time	Session Title - Location - Chair
Wednesday June 13th	
3:00-4:00 pm	**Poster III - Medical and Environmental Applications - Ballroom - Patricia Schuster** **0478** - 29 - Increasing the Efficiency of Lens Coupled MeV Radiography - *Jacob Mendez* (United States) **0380** - 30 - Determination of oil and water in drilled bore cores via fast-neutron resonance transmission radiography - *David Vartsky* (Israel) **0097** - 31 - A novel estimation method of water-equivalent thicknesses of secondary particle tracks using secondary electron bremsstrahlung emitted from therapeutic ion beams for attenuation correction - *Mitsutaka Yamaguchi* (Japan) **0107** - 32 - Lead Rubber as an Effective Substitute of Electron Beam Bolus in Electron Beam Therapy - *Ing Ming Hwang* (ROC) **0199** - 33 - A Consideration for Interpretation of between scatter degradation factor and image quality according to beam-hardening in medical radiography - *KYOTAE KIM* (Republic of Korea) **0342** - 34 - Sterilization and Advanced Manufacturing Using Superconducting Electron Linacs - *Valeriia Starovoitova* (USA) **0374** - 35 - Mechanical x-ray (MEXRAY) generator for MeV radiography - *Nicola Winch* (United States) **0455** - 36 - Elemental distribution of benign prostatic hyperplasia cell line using synchrotron X-ray microfluorescence - *Roberta Leitao* (Brazil) **0158** - 37 - The Classification and Identification of Tumor and Normal Breast Tissues Using a Comparison of Two X-ray Fluorescence and X-ray Diffraction Techniques - *Duaa Alaroui* (Canada) **0211** - 38 - Using an On-board Cone-beam Computed Tomography Scanner as a Reading Modality for Gel Dosimetry: a feasibility study - *Yan Lin Liu* (Taiwan) **0213** - 39 - Application of compressible breast phantoms on the estimation of average glandular dose in mammography - *ruei chi lin* (Taiwan) **0214** - 40 - Three-Dimensional Dose Evaluation of the Blood Irradiator using Monte Carlo Simulation and MAGAT gel dosimeter - *Yan Lin Liu* (Taiwan) **0217** - 41 - Noise reduction filtering in CT polymer gel dosimetry: comparison MDCT and CBCT - *Yu Cheng Kuo* (Taiwan) **0218** - 42 - CBCT polymer gel dosimetry for pretreatment verification in adaptive radiation therapy - *Chia Jung Tsai* (Taiwan) **0247** - 43 - Study of radon exhalation as a function of soil water content - *belen juste* (Spain) **0261** - 44 - Estimation for Radiation Dose and Risk of exposure induced cancer death based on EOS imaging system - *Chia Hui Chen* (Taiwan) **0415** - 45 - Radiation dosimetry using thermoluminescence of Nd doped $LiYF_4$ single crystals - *Noriaki Kawaguchi* (JAPAN) **0232** - 46 - Radiation damage evaluation of the optical fiber type OSL small size dosimeter using for the radiotherapy dosimetry - *Yuho Hirata* (Japan) **0105** - 47 - A Radiation Distribution Modeling for Development of Mobile Diagnostic Radiography with Low Dose Exposure - *Yoonsuk Huh* (South Korea) **0203** - 48 - Radon Distribution Modelling in the Typical Vietnamese Building Based on CFD Code - *Sy Minh Tuan Hoang* (Vietnam)
4:00-5:30 pm	**Nonproliferation, Safeguards, and Homeland Security - Mendelssohn - Sara Pozzi** * **0489** - Associated Particle Imaging: History, Recent Advances, and Research Needs - *Jason Hayward* (USA) * **0485** - Nontraditional detectors in nonproliferation and security - *Anna Erickson* (USA) **0063** - Use of Active Neutron Interrogation Post-Irradiation Decay Kinetics to Assess Fissionable Assemblies - *David Chichester* (USA) **0425** - High-order angular correlation of californium-252 fission neutrons and the effect of detector crosstalk - *Rashed Sarwar* (United Kingdom) **0315** - Multiple Monoenergetic Gamma Radiography for Nuclear Smuggling Detection in Commercial Cargo - *Brian Henderson* (United States)
4:00-5:30 pm	**Detector Electronics and Signal Processing - Hussey - Gianluigi De Geronimo** **0286** - Digital Pulse Deconvolution With Adaptive Shaping For Real-Time High-Resolution High-Throughput Gamma Spectroscopy - *Shefali Saxena* (United States) **0312** - Development and applications of miniature TDCR acquisition system for in-situ radionuclide metrology - *Valentin Jordanov* (USA) **0316** - Front-End ASIC for Germanium Strip Detectors - *Eric Wulf* (USA) **0389** - A PET detector performance evaluation platform with FPGA-based 1-bit sigma-delta modulation readout electronics - *Xinyi Cheng* (USA) **0363** - Microstructural Engineering of the Near-UV Quantum Efficiency in VO_2 Thin Film Based Neutron Detectors - *Jason Creeden* (United States) **0412** - Improvement of MRPC time reconstruction based on neural network algorithm - *Fuyue Wang* (China)
6:00-9:00 pm	**Conference Dinner - Henry Ford Museum of American Innovation - The Spirit of Henry Ford**

Time	Session Title - Location - Chair
Thursday June 14th	
7:30-5:00 pm	**Conference Registration - 2nd Floor Concourse -**
8:00-9:30 am	**Nonproliferation, National and Homeland Security Applications - Mendelssohn - Zhong He** * **0488** - Current and Future Radiation Detection Development and Procurement Programs at the Joint Product Leader for Radiological and Nuclear Defense - *Kristen Purvis* (USA) **0182** - End user experience with the SCoTSS Compton imager and directional survey spectrometer - *Laurel Sinclair* (Canada) **0299** - Adaptive, Multi-Energy Computed Tomography (AMECT) for Security Inspection System - *Anatoli Arodzero* (USA) **0320** - PIPS-CZT: A Compact, Low-Cost Atmospheric Radioxenon Detection System - *Steven Czyz* (United States) **0484** - Characterization of a Low Background Proportional Counter for a High Throughput Argon-37 Collection and Measurement System - *Thomas Alexander* (USA) **0156** - Comparison of Pulse Shape Discrimination Performance of Stilbene and Liquid Scintillator under High Count-Rate Conditions - *Willem Langeveld* (United States)
8:00-9:30 am	**Unconventional Radiation Detectors and Techniques - Hussey - Igor Jovanovic** * **0445** - Liquid Xenon Detectors: New Developments and Applications in Dark Matter Detection, Neutrino Physics, and Homeland Security - *Daniel McKinsey* (USA) * **0307** - A large-scale demonstration of scalable TES microcalorimeter readout: The SLEDGEHAMMER gamma-ray spectrometer - *Dan Becker* (USA) **0222** - Determination of individual L-X-ray line emission intensities in the decay of Cm-244 with a high energy resolution metallic magnetic calorimeter - *riham mariam* (France) **0442** - A frequency coded source using transmission nuclear resonance fluorescence for isotope identification and assay - *Ruaridh Macdonald* (United States) **0399** - Measurement of Muon-induced Fast Neutrons from Surrounding Rock in the WATCHBOY detector - *Felicia Sutanto* (USA)
9:30-10:30 am	**Poster IV - Physics, Security Applications, and Signal Processing - Ballroom - Angela Di Fulvio** **0160** - 1 - Radiological Isotopic Categorization using Modern Machine Learning - *Emma Hague* (United States) **0093** - 2 - Pulse shape discrimination with a low-cost digitizer using commercial off-the-shelf components - *Matthew Recker* (USA) **0096** - 3 - Investigating the Non-ideal Behavior of Amptek A111 Charge Sensitive Preamplifier & Discriminator Boards Used in Common Safeguards Neutron Coincidence Counters - *Angela Simone* (USA) **0210** - 4 - Low Cost Current Mode Data Acquisition Board - *SHUANG CUI* (United States) **0215** - 5 - A Channel Number Reduction Technique for SiPM Sensor Arrays by Using a Unity-Gain Amplifier - *Inyong Kwon* (South Korea) **0264** - 6 - RHBD Techniques to Minimize TID Effects from High Radiation Dose in Digital Integrated Circuits - *Sunghoon Kim* (Republic of Korea) **0340** - 7 - Development of an Efficient Multiplexing Scheme for Multichannel Detection Systems Based on Organic Scintillators and Silicon Photomultipliers - *Marc Wonders* (USA) **0410** - 8 - Bayesian unmixing algorithms for identification of gamma sources using radiation portal monitors - *Yoann Altmann* (United Kingdom) **0437** - 9 - Application of Convolutional Neural Networks to Radiation Detection: An Empirical Study - *Carl Britt* (United States of America) **0364** - 10 - Evaluation of Covariant Behavior of Experimental Quantities through Statistical Analysis of Matched Pairs of Pulse Height Data - *RAMKUMAR VENKATARAMAN* (United States of America) **0354** - 11 - On the Fabrication and Characterization of Heterogeneous Composite Neutron Detector with Triple-Pulse-Shape-Discrimination Capability - *Albert Foster* (United States) **0383** - 12 - Development of a Sub-Miniature Gamma Camera for Multimodal Imaging System - *Young Jun Jung* (Republic of Korea) **0393** - 13 - Real-time performance analysis and parameter optimization for spectral anomaly detection - *Rebecca Detwiler* (USA) **0140** - 14 - Comparison of gamma ray localization using system matrixes obtained by either MCNP Simulations or Ray-driven Calculations for Coded-aperture imaging systems - *Manhee Jeong* (USA) **0048** - 15 - Applications of Principal Component Analysis for Energy Reconstruction in Position-Sensitive Semiconductor Detectors - *Bennett Williams* (United States) **0452** - 16 - Improving spatial reconstruction algorithms for near-field imaging - *Timothy Jacomb Hood* (USA) **0454** - 17 - Near-field 3D Spherical Active Coded Aperture Gamma-ray Imaging - *Daniel Hellfeld* (USA) **0480** - 18 - Design and Construction of MATADOR: An Adaptive Time Encoded Imaging System - *Niral Shah* (United States) **0472** - 19 - Developing of Dual Radiation Rotating Scattering Mask to Detect and Localize Neutron and Gamma Sources - *Eric Steinfelds* (United States) **0198** - 20 - A coded aperture imager with DOI scintillators: Monte Carlo simulation - *Wonho Lee* (South Korea) **0066** - 21 - A Study on the Construction Method of Color X-ray Image Using Different Energy Domain Images Obtained by Applying Different Filters - *Giyoon Kim* (Republic of Korea) **0387** - 22 - Scintillator Performance for Fast Neutron Transmission Radiography at the Los Alamos Neutron Science Center - *Amanda Madden* (United States) **0236** - 23 - Development of 4π sensitive Compton gamma imaging for detection of radioactive materials - *Kohei Uema* (Japan) **0404** - 24 - Gamma-Ray Tracking for High Energy Gamma-ray Imaging in Pixelated CdZnTe - *Daniel Shy* (US) **0474** - 25 - Characterization of a Large-Area iQID Imager for Safeguards Applications - *Ardelia Clarke* (United States) **0325** - 26 - Uranium enrichment determination using long-lived delayed neutron time emission - *Jason Nattress* (United States) **0188** - 27 - Information driven safeguards approach for spent fuel dry cask storage using a new remote monitoring system - *athena sagadevan* (United States) **0358** - 28 - Nuclear disarmament verification via resonant phenomena - *Jake Hecla* (USA) **0099** - 29 - Prompt Fission Neutron Anisotropy in Low-Multiplying Subcritical Pu Metal Assemblies - *Tony Shin* (USA)

Time	Session Title - Location - Chair
Thursday June 14th	
9:30-10:30 am	**Poster IV - Physics, Security Applications, and Signal Processing - Ballroom - Angela Di Fulvio** **0157** - 30 - Algorithm development for the non destructive assay of nuclear waste - *Kevin Tree* (United Kingdom) **0317** - 31 - Detection of U-235 in uranium dioxide using TMFDs in active neutron interrogation and implications for HEU interdiction - *Alexander Hagen* (United States of America) **0278** - 32 - Verification and Validation of Atmospheric Transport Models with the UF Training Reactor - *Gabriel Sandler* (Alachua) **0260** - 33 - Measurement Challenges and Approaches in Cargo Scanning to Clear SNM with a 9 MV Bremsstrahlung Beam - *Jason Hayward* (USA) **0205** - 34 - A PIXE/PIGE Facility at the 2-MV KIST Tandem Ion Accelerator: Design and Simulations - *Sy Minh Tuan Hoang* (Vietnam) **0133** - 35 - Enrichment and Multiplication Estimation of Shielded Uranium Assemblies Under Active Interrogation Using Inverse Methods - *Aaron Nowack* (United States) **0104** - 36 - Overburden monitoring with muon detection - *Joshua Flygare* (United States) **0139** - 37 - New generation PIPS detector with improved efficiency for low energy beta counting - *Sofie Put* (Belgium) **0183** - 38 - Determination of Neutron Flux Anisotropy from a Compact DT Generator and its Implications for Shielding Design - *Manish Sharma* (USA) **0184** - 39 - A Monte-Carlo simulation on changes of the leakage radiation of X-ray Collimator by various thicknesses of lead shields - *JaeHyuk Kim* (Rep of Korea) **0258** - 40 - The study of a small volume fast neutron source realized with the electrodisintegration reactions - *Yigang Yang* (China) **0350** - 41 - The ABALONE Photosensor Technology - *Daniel Ferenc* (United States) **0368** - 42 - Fast Timing Micropattern gaseous detector (FTM) simulations for future colliders and medical applications - *YASSER MAGHRBI* (Kuwait) **0378** - 43 - Research and Development of Cold Neutron Microscope in China - *Xiaodong Zhang* (China) **0440** - 44 - Investigating the Temperature Dependence in Organic Scintillator Detectors - *Patricia Schuster* (United States) **0475** - 45 - Irradiation of avalanche photodiodes to achieve increased gain in signal output - *Robert Zedric* (USA) **0271** - 46 - On operational state classification of nuclear reactor facility by fusion of gaseous effluent measurements - *Camila Ramirez* (United States) **0309** - 47 - The development of an advanced airborne gamma-ray spectrometry system and its applications - *Qifan Wu* (China) **0360** - 48 - Development of innovative radiation detection and instrumentation techniques and assessment methods for Radiological Dispersive Device (RDD) - *Alexander Rhoads* (United States) **0405** - 49 - ^{40}K Background Suppression in KSr_2I_5:Eu^{2+} Scintillators - *Eric Lukosi Luko* (US) **0237** - 50 - Design Optimization Studies for Hemispherical Rotational Modulation Collimator (H-RMC) - *Jooyub Lee* (Republic of Korea) **0457** - 51 - Study on Zinc Tungstate Crystals for Dark Matter Search - *Shunsuke Kurosawa* (Japan) **0187** - 53 - Development of high efficiency multi-element gaseous microdosimetric detector - *Ye Eun Kim* (Canada) **0302** - 54 - Automated Drones for Radiation Source Searching with Reinforcement Learning - *Zheng Liu* (United States) **0295** - 55 - Conversion Electron Probabilities of Emission Per Decay for Isotopic Analysis of Special Nuclear Material - *Mara Watson* (USA) **0351** - 56 - Energy Calibration of β/γ Events in Low Temperature Detection for Crystal-based Neutrinoless Double Beta Decay Experiment - *Inwook Kim* (Korea) **0451** - 57 - Characterisation, Performance Assessment and Improvement of Small Anode Germanium (SAGe) Well Detector for Environmental Radio-assay Applications using Pulse Shape Analysis. - *Otobong Thomas* (United Kingdom)
10:30-12:00 pm	**Space and Nuclear Physics Applications - Mendelssohn - Zhong He** * **0062** - High Energy Photon Detectors in the Era of Gravitational-Wave Multi-Messenger Astronomy - *Keith Riles* (USA) * **0420** - High Resolution Mapping of Large-Area Pixelated CZT Detector Planes - *Branden Allen* (USA) **0386** - Radiation Transport Calculations Supporting the Development of a Compton Imager for Planetary Science Gamma-ray Spectroscopy - *James Tutt* (USA) **0081** - Time Projection Chamber (TPC) Detectors for Nuclear Astrophysics Studies With Gamma-Beams. - *Moshe Gai* (USA) **0411** - Next generation experiments with the Active Target Time Projection Chamber - *Yassid Ayyad* (United States)
10:30-12:00 pm	**Scintillation Detectors III - Hussey - Marek Flaska** * **0169** - Handheld Radioisotope Identification Detectors Employing Strontium Iodide and Gadolinium Garnet - *Nerine Cherepy* (US) **0477** - Characterization of wavelength-shifted hygroscopic scintillators using dye-doped polymer films - *Hayley Suitts* (USA) **0400** - Gd based ceramic scintillators - *Jarek Glodo* (United States) **0447** - Towards directional sensitivity to reactor antineutrinos with a segmented pulse shape discriminating (PSD) plastic scintillator detector - *steven dazeley* (usa) **0333** - Development of LuAG Ceramic Scintillator for Future HEP Experiments - *Chen Hu* (United States) **0482** - Enhancing efficiency of semiconductor nuclear voltaic batteries with scintillators - *Sha Xue* (United States)
12:00-1:30 pm	**Lunch Break - On Own -**
1:30-3:00 pm	**Liquid Detectors for Neutrino Detection and Gas Detectors for Nuclear Physics - Mendelssohn - Zhong He** * **0492** - An overview of neutrino detection techniques (mostly at low energies) - *Adam Bernstein* (USA) * **0083** - Neutrino Detection in China - *Guofu Cao* (China) **0241** - Development of a gaseous proton-recoil detector for neutron flux measurements below 1 MeV neutron energy - *Ludovic MATHIEU* (FRANCE) **0303** - Development of new micro-pattern gaseous detector for AT-TPC applications - *Marco Cortesi* (USA) **0390** - Development of a Thick Gas Electron Multiplier based Beta-Ray Detector - *Matthew Bernacci* (Canada)

Time	Session Title - Location - Chair
Thursday June 14th	
1:30-3:00 pm	**Radiation Detection using Mobile/UAVs - Hussey - Simon Labov** **0481** - Mobile Urban Radiation Search (MURS) - *Joseph Curtis* (United States) **0357** - Data Fusion for a Vision-Aided Radiological Detection System: Methods for Tracking Radiological Material - *Kelsey Stadnikia* (United States) **0180** - Flight Performance of the Advanced Radiation Detector for UAV Operations (ARDUO) - *Carolyn Chen* (Canada) **0189** - Autonomous Multi-Robot System for Detection and Localization of Radioactive Sources - *John Bird* (United States) **0396** - Spectral Methods to Detect and Quantify Airborne and Ground-Based Sources - *Rebecca Detwiler* (USA) **0429** - Demonstration of Correlations between Radiological Background Source Terms and Panoramic Video Collected from a Mobile Detector System - *Mark Bandstra* (USA)
3:00-3:30 pm	**Coffee Break - Lobby -**
3:30-5:00 pm	**Plastic Scintillators (DNDO projects) - Mendelssohn - David Wehe** **0103** - An Overview - Root Cause Analysis and Solutions for Plastic Gamma Detector Degradation in Radiation Portal Monitors (RPMs) - *Alan Janos* (USA) **0141** - Nature of Moisture-Induced Fogging Defects in Scintillator Plastic - *Michael Lance* (USA) **0125** - Environmental Conditions Leading to Fogging in Scintillator Plastics - *Nicholas Myllenbeck* (USA) **0059** - Predictive model of scintillator plastic fogging in portals - *Stephen Payne* (USA) **0146** - Plastic scintillators stable for operating in wide ranges of humidity and temperature variations - *Natalia Zaitseva* (USA) **0098** - Investigations of Degradation and Encapsulation of Plastic Scintillator - *Richard Kouzes* (USA)
3:30-5:00 pm	**Active Interrogation Techniques - Hussey - Namdoo Moon** * **0343** - Review of Active Interrogation Techniques - *Joseph Bendahan* (US) **0204** - Cyclotron-based Multiple Monoenergetic Gamma Ray (MMGR) Radiography System for Special Nuclear Material Detection - *Hin Lee* (United States) **0323** - Characterization of a deuteron-driven boron nitride source for use in active interrogation - *Jason Nattress* (United States) **0138** - MV X-ray Compton Scatter Detection System - *SHUANG CUI* (United States) **0344** - Niowave X-ray Interrogation System - *Valeriia Starovoitova* (USA) **0487** - Laboratory demonstration of IED detection using a high flux neutron source - *Katie Rittenhouse* (United States)

6 Abstracts

6.1 Plenary Abstracts

Plenary I

Tuesday 8:45 - 9:45 am in Rackham Auditorium with David Wehe

Imaging Liquid Xenon Detectors for the Search of Dark Matter Weakly Interacting Massive Particles

Aprile, Elena (1)

Physics Department, Columbia University, Irvington (1)

The nature of the dark matter, a dominant component of the Universe, remains one of the most fundamental open question in physics today despite decades of experimental efforts. A leading class of dark matter candidates are Weakly Interacting Massive Particles (WIMPs) and direct detection experiments in deep underground laboratories around the world are actively searching for WIMPs with a variety of detectors and target materials. Liquid xenon detectors such as those developed by the XENON collaboration have shown the best detection capability for WIMPs with a mass larger than 10 GeV/c^2 all the way to 100 TeV/c^2 scale, which is way beyond the reach of the Large Hadron Collider. The current XENON1T experiment, the first to use several thousands of kilograms of Xe in the largest LXe dark matter detector realized to-date, is leading the field with the best detection sensitivity in the region predicted by popular theory models. I will discuss the status of the field and of the XENON1T experiment.

Plenary II

Tuesday 9:45 - 10:45 am in Rackham Auditorium with Zhong He

Modernizing the IAEA verification instrumentation: Lessons from experience and vision to the future

Lebrun, Alain (1)

IAEA (1)

To draw safeguards conclusions, the IAEA continues to heavily rely on verification data acquired in the field by inspectors and data acquired continuously at facilities through unattended systems. Safeguards equipment and associated data collection software have evolved considerably over the last decade, during which new platforms and detectors have been introduced. A long list of new systems spans the main operating areas of safeguards instrumentation including optical surveillance, unattended monitoring, non-destructive assay, remote data transmission and containment. In addition to acquisition of new verification capabilities such as tomography, radiation imaging or fast neutron assay, modernization of the IAEA verification tools includes ongoing development of software packages able to automatically review and evaluate large sets of verification data including surveillance and radiation monitoring data. In partnership with Member State Support Programmes, research institutions and contractors, experts from the Division of Technical and Scientific services are managing multiple projects to continue modernizing the arsenal of technologies available for safeguards verification. Further, the IAEA is now implementing innovative approaches including technology crowd sourcing to identify and evaluate emerging technologies in use in other domains of research or industry that can contribute to improving safeguards verification effectiveness and efficiency. Through multiple examples the talk will address lessons learned from completed projects, highlight current development undertakings and describe the IAEAs vision to future verification technologies.

Plenary III

Tuesday 11:00 - 12:00 pm in Rackham Auditorium with David Wehe

FRIB: The Path to Scientific Discovery

Nazarewicz, Witold (1)

National Superconducting Cyclotron Laboratory, Michigan State University, East Lansing (1)

The Facility for Rare Isotope Beams (FRIB) at MSU will be a world-leading laboratory for the study of nuclear structure, reactions, and astrophysics. FRIB will be essential for gaining access to key regions of the nuclear chart, where the measured nuclear properties will challenge established concepts. Nuclear theory will play a critical role in providing the intellectual framework for the science at FRIB. The long-term vision is to arrive at a comprehensive and unified description of nuclei and their reactions, grounded in the interactions between the constituent nucleons. In this talk, advances in rare isotope research will be reviewed in the context of the overarching scientific questions.

6.2 Tuesday Afternoon

6.2.1 Scintillation Detectors I (Tuesday 1:30 - 3:00 pm in Mendelssohn with David Wehe)

Scintillation Detectors I - Tuesday 1:30 - 3:00 pm in Mendelssohn with David Wehe

Advances in Scintillation Materials

Shah, Kanai S. (1)

RMD, Inc., 44 Hunt Street, Watertown, MA 02472, USA (1)

In this presentation, new developments and emerging trends in scintillation materials research will be discussed. Dual mode elpasolite materials that provide simultaneous detection of gamma-rays and thermal neutrons with high energy resolution (for gamma-rays) and high efficiency (for gamma-rays and thermal neutrons) will be covered in detail. Flexibility of the elpasolite family in providing new compositions through compositional tuning will be emphasized. Examples of new instruments that use these novel scintillators will be provided. Some recent trends in development of high performance scintillators for gamma-ray and high energy X-ray detection will be discussed, including crystalline as well as polycrystalline materials. Finally, low cost detector solutions involving organic scintillators and organic-inorganic scintillator combinations will be covered. This work has been supported by the U.S. Department of Homeland Security, Domestic Nuclear Detection Office, under competitively awarded contract HSHQDC-15-C-B0041 and HSHQDC-15-C-B0042 and US Defense Threat Reduction Agency, under competitively awarded contract HDTRA1-17-C-0053 and HDTRA1-14-C-0020 and US Department of Energy, under competitively awarded contract DE-SC0015793. This support does not constitute an express or implied endorsement on the part of the Government.

Scintillation Detectors I - Tuesday 1:30 - 3:00 pm in Mendelssohn with David Wehe

Organic Spectroscopic Scintillators based on Quantum Dot Nanocomposites

Pei, Qibing (1)

University of California, Los Angeles (1)

Spectroscopic gamma-photon detection has widespread applications for research, defense, and medical purposes. However, current commercial detectors are either prohibitively expensive for wide deployment or incapable of producing the characteristic gamma photopeak. We will report the synthesis of transparent, ultra-high-loading quantum dot/polymer nanocomposite monoliths for gamma scintillation. The efficient Frster resonance energy transfer of the high-atomic-number quantum dots to lower-band-gap organic dyes enables the extraction of quantum-dot-borne excitons for photon production, resolving the problem of severe light yield deterioration found in previous nanoparticle-loaded scintillators. As a result, the nanocomposite scintillator exhibited simultaneous improvements in both light yield (visible photons produced per MeV of gamma photon energy) and gamma attenuation. With these enhancements, a 662 keV Cs-137 gamma photopeak with 9.8% resolution has been detected using a quantum-dot nanocomposite scintillator, demonstrating the potential of such nanocomposite system in the development of high-performance low-cost spectroscopic gamma detectors.

Scintillation Detectors I - Tuesday 1:30 - 3:00 pm in Mendelssohn with David Wehe

Plastic scintillators produced in one day with efficient pulse shape discrimination and thermal neutron capture.

Lim, Allison (1), Yemam, Henok A. (1), Mahl, Adam (1), Latta, Joseph (1), Greife, Uwe (1), Sellinger, Alan (1)

Colorado School of Mines, Golden, CO 80401 (1)

Pulse shape discrimination (PSD) and thermal neutron capture are important methods that can efficiently sort and separate neutron and gamma radiation signals. PSD is currently achieved in plastic scintillators by over-doping poly(vinyl toluene) (PVT) matrices with fluorescent molecules. Meaningful separation of the signals requires addition of >20 wt% 2,5-diphenyloxazole (PPO) fluor in PVT. At these concentrations PPO acts as a plasticizer, negatively affecting the physical properties of the final plastic such as hardness, machinability, and thermomechanical stability. This work addresses these issues by implementing a cost-effective solution using cross linking chemistry via commercially available bisphenol A dimethacrylate (BPA-DM), and a synthesized fluorinated analogue. Both improve the physical properties of over-doped PPO based plastic scintillators without degrading the measured light yield or PSD and Figure of Merit (FoM). FoM values approaching 2.0 are routinely achieved using our process. In addition, the fluorinated analogue enhances the hydrophobicity of the plastic scintillators, which may improve the scintillators resistance to water diffusion and subsequent radiation response degradation. We further report on the synthesis of inexpensive 10B-based molecules that achieve equal to better thermal neutron capture compared to carboranes. The new formulations improve the feasibility of widely deploying long lifetime PSD capable plastic scintillators in large area coverage assemblies.

Scintillation Detectors I - Tuesday 1:30 - 3:00 pm in Mendelssohn with David Wehe

Physical and Scintillation Degradation of Plastic Scintillators

Loyd, Matthew (1,2), Pianassola, Matheus (1,2), Hurlbut, Charles (3), Sideropoulos, Lester (4), Koschan, Merry (1), Melcher, Charles L. (1,2), Zhuravleva, Mariya (1,2)

Scintillation Materials Research Center, University of Tennessee, Knoxville, TN (1), Department of Materials Science and Engineering, University of Tennessee, Knoxville, TN (2), Eljen Technology, Sweetwater, TX (3), Nucsafe, Oak Ridge, TN (4)

Plastic scintillation detectors based on polyvinyl toluene (PVT) have been successfully used in numerous radiation portal monitors for many years. Recent studies have shown that environmental conditions such as repeated cycles of extreme temperature and humidity result in a reduced useful lifetime of these detectors and increased maintenance cost. At present, the mechanisms causing internal fogging, discoloration, and surface crazing are not fully understood. This study investigates the nature of both surface and bulk defects in PVT and PS-based scintillators. Samples for the study were obtained from Eljen and Nucsafe. We used accelerated aging experiments via temperature and humidity cycling in laboratory conditions to create observable defects in small samples (<1 in3). A bench-top environmental chamber has been used to induce temporary and permanent fogging. Optical microscopy was used in conjunction with time-lapse photography to visualize the production and disappearance of temporary fogging defects. A micro-environmental stage has been developed for in-situ optical microscopy at varying temperatures and relative humidities. Optical and scintillation properties have been measured through at various levels through the width of an aged PVT block. In addition to aged samples, fresh PVT, PS, and new experimental formulations have been examined.

Scintillation Detectors I - Tuesday 1:30 - 3:00 pm in Mendelssohn with David Wehe

Characterization of the light output anisotropy of stilbene crystals

Weldon, Robert A. (1), Mueller, Jonathan M. (1), Mattingly, John K. (1)

North Carolina State University (1)

We have measured the scintillation response anisotropy for protons recoiling along the a, b, and c crystalline axes for several energies between 1.3-10 MeV using neutrons produced with the tandem van de Graaff accelerator at Triangle Universities Nuclear Laboratory. Four sets of measurements were performed including (1) measurements using scatter kinematics with an 11.33 MeV neutron beam, (2) measurements using scatter kinematics with a 4.83 MeV neutron beam, (3) measurements of 4.83 MeV full energy deposition events along the a and b axes, and (4) measurements of the event count rate along the a and b axes from a ^{252}Cf neutron source. Each set of measurements found the maximum scintillation response for proton recoils along the a-axis, the minimum along the c-axis, and a value between the two extrema along the b-axis. This result is in disagreement with previous literature which reported the direction of the scintillation response at a maximum for recoils along the b-axis, a minimum along the c'-axis, and a value between the extrema along the a-axis.

Scintillation Detectors I - Tuesday 1:30 - 3:00 pm in Mendelssohn with David Wehe

Charge drift in organic liquids at room temperature

Bergevin, Marc (1), Dazeley, Steven (1), Walsh, Nick (1), Sangiorgio, Samuele (1), Keefer, Greg (1)

Lawrence Livermore National Laboratory (1)

Room temperature Organic Liquid Time Projection Chambers (TPCs) have great potential applications, such as high precision antineutrino physics detectors and high-efficiency neutron camera imaging devices, and dark matter detectors. It is known that electronegative impurities, such as water and oxygen can affect the drift of charge through insulating liquids and, can in turn, impact the functionality of TPCs. Purification is therefore key to improving this technology. We will present progress made at LLNL for purification of a selection of organic liquid scintillators and present the impact of purification on electron-drift properties in organic liquids. We will describe the VADER (Vessels for Assessing the Drift of Electrons Relatively) experimental apparatus used to evaluate charge drift-properties. We will also summarize the status of a new dual-phase organic-liquid noble-gas called DARTH TPC (Demonstration of A Room-Temperature Hydrogenous Time Projection Chamber). This work was performed under the auspices of the US Department of Energy by Lawrence Livermore National Laboratory under contract DE-AC52-07NA27344, release number LLNL-ABS-747336.

6.2.2 Particle/Photon Cancer Therapy, and Other Medical Imaging Applications (Tuesday 1:30 - 3:00 pm in Hussey with Ling-Jian Meng)

Particle/Photon Cancer Therapy, and Other Medical Imaging Applications - Tuesday 1:30 - 3:00 pm in Hussey with Ling-Jian Meng

Current and future needs for in vivo imaging and dose verification in proton beam radiotherapy.

Polf, Jerimy C. (1)

University of Maryland School of Medicine (1)

Purpose: To provide an overview of new radiation detection techniques emerging in particle beam radiotherapy, and discuss their current and future potential to improve cancer treatments and our understanding of cancer biology. Topics covered: The discussion will provide a clinical perspective of the current limitations of particle beam therapy, how they affect patient treatment, and current clinical methods to mitigate these affects. This will be followed by a discussion of the development of techniques to detect and image secondary radiation emitted from the patient during particle beam delivery is being used to help verify proper dose delivery. Next, emerging techniques, such as the measurement of the secondary radiation energy spectra and time of flight profiles, could potentially be used to determine how a tumor and healthy tissues are responding to treatment will be discussed. Finally what directions particle beam therapy is moving and what detection and imaging requirements will be needed to fully integrate these techniques into future clinical workflows will be discussed. Goals: Those attending the talk should gain knowledge about the clinical process of particle beam treatment delivery. Limitations in our ability to precisely delivery particle therapy beams will be discussed as well as current methods to mitigate the effects limitations.

Particle/Photon Cancer Therapy, and Other Medical Imaging Applications - Tuesday 1:30 - 3:00 pm in Hussey with Ling-Jian Meng

Precision imaging of 4.4 MeV gamma rays using a 3-D position sensitive Compton camera

Kataoka, Jun (1), Koide, Ayako (1), Masuda, Takamitsu (1), Taya, Takanori (1), Mochizuki, Saku (1), Sueoka, Koki (1), Tagawa, Leo (1), Fujieda, Kazuya (1), Maruhashi, Takuya (1), Kurihara, Takuya (1), Inaniwa, Taku (2)

Research Institute for Science and Engineering, Waseda University, Japan (1), National Institute of Radiological Sciences, QST, Japan (2)

Imaging of nuclear gamma-ray lines in the 1-10 MeV range is far from being established in both medical and physical applications. In proton therapy, 4.4 MeV gamma rays are emitted from the excited nucleus of either $^{12}C^*$ or $^{11}B^*$ and are considered good indicators of dose delivery and/or range verification. Further, in gamma-ray astronomy, 4.4 MeV gamma rays are produced by cosmic ray interactions in the interstellar medium, and can thus be used to probe nucleothynthesis in the universe. In this paper, we present a high-precision image of 4.4 MeV gamma rays taken by newly developed 3-D position sensitive Compton camera (3D-PSCC). To mimic the situation in proton therapy, we first irradiated water, PMMA and $Ca(OH)_2$ with a 70 MeV proton beam, then we identified various nuclear lines with the HPGe detector. The 4.4 MeV gamma rays constitute a broad peak, including single and double escape peaks. Thus, by setting an energy window of 3D-PSCC from 3 to 5 MeV, we show that a gamma ray image sharply concentrates near the Bragg peak, as expected from the minimum energy threshold and sharp peak profile in the cross section of $^{12}C(p,p)^{12}C^*$.

Particle/Photon Cancer Therapy, and Other Medical Imaging Applications - Tuesday 1:30 - 3:00 pm in Hussey with Ling-Jian Meng

Detection Systems for Range Monitoring in Proton Therapy: Needs and Challenges

Pausch, Guntram (1,2), Berthold, Jonathan (1,3), Enghardt, Wolfgang (1,2), Roemer, Katja (4), Straessner, Arno (3), Wagner, Andreas (4), Werner, Theresa (1,2), Koegler, Toni (1,2)

OncoRay - National Center for Radiation Research in Oncology, Faculty of Medicine and University Hospital Carl Gustav Carus, Technische Universitaet Dresden, Helmholtz-Zentrum Dresden - Rossendorf, Dresden, Germany (1), Helmholtz-Zentrum Dresden-Rossendorf, Institute of Radiooncology - OncoRay, Dresden, Germany (2), Technische Universitaet Dresden, Institute for Nuclear and Particle Physics, Dresden, Germany (3), Helmholtz-Zentrum Dresden - Rossendorf, Institute of Radiation Physics, Dresden, Germany (4)

In-vivo range verification has been a hot topic in particle therapy for more than a decade. In spite of vast efforts made by research groups all over the world, clinical means for routinely monitoring the range of therapeutic proton or carbon ion beams in the patient's body and to ensure their correspondence with the treatment plan are not yet available. The paper reviews recent approaches with focus on prompt-gamma based methods, and points to challenges that have not yet been fully recognized or discussed: First, the macro time structure of treatment beams in common proton therapy facilities requires detection systems with extreme load tolerance, throughput capability, and stability against load variations. Second, the test time available for verifying the range of a single pencil beam spot is of the order of milliseconds, which limits the number of prompt gamma events that can be detected and processed. Tight event selection by passive or active collimation as applied in all imaging setups sharpens the information carried by a valid event but strongly reduces their total number. It might be better to use a multitude of uncollimated detectors acquiring time and energy signatures of every gamma hit with reasonable precision, and to pick up all the pieces of information comprised in timing, energy, and coincidence patterns irrespective of their sharpness. This would maximize the number of valid events on the expense of information sharpness, and could eventually increase the total yield of information exploitable for range verification. Some aspects of such a strategy have already been realized with the Prompt Gamma-Ray Timing (PGT) and the Prompt Gamma Peak Integration (PGPI) techniques proposed recently. Data analysis schemes for a more generalized approach have not yet been developed, but the hardware to be used can already be sketched: Prompt gamma rays should be detected with scintillation detector blocks consisting of single pixels with individual light readouts and independent electronics channels, similar to those developed for applications as PET-MR. Prompt-gamma detection is, however, much more demanding with respect to dynamic range, energy resolution, load acceptance, and stability. The paper will detail and discuss corresponding requirements that represent a challenge for the detector physics community, and report on activities at HZDR and OncoRay to explore the available options.

Particle/Photon Cancer Therapy, and Other Medical Imaging Applications - Tuesday 1:30 - 3:00 pm in Hussey with Ling-Jian Meng

Neutron and charged particle trackers: scintillating fiber devices for particle therapy applications

Traini, Giacomo (1,2), Battistoni, Giuseppe (6), De Simoni, Micol (2,4), Fischetti, Marta (2,4), Gioscio, Eliana (2,5), Mancini Terracciano, Carlo (1,2), Marafini, Michela (2,5), Mattei, Ilaria (6), Mirabelli, Riccardo (1,2), Muraro, Silvia (7), Sarti, Alessio (3,4,5), Sciubba, Adalberto (2,4,5), Solfaroli Camillocci, Elena (1), Valle, Serena Marta (5,6), Patera, Vincenzo (2,4,5)

Dipartimento di Fisica, Sapienza Universita' di Roma, Roma, Italy (1), INFN Sezione di Roma, Roma, Italy (2), Laboratori Nazionali di Frascati dellINFN, Frascati, Italy (3), Dipartimento di Scienze di Base e Applicate per Ingegneria, Sapienza Universita' di Roma, Roma, Italy (4), Museo Storico della Fisica e Centro Studi e Ricerche E. Fermi, Roma, Italy (5), INFN Sezione di Milano, Milano, Italy (6), INFN Sezione di Pisa, Pisa, Italy (7)

The use of C, He and O as beam particles when administering Particle Therapy (PT) treatments is getting more and more widespread as a consequence of the enhanced Relative Biological Effectiveness and Oxygen Enhancement Ratio of such projectiles with respect to protons. The advantages in the tumour control probability, related to the improved efficacy of such incoming radiation, are calling for an online monitor of the dose release spatial distribution. Such technology is currently missing in the clinical routine for all PT treatments. While for protons some preliminary encouraging results have been obtained exploring prompt and $\beta\hat{+}$ annihilation photons detection, the monitoring of treatments involving heavier ions is posing a significant technical challenge. In this contribution the status of Z>1 ions PT treatments monitoring, exploiting the detection of either charged particles or neutrons, is reviewed. While charged particles can be used to provide an online feedback to the beam control system, by correlating the secondary fragments emission profile with the position of the Bragg Peak, neutrons have to be monitored to improve the experimental description of the secondary radiation component that significantly contributes to an undesired and not negligible dose deposition far away from the tumor region, enhancing the risk of secondary malignant neoplasies development after the treatment. In this contribution two tracker detectors, that employ layers of scintillating fibres as active mean, are presented. The first one, named Dose Profiler (DP), is designed for secondary charged fragments measurements and is planned to be used as a beam range monitor in PT treatments with Carbon ions beam. The second one is dedicated to the fast and ultrafast neutron measurements for the characterisation of the secondary neutron component, in the frame of the MONDO (MOnitor for Neutron Dose in hadrOntherapy) project. The DP is currently under development within the INSIDE collaboration (Innovative Solutions for In-beam Dosimetry in hadrontherapy). It is composed of six layers (20 20 cm$\hat{2}$) of square scintillating fibres coupled to Silicon Photo-Multipliers, followed by two plastic scintillator layers. The detector, assembled and tested using a proton beam in 2017, has been included in a clinical trial that will be performed at CNAO in late spring 2018. The DP design and the performances measured using MIPs and protons, as well as the preliminary results obtained in test with anthropomorphic phantoms at CNAO will be reviewed. The MONDO detector, that exploits the tracking of the recoil protons produced in single and double-elastic scattering neutron interaction to measure the neutron kinetic energy and its incoming direction, is a matrix of scintillating fibres, arranged in x-y oriented layers (total active volume 101020 cm$\hat{3}$filled with squared 250μm fibres), that are read-out by a dedicated SPAD sensor produced in collaboration with by FBK (Fondazione Bruno Kessler). The detector is currently under development: the expected performances computed using a MonteCarlo simulation and the preliminary measurements obtained using a proton beam and a tracker prototype will be presented.

Particle/Photon Cancer Therapy, and Other Medical Imaging Applications - Tuesday 1:30 - 3:00 pm in Hussey with Ling-Jian Meng

Monte Carlo code application to the study of 3D neutrons distribution in a radiotherapy bunker and validation with experimental measurements

Noverques Medina, Aina (1), Juste Vidal, Beln (1), Sancho Fernndez, Mara (1), Verd Martn, Gumersindo (1)

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High energy photons created in LinAc interact with nuclei of high Z materials inside the accelerator and liberate neutrons. These neutrons scatter throughout the treatment room and could reach the patient. As neutrons have a high Relative Biological Effectiveness (RBE) even small neutron doses may be harmful to the patient. In this case special radiation protection methods have to be implemented in order to prevent the exposure of patient and medical staff. Unwanted neutrons generated by LinAcs are usually considered negligible for radiotherapy patients, but accounted when designing radiation protection for treatment rooms. This work is focused on the study of the 3D distribution of neutrons generated by the photonuclear reactions when the LinAcs operates with a 15 MeV photon treatment beam. The purpose of this work is to check that the photoneutrons generated do not risk the radiotherapy patients health and clinical staff. In addition, we present an accurate and realistic methodology for the design of the radiotherapy bunkers geometry and the results management with code Monte Carlo (MC). Experimental neutron measurements always require hard works and a lot of time and resources, so Monte Carlo simulations is an alternative method faster and more flexible to provide results. Nevertheless, experimental measurements using two different neutron detectors were performed to validate MC results.

Particle/Photon Cancer Therapy, and Other Medical Imaging Applications - Tuesday 1:30 - 3:00 pm in Hussey with Ling-Jian Meng

High-Resolution Compton Tomography for Small Animal Molecular Imaging

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Radiopharmaceuticals play a central role in modern medicine with many applications in both medical diagnostics and radiotherapy. Specific examples include emission tomography techniques for diagnostic imaging and targeted radiotherapy for cancer treatment. A critical component of the development of new radiopharmaceuticals is the ability to rapidly and efficiently evaluate the relevant pharmacokinetic properties of candidate molecules. Molecular imaging of a living, model system provides a non-invasive means to rapidly assay biodistribution and time-dependent pharmacokinetics of candidate molecules in vivo. In particular, PET and SPECT imaging modalities have been employed with small-animal models (e.g. microPET and microSPECT) to great effect for the preclinical evaluation of pharmaceuticals. However, these well-established small-animal molecular imaging techniques are subject to limitations that prevent their application in some scenarios. PET imaging relies on the (nearly) colinear emission of annihilation photons, thus requiring a positron-emitting radionuclide to provide the imaging signal. SPECT is a collimated imaging modality, thus it is subject to a severe decrement in imaging efficiency with increasing incident photon energy, often becoming impractical for incident photons with an energy greater than several hundred keV. In this work, another tomographic modality based on Compton imaging is proposed to overcome these limitations and broaden the scope of potential applications for small animal molecular imaging. Using a Compton imaging system based on planar HPGe detectors with orthogonal strip segmented electrodes in conjunction with a rotational stage for sample mounting, 3D spectroscopic imaging is demonstrated for gamma-rays with incident energy from 250 keV up to 1500 keV. Image resolution on the order of 5mm for a tomographic system with a 60mm bore radius, or better than 5 degrees FWHM, is demonstrated for 662 keV photons. Reconstruction of more complex (i.e. non-point) source distributions are shown, demonstrating the efficacy of Compton tomography for biodistribution studies in the small-animal regime. This work demonstrates the feasibility of Compton tomography to extend spectroscopic molecular imaging capabilities to gamma-ray energies above 511 keV, enabling the evaluation of non-traditional radionuclides and radiopharmaceuticals, as well as new applications such as theranostic imaging and biological radionuclide uptake studies.

6.2.3 Poster I - New Radiation Detectors (Tuesday 3:00 - 4:00 pm in Ballroom with Mark Hammig)

Poster I - New Radiation Detectors - Tuesday 3:00 - 4:00 pm in Ballroom with Mark Hammig

Scintillation properties of Eu-doped BaFBr crystal

Yanagida, Takayuki (1), Watanabe, Kenichi (2), Okada, Go (1), Kawaguchi, Noriaki (1)

Nara Institute of Science and Technology (1), Nagoya University (2)

Phosphor materials have been used in radiation detectors, and these phosphors are classified into two types, such as scintillators and storage phosphors for dosimeters. The scintillator has a function to convert a high energy ionizing radiation photon/particle to hundreds of visible photons via energy transportation from the host matrix to emission centers immediately. On the other hand, storage phosphors for dosimeters accumulate the incident radiation energy as form of carrier trapping, and these storage phosphors are used in personal dose monitoring and imaging plate applications. Among storage phosphors for dosimeters, Eu-doped BaFBr (Eu:BaFBr) is one of the most common materials. Generally, Eu:BaFBr is used in a ceramic form for imaging plate, and studies on crystal form for scintillator are not common. In this study, we prepared Eu:BaFBr crystal by the Bridgeman method, and evaluated scintillation properties. When we evaluate scintillation emission spectrum under X-ray excitation, an intense emission peak appeared at 395 nm due to 5d-4f transition of divalent Eu ion, and the scintillation decay time under X-ray irradiation was 1.3 s. When we irradiated gamma-rays from 137Cs, a clear photoabsorption peak was observed in the pulse height spectrum, and the scintillation light yield was estimated to be 27000 ph/MeV. By using various radio isotopes, we investigated the relation between peak channels of photoabsorption peak and gamma-ray energies, and confirmed a linear relationship from 60 keV to 1.27 MeV. To the best of our knowledge, this is the first report of Eu:BaFBr crystal on the gamma-ray detector properties.

Poster I - New Radiation Detectors - Tuesday 3:00 - 4:00 pm in Ballroom with Mark Hammig

Scintillation properties of Eu-doped SrF_2 translucent ceramic

Kato, Takumi (1), Usui, Yuki (1), Okada, Go (1), Kawaguchi, Noriaki (1), Yanagida, Takayuki (1)

Graduate School of Materials Science, Nara Institute of Science and Technology (1)

Inorganic scintillators are one of the luminescent materials which absorb and instantly convert the energy of incident ionizing radiation to thousands of ultraviolet/visible photons. The interest in new scintillation materials is promoted by an increasing number of new applications in medical, security, environmental monitoring and particle physics. Today, almost all the scintillators used in practice are bulk single crystals due to the outstanding properties such as high transparency, and high light yield. However, recent studies have opened up a new possibility of using transparent ceramics as scintillators material thanks to the recent advancement of improved ceramic synthesis technologies developed in the laser field. Compared with the single crystals, ceramic scintillators have many advantages such as the mechanical strength, flexible geometric shape to be prepared and cost effectiveness. Furthermore, they have also been found to show an equivalent performance as a scintillator compared with the single crystal form. Up to now, our groups have been developing and evaluating BaF_2 and CaF_2 transparent ceramic for scintillator applications. In this study, to extend our previous research, we developed Eu-doped SrF_2 translucent ceramics and characterized scintillation properties. The Eu-doped sample showed emission peaks at 300, 420 and 580 nm, and it was thought that these origins were self-trapped excitation, 5d-4f transitions of Eu^{2+} ions and 4f-4f transitions of Eu^{3+} ions, respectively. We measured pulse height spectra under ^{57}Co -ray irradiation. The Eu-doped sample shows clear photoabsorption peak, and the light yields of was 17,900 photons/MeV.

Poster I - New Radiation Detectors - Tuesday 3:00 - 4:00 pm in Ballroom with Mark Hammig

X-ray induced luminescence properties of Ce-doped $Ca_3Sc_2Si_3O_{12}$ single crystal

Kato, Takumi (1), Usui, Yuki (1), Okada, Go (1), Kawaguchi, Noriaki (1), Yanagida, Takayuki (1)

Graduate School of Materials Science, Nara Institute of Science and Technology (1)

Inorganic scintillators, which convert high energy ionizing radiation to thousands of visible photons, have been playing a major role in many fields of radiation detection, including medical imaging, security, oil-logging, environmental monitoring, astrophysics and particle physics. The emission mechanism of common scintillators is composed of three processes converting a radiation into a lot of electrons, transporting electrons to emission centers and emitting photons by electron-hole recombination. Thus, a scintillation light yield (LY) is greatly correlated with a quantum yield (QY) in photoluminescence (PL), and it is common that a phosphor with a high QY shows a high LY. For examples, Ce-doped $Y_3Al_5O_{12}$ (YAG) and $Gd_3Al_2Ga_3O_{12}$ (GAGG) have both high QY and LY. In this study, we focused on $Ca_3Sc_2Si_3O_{12}$ (CSSG) of which the crystal structure is the same garnet as YAG and GAGG. PL properties of a Ce-doped CSSG were reported by Shimomura et al. in 2007, and it emits strong yellowish green light due to 5d-4f transitions of Ce^{3+} ions under excitation light. On the other hand, no report about scintillation properties of Ce-doped CSSG has been found although already scintillation properties of Pr-doped CSSG were reported. Therefore, in this study, we synthesized Ce-doped CSSG single crystal using by the floating zone (FZ) method. We prepared undoped as a reference, and three different concentration (0.01, 0.1 and 1.0 %) Ce-doped CSSG. After the synthesis, we measured PL spectrum, PL decay constant and QY as PL properties, and scintillation spectrum, scintillation decay constant and pulse height spectrum as scintillation properties. The 0.1% Ce-doped CSSG possesses the highest QY among the present samples, and it reached to 80 %. When we measured X-ray induced scintillation spectra, the 0.1 % Ce-doped CSSG showed an intense emission band peaking around 510 nm, and the scintillation decay constants was 60 ns. This value was reasonably consistent with that of Ce-doped luminescence materials reported by earlier study. The samples excluding the 1.0% Ce-doped CSSG showed clear photoabsorption peak. The light yield was estimated on a comparison with commercial NaI:Tl. The light yield of the 0.1 % Ce-doped CSSG is 4,000 ph/MeV. To the best of our knowledge, this work is the first to report the QY and LY of the Ce-doped CSSG.

Poster I - New Radiation Detectors - Tuesday 3:00 - 4:00 pm in Ballroom with Mark Hammig

Crystal growth, crystal structure, optical and scintillation properties of self-activated Cs4YbI6

Wu, Yuntao (1,2), Li, Qi (3,4), Rutstrom, Daniel J. (1,2), Greeley, Ian (1,2), Loyd, Matthew (1,2), Stand, Luis (1,5), Zhuravleva, Mariya (1,2), Koschan, Merry (1), Melcher, Charles L. (1,2,5,6)

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A self-activated Cs4YbI6 single crystal was grown by the vertical Bridgman method. Crystal structure refinements verified the phase purity and the trigonal crystal system with a space group of R-3c. Luminescence and scintillation properties were systematically studied. Upon ultraviolet light (360 nm) excitation, the Cs4YbI6 crystal exhibits bluish-green emission centered at 450 and 480 nm, due to spin-allowed and spin-forbidden transitions of Yb2+ activators. The lifetimes of corresponding emission bands at room temperature are tens and hundreds of nanoseconds, respectively. X-ray excited radioluminescence spectrum is dominated by the spin-forbidden transition of Yb2+ at 480 nm. The absolute light yield is 2700200 photons/MeV with a principal scintillation decay time of 33 ns. The physical explanation for the low light yield observed is proposed.

Poster I - New Radiation Detectors - Tuesday 3:00 - 4:00 pm in Ballroom with Mark Hammig

Improvement of europium doped strontium iodide scintillating crystals by aliovalent codoping

Wu, Yuntao (1,2), Li, Qi (3,4), Rutstrom, Daniel J. (1,2), Greeley, Ian (1,2), Loyd, Matthew (1,2), Stand, Luis (1,5), Zhuravleva, Mariya (1,2), Koschan, Merry (1), Melcher, Charles L. (1,2,5,6)

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Excellent energy resolutions of inorganic scintillators are essential to the performance of the radiation detectors for gamma-ray spectroscopy. Europium doped strontium iodide (SrI2:Eu2+) is one of the most cutting-edge inorganic scintillators mainly due to its low radioactive background, high light yield, and excellent gamma-ray energy resolution. Nevertheless, there are still many studies attempting to optimize the energy resolution of SrI2:Eu2+, but none have been successful so far. In this work, we achieve an improvement of energy resolution of SrI2:Eu2+ single crystals by aliovalent codoping, namely Zr4+ codoping, and the underlying explanations are provided based on the understanding of the electronic structure and defect structure. The energy resolution of Bridgman-grown SrI2:Eu2+ single crystals is improved from 2.800.05% to 2.500.05% at 662 keV and from 5.40.1% to 5.00.1% at 122 keV by Zr4+ codoping, and without light yield deterioration.

Poster I - New Radiation Detectors - Tuesday 3:00 - 4:00 pm in Ballroom with Mark Hammig

Comparative study of scintillation properties of CsBr:Tl transparent ceramic and single crystal

Kimura, Hiromi (1), Kato, Takumi (1), Nakauchi, Daisuke (1), Okada, Go (1), Kawaguchi, Noriaki (1), Yanagida, Takayuki (1)

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Scintillators have a function to convert an absorbed energy of ionizing radiation such as X- and -rays into low energy photons immediately. Scintillators have been used in various fields such as medicine, security and high energy physics. In the practical applications, Tl doped alkali halide scintillators such as NaI:Tl and CsI:Tl are used for a long time. They have notable properties in single crystal form such as high light yield of several tens thousands photons/MeV and high effective atomic number (Z_{eff} >50). Among alkali halide materials, CsBr has also attracted much attention as a scintillator because CsBr has high effective atomic number (Z_{eff} = 50.1). Recently we found that CsBr:Tl had a high scintillation light yield in a transparent ceramic form, and higher scintillation performance would be expected in a single crystal form. In this study, we have grown CsBr:Tl single crystal by the vertical Bridgman-Stockbarger method, and then investigated the scintillation properties, in comparison with CsBr:Tl transparent ceramic synthesized by spark plasma sintering. As a result of scintillation properties, we confirmed that both samples show scintillation emission characterized by peaking around 350 and 510 nm. These origins are attributed to and $^3P_1{}^1S_0$ transitions of Tl^+ ion and off-center STE localized near the Tl^+ ion, respectively. To evaluate a scintillation light yield, we measured a pulse height spectra by using ^{137}Cs. In the single crystal sample, the photoabsorption peak was clearly observed, and the scintillation light yield resulted 25,000 ph/MeV while that of the ceramic was 18,000 ph/MeV. To evaluate the linearity between -ray energies and peak channels, several radiation source including ^{109}Cd, ^{57}Co, ^{133}Ba, ^{22}Na and ^{137}Cs were used, and we can confirm a good linearity to the -ray energy.

Poster I - New Radiation Detectors - Tuesday 3:00 - 4:00 pm in Ballroom with Mark Hammig

Scintillation characteristics of a heterogeneous composite detector in shards geometry

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We report the observation of an intermediate time characteristic of pulses produced by a heterogeneous composite detector exposed to γ radiation. The 7.2 cm x 5.1 cm cylindrical composite detector consists of polyvinyl toluene (PVT) loaded with 7.5% by weight lithium glass in a 500 μm diameter shard geometry. When the detector is exposed to a (^{60}Co) γ-ray source, a continuum of intermediate pulse shapes in observed, corresponding neither to characteristic scintillation decay constant originating from glass nor from PVT. The mechanism for production of these intermediate pulse shapes is the simultaneous energy deposition in PVT and glass, which can occur when the electron produced in gamma interaction with any scintillator component has a mean free path that exceeds the average distance between adjacent glass shards. The resulting features seen in pulse shape discrimination space may impact the gamma rejection performance of heterogeneous composite detectors, including setting the limit to the glass content that provides an acceptably small gamma misclassification rate.

Poster I - New Radiation Detectors - Tuesday 3:00 - 4:00 pm in Ballroom with Mark Hammig

Development of two-dimensional quantum confinement material $(C_6H_5C_2H_4NH_3)_2Pb_{1-x}Sr_xBr_4$ for scintillation detectors

Akatsuka, Masaki (1), Kawano, Naoki (2), Kato, Takumi (1), Nakauchi, Daisuke (1), Okada, Go (1), Kawaguchi, Noriaki (1), Yanagida, Takayuki (1)

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The excitons with quantum confinement effect exhibit a high emission intensity and fast lifetime, so scintillators with such exciton luminescence has attracted much attention for a long time. In the previous study, organic-inorganic layered perovskite type compounds were reported to form a two-dimensional nanostructure, and a highly efficient exciton luminescence was observed in photoluminescence. Moreover, such a material shows a high scintillation light yield with fast decay time under X- and gamma-ray irradiations. In order to expand our knowledge on the organic-inorganic layered perovskite type scintillators, in this study, we prepared new single crystalline materials such as $(C_6H_5C_2H_4NH_3)_2Pb_{1-x}Sr_xBr_4$ (x = 0.1, 0.25, 0.5) by the poor-solvent diffusion method and then evaluated the scintillation properties as a function of the ratio of Sr/Pb ratio. By tuning Sr/Pb ratio, a change of luminescence properties due to exciton can be expected. When we evaluated scintillation emission spectrum under X-ray excitation, the emission peak appeared around 440 nm owing to exciton generated in the inorganic layer. The scintillation decay curves under the X-ray irradiation were approximated by sum of three exponential decay functions, and these decay components were $\sim$ 12, $\sim$ 40 and $\sim$ 230 ns. We obtained the pulse height spectra of ^{137}Cs gamma-rays measured by using $(C_6H_5C_2H_4NH_3)_2Pb_{1-x}Sr_xBr_4$ (x = 0.1 and 0.25). In both the spectra, a photoabsorption peak and Compton edge were clearly observed, and scintillation light yields, estimated by comparing with Ce-doped Gd_2SiO_5 which had a similar emission wavelength with our samples, were 19700 and 18500 ph/MeV for x = 0.1 and 0.25 samples, respectively. By using various radioisotopes, we investigated the relation between peak channels of photoabsorption peak and gamma-ray energies, and confirmed a linear relationship from 22 keV (^{109}Cd) to 662 keV (^{137}Cs) in these two samples.

Poster I - New Radiation Detectors - Tuesday 3:00 - 4:00 pm in Ballroom with Mark Hammig

Comparative study of Ce-doped $Tb_3Al_5O_{12}$ crystal scintillators with different Ce-concentrations

Nakauchi, Daisuke (1), Okada, Go (1), Kawaguchi, Noriaki (1), Yanagida, Takayuki (1)

Nara Institute of Science and Technology (1)

Scintillators have been utilized to detect high-energy photons and particles in various fields including medical imaging, security, astrophysics, high-energy physics, and well-logging. In general, the desired characteristics of scintillators include high light yield (LY), short decay time, high energy resolution, low afterglow, and high effective atomic number especially for X- and gamma-ray detections. To date, Ce-doped rare-earth aluminum garnet ($RE_3Al_5O_{12}$, RE=Y, Gd, Lu) scintillators have been intensively studied owing to their distinct scintillation properties such as high LY and fast response. We previously investigated scintillation properties of Ce-doped $Tb_3Al_5O_{12}$ (TAG) bulk crystals and confirmed a notably high LY (57,000 photons/MeV). To extend our previous studies on Tb-based garnet materials for scintillator applications, we studied TAG single crystals with different Ce-concentrations. Under X-ray irradiation, the samples exhibit scintillation with a broad emission band peaking at around 550 nm as well as a few sharp peaks at 580 nm. The former emission is attributed to the 5d-4f transitions of Ce3+ while the latter seems to be the 4f-4f transitions of Tb^{3+} ($^5D_4{}^7F_4$). From the pulse height spectrum of ^{137}Cs gamma-ray measured using Ce:TAG crystals, all the samples show clear photoabsorption peaks. From the peak position, the 3% Ce-doped sample seems to exhibit the highest LY.

Poster I - New Radiation Detectors - Tuesday 3:00 - 4:00 pm in Ballroom with Mark Hammig

Comparative study of Eu-doped $SrAl_2O_4$ crystal and translucent ceramic for X- and gamma- ray measurements

Nakauchi, Daisuke (1), Nakamura, Fumiya (1), Okada, Go (1), Kawaguchi, Noriaki (1), Yanagida, Takayuki (1)

Nara Institute of Science and Technology (1)

Luminescent materials have been utilized in radiation detection, and they are classified into two types such as scintillators and storage-type phosphors. Scintillators convert a single quantum of ionizing radiation into thousands of low energy photons immediately, so they have been playing an important role in various fields of radiation detections including medical imaging, security and so on. On the other hand, storage-type phosphors have a function to store and accumulate the incident radiation energy and emit a light with external stimulations of light or heat. In our previous study, we have shown that singly Eu-doped $SrAl_2O_4$ crystals show notably high scintillation light yield (46,000 photons/MeV). In this study, we prepared Eu:$SrAl_2O_4$ translucent ceramic for the first time, and the scintillation properties of translucent ceramic and single crystal are evaluated for comparison. Under X-ray irradiation, the samples exhibit scintillation with a dominant broad emission around peaking at 520 nm. Suggested from the spectral shape, the emission origin would be due to Eu^{2+}. From the pulse height spectra of ^{137}Cs gamma-rays measured using Eu:$SrAl_2O_4$, the light yield of the crystal and ceramic samples are 26,000 and 5,500 ph/MeV, respectively.

Poster I - New Radiation Detectors - Tuesday 3:00 - 4:00 pm in Ballroom with Mark Hammig

Auger-free luminescence characteristics of $Cs(Ca_{1-x}Mg_x)Cl_3$

Takahasi, Keisuke (1), Koshimizu, Masanori (1), Fujimoto, Yutaka (1), Yanagida, Takayuki (2), Asai, Keisuke (1)

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Measurements of high counting rates of radiation are required for various applications. The development of fast-response scintillators is one of the promising ways to solve the issue. For this, we focused on Auger-free luminescence (AFL) in inorganic crystals. AFL is the radiative recombination of the outermost core hole with a valence electron. AFL is known to be a fast luminescence process with a typical decay time constant on the order of nanoseconds or less. A group of materials that exhibit AFL are CsCl-based compounds, e.g., CsCl, $CsCaCl_3$, and $CsMgCl_3$. However, there is no group of materials suitable for use in fabricating scintillators. Therefore, it is necessary to search for new materials that exhibit more efficient AFL. To create new CsCl-based materials that exhibit AFL, we aimed to produce AFL-exhibiting $Cs(Ca_{1-x}Mg_x)Cl_3$. In this study, we fabricated crystals of $Cs(Ca_{1-x}Mg_x)Cl_3$ over the entire range of mole fractions, and characterized their luminescence and scintillation properties, which depend on the Cs/Mg proportion in the crystals. In the luminescence spectra of $Cs(Ca_{1-x}Mg_x)Cl_3$ for excitation at 200 nm, corresponding to the excitation within the band gap, we observed a broad peak for $Cs(Ca_{1-x}Mg_x)Cl_3$. The results indicate that the crystals of $Cs(Ca_{1-x}Mg_x)Cl_3$ had at least one kind of defects or impurity sites involved in the luminescence. In the luminescence spectra for excitation at 150 nm, corresponding to the interband excitation, we observed broad bands that may be ascribed to self-trapped excitations (STEs) for $CsCaCl_3$, $Cs(Ca_{0.75}Mg_{0.25})Cl_3$ and $Cs(Ca_{0.25}Mg_{0.75})Cl_3$. In addition, we observed bands for $Cs(Ca_{0.50}Mg_{0.50})Cl_3$ and $CsMgCl_3$ at a wavelength similar to that in the case for excitation at 200 nm. In the X-ray-excited radioluminescence (XRL) spectra, we observed bands and shoulders corresponding to the intrinsic AFL for both $CsCaCl_3$ and $CsMgCl_3$ crystals. For the mixed crystals, we also observed bands whose wavelengths are similar to those for $CsCaCl_3$. Therefore, these bands may also be ascribed to AFL. In the scintillation temporal profiles of $Cs(Ca_{1-x}Mgx)Cl_3$, we observed fast components having decay time constants of 12 ns, which are typical for CsCl-based AFL. The proportions of the fast components are very large, i.e., at least 85%. $CsMgCl_3$ exhibited the fastest decay time, 1.1 ns, and the least proportion of 85% for the fast component.

Poster I - New Radiation Detectors - Tuesday 3:00 - 4:00 pm in Ballroom with Mark Hammig

Development of liquid scintillators based on mixed-organic solvents containing ^{6}Li for neutron detection

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The demand for neutron detectors for use in the search for natural resources and in security system is increasing significantly. In this regard, detectors containing ^{3}He are typically used. However, because of the shortage of ^{3}He, an alternative approach to fabricating neutron detectors is necessary. In this context, ^{6}Li has a larger cross-section for the reaction with neutrons and is much more earth-abundant than ^{3}He, and various approaches to using ^{6}Li have been developed. However, in general approaches such as the use of inorganic scintillators containing ^{6}Li, it is difficult to achieve both scalability and low cost. To solve this issue, the use of liquid scintillators is suitable. In this study, we propose developing liquid scintillators based on mixed-organic solvents containing ^{6}Li. Powder of ^{6}LiCl and the phosphors, DPO and POPOP, were added to a mixed organic solvent consisting of toluene and ethanol for use as a liquid scintillator. We report the fabrication method and scintillation properties of a liquid scintillator containing ^{6}Li compounds. The absorption spectra of the samples show that the samples are transparent at scintillation wavelengths over 400 nm. In X-ray-induced radioluminescence (XRL) spectra, peaks were observed at the wavelength expected to produce scintillations (430 nm). A fast component having a decay time is observed in the scintillation temporal profiles, and the behavior of typical organic scintillators is obtained. These results confirm that the approach of using mixed organic solvents produces a liquid scintillator. In the pulse height spectra obtained with a ^{252}Cf neutron source, the peaks of both samples are observed at 198 and 170 channels in toluene-to-ethanol weight ratios of 6:4 and 4:6, respectively. Compared with the channel of the energy peak for a Li-glass scintillator (GS), the light yields of these samples are 1200 and 1000 photons/neutron, respectively. Considering the solubility of ^{6}Li, it is confirmed that the light yield is lower for increasing solubility of ^{6}Li. In conclusion, using the mixed organic solvent approach, we succeeded in developing a scintillator containing ^{6}Li for neutron detection.

Poster I - New Radiation Detectors - Tuesday 3:00 - 4:00 pm in Ballroom with Mark Hammig

Radiochromic properties of organic films based on a diarylethene molecule

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Radiochromic materials have long been used for radiation detection and as a simple and convenient means of radiation imaging and quantifying the dosage of the radiation via a visible change in color upon irradiation. Many inorganic materials are known to exhibit radiochromism; however, organic materials exhibiting radiochromism are relatively rare. Organic radiochromic materials are useful for dosimetry and radiation imaging in applications in which tissue-equivalence is an issue. In addition, owing to their flexibility and plasticity, organic materials can be used in complex systems such as the human body. Recently, several research groups including ours, have developed radiochromic materials based on photochromic molecules. Photochromism is the reversible change in color of an organic molecule upon irradiation with light of different wavelengths, which mainly arises from isomerization. Radiochromism is achieved in molecules that undergo isomerization under ionizing irradiation via two processes: (i) through the direct excitation of the molecule by the ionizing radiation and (ii) through isomerization owing to the absorption of scintillation. In this study, we fabricated radiochromic materials based on a photochromic diarylehene molecule, 2,3-bis(2,4,5-trimethyl-3-thienyl)maleimide (BTTM). BTTM has an open-ring structure in its ground state, which undergoes isomerization to a closed-ring structure upon UV irradiation, accompanied by a change in color from yellow to red. Herein, we present the radiochromic behavior of BTTM-based materials, with an emphasis on the differences between the processes (i) and (ii) mentioned above. In the absorption spectra of a sample before and after UV irradiation, absorption bands appear at 370 and 520 nm, which correspond to the absorption of the closed-ring isomer. On the other hand, in the absorption spectra of the sample before and after X-ray irradiations, we observed an increase in absorbance at 570 nm with an increase in X-ray dose, while a decrease in absorbance was observed at 360 nm. These changes indicate that the BTTM-based films exhibit radiochromic behavior. Interestingly, the changes in the absorption spectra are quite different from those in the absorption spectra after UV irradiation. The absorbance at 560 nm as a function of X-ray dose was enhanced for samples with high BTTM concentrations. For the sample without the phosphor molecule b-PBD, the absorbance gradually decreased to the original value after irradiation with X-rays. On the other hand, for the sample with b-PBD, the absorbance after X-ray irradiation hardly changed. In addition, the absorption spectra were initialized after irradiation with visible light in both cases. These results strongly suggest that BTTM changes into different isomers with different thermal stabilities at room temperature after irradiation by UV light and X-rays.

Poster I - New Radiation Detectors - Tuesday 3:00 - 4:00 pm in Ballroom with Mark Hammig

New Scintillating Bolometer Crystals for Rare Particle Detection

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In the search to better understand the fundamental physics of our universe, a crucial goal is elucidating the nature of fundamental particles. Thus, discovering new weakly interacting particles, such as dark matter, and increasing our understanding of known ones, such as neutrinos, are high priority research areas in nuclear physics. The Majorana nature of neutrinos is one of the most important questions being pursued in physics today. This has given the search for neutrinoless double beta decay ($0\nu\ \beta\ \beta$) a high priority among proposed nuclear physics experiments. If the neutrino is a Majorana particle, then, in models of Leptogenesis, the neutrino is responsible for the matter-antimatter asymmetry that we observe in the universe. Recent advances in cryogenic bolometers have significantly improved detector sensitivity and background rejection, with sub-keV thresholds now possible. The available detectors, however, are still not sensitive enough to solve this mystery, and the next generation of detectors will need to better discriminate background events. Scintillating bolometers are one of the more promising approaches to further push the limits of sensitivity. The research reported here investigates the synthesis, purification, and crystal growth of suitable scintillation materials, and the fabrication and testing of these materials as bolometers at cryogenic temperatures. With an objective of detecting rare events such as neutrinoless double beta decay, we considered scintillating crystals that contain an isotope known to have double beta decay. In this work, we report on two different compositions of sodium molybdate crystals ($Na_2Mo_2O_7$ and $Na_2Mo_4O_{13}$), as well as $LiInSe_2$ for other nuclear physics rare event experiments. This work has been supported by the US Department of Energy SBIR grant No. DE-SC0015200, and by funding from the Massachusetts Institute of Technology.

Poster I - New Radiation Detectors - Tuesday 3:00 - 4:00 pm in Ballroom with Mark Hammig

Monte Carlo simulation of CLYC-PVT composite scintillators for gamma/neutron detection

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We report on the development of a Geant4 Monte Carlo model of scintillation in CLYC-PVT composite scintillators. The simulated pulse height spectrum of a 9-CLYC-pillar composite predicted an energy resolution of 5.3% at 662 keV and closely matched measured results with 4.7% at 662 keV. In a two-pillar model, composite scintillation performance was correlated to the energy resolutions and light yields of the individual CLYC pillars. Finally, a pulse shape discrimination plot was generated with all the characteristics of the experimental plot, which are explained by corresponding physics models in the simulation. Future work will test the model against more experiments and assist in the design of handheld and backpack radiation detectors using CLYC-PVT. This work has been supported by the U.S. Department of Homeland Security, Domestic Nuclear Detection Office, under competitively awarded contract HSHQDN-17-C-00008. This support does not constitute an express or implied endorsement on the part of the Government.

Poster I - New Radiation Detectors - Tuesday 3:00 - 4:00 pm in Ballroom with Mark Hammig

Characterization of a 13 CLYC Crystal

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A compact unattended sensor is being developed for detection of anomalous radiation sources. The sensor uses a CLYC (Cs_2LiYCl_6:Ce) scintillator for combined gamma-ray spectroscopy and thermal neutron detection. Since the sensor must have an overall diameter of 2 or less, a custom-ordered 13 CLYC crystal was procured to provide more sensitivity than the more traditional 11 size. The detector was characterized using both 1 and 2 super bialkali PMTs. The energy resolution approached 5.5% FWHM at 662 keV with the source in certain positions, but the light output also depended on the location of the source. Related characteristics and testing of the detector are reported.

Poster I - New Radiation Detectors - Tuesday 3:00 - 4:00 pm in Ballroom with Mark Hammig

Position sensitive scintillation detector using polymer-based plastics and pulse shape analysis

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Position sensitive detector systems typically achieve greater spatial resolution by reducing the active area of the sensor whilst increasing the number of sensors in the detector array. Most position sensitive detectors, specifically for medical imaging, utilize position-sensitive photomultiplier tubes (PMT) or position-sensitive avalanche photo-diode arrays. These methods require a number of digital channels equal to the number of sensors and result in an increase in the size, cost and complexity of the associated digital acquisition electronics. Furthermore, due to the requirement for improved medical imaging systems, almost all position sensitive radiation detector research is directed towards the detection and localisation of electromagnetic radiation for systems such as MRI, PET and SPECT. It is hypothesized that by adopting various scintillator geometries and doping agents pulse-shape features can be induced that can then be detected, analyzed and used to infer the location of the particle interaction. The fabrication of a novel position sensitive detector, constructed from a recently developed polymer-based scintillator material, is reported. The detector is constructed from laminated discs of the scintillator material and crucially uses only a single PMT and digital acquisition channel. The material could permit low volume, low cost detector fabrication with an infinite degree of freedom of form and composition; properties that influence signal characteristics. Furthermore, neutron sensitive variants of the material have also recently been developed. Determining the location of a particle interaction within a laminated detector by pulse-shape analysis of the signal originating from a single PMT would reduce the costs associated with digitizing electronics, increase portability and could potentially increase spatial resolution. A position sensitive detector of this sort that is also sensitive to neutrons has uses in nuclear security, safeguards, imaging and tomography.

Poster I - New Radiation Detectors - Tuesday 3:00 - 4:00 pm in Ballroom with Mark Hammig

Evaluation of PVT Scintillators for Fast Neutron Imaging

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Two Polyvinyltoluene (PVT) scintillators, provided by Lawrence Livermore National Laboratory (LLNL), with different dimensions have been characterized in terms of resolution and relative light output at the Ohio State University Research Reactors (OSURR) beam facility. Shielding with lead and lithiated glass reduced thermal neutron, gamma ray and x-ray content in the beam. Scintillators were exposed to fast neutrons, and images were obtained with a setup consisting of an EMCCD camera, a mirror and a light-tight apparatus. All scintillators had the same diameter of 4 with black backing, but had different thicknesses of 3 mm and 10.5 mm. A plastic screw and a phantom fabricated from High Density Polyethylene (HDPE) were imaged. The objects were also placed inside a 1.5 cm thick lead cask, demonstrating neutrons ability to image through shielding materials with a high atomic number. The HDPE block, 6 in thickness, was used to create an edge profile to generate the modulation transfer function, which gave image resolution. Resolution of the 3 mm thick scintillator is better than the 10.5 mm thick scintillator as increasing thickness caused more photon scattering, degrading image resolution. The 10.5 mm thick scintillator has higher relative light output, obtained from the gray scale value, since the thicker materials would have more attenuation power for the neutron. This study investigates how thickness affects the performance of PVT scintillators in fast neutron detection.

Poster I - New Radiation Detectors - Tuesday 3:00 - 4:00 pm in Ballroom with Mark Hammig

Cherenkov Detectors for Gamma and Neutron Detection

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Cherenkov Radiation is a phenomenon that takes place when an energetic charged particle, an electron for example, is travelling faster than the speed of light through a medium that has a refractive index greater than 1 and interacting with the molecules of that medium to generate photons with wavelengths in the range of the violet color creating a blue glow. The objective of this work is to engineer, manufacture and test Cherenkov scintillation detectors for detection of high energy of gammas and neutrons with increasing sensitivity. In this work, we will entail the development of efficient Cherenkov scintillation detectors, present measurement results of the response of representative samples to gamma and neutron radiation, and provide the simulation results of the expected response of a target detector.

Poster I - New Radiation Detectors - Tuesday 3:00 - 4:00 pm in Ballroom with Mark Hammig

Tensile, flexural, and light output measurements of selected organic scintillators for evaluation of their potential as structural materials

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In order to design structures, such as unmanned vehicle structures, out of plastic scintillator, e.g., for radionuclide searches, suitable materials must either be identified or developed. In searches utilizing unmanned vehicles, the absence of an additional detector attached to the vehicle body as a payload could enable the vehicle to travel faster, carry a longer lived battery, or carry other auxiliary equipment which may be useful for search and/or response. To this end, two mechanical characteristics of selected organic scintillators manufactured by Eljen technologies, Sandia Livermore, and Lawrence Livermore National Lab have been measured. Specifically, tensile and flexural tests have been performed to ASTM specifications on organic scintillators with polyvinyl toluene (PVT), polystyrene (PS), or crosslinked versions of these bases. In addition to these mechanical tests, light output testing was performed in order to quantify whether crosslinking affects light output in the particular scintillator compositions we measured. We found that the tested plastic scintillators have strengths that are comparable to the properties of common structural plastics used in unmanned aerial vehicles. We also show that crosslinking EJ-200 PS increases its flexural strength while affecting its light output in a negligible way. Keywords: Unmanned radionuclide search, organic scintillators, mechanical testing Acknowledgements This material is based on work supported in part by BAE Systems Contract No. W911NF-08-2-0004, in part by the Department of Energy National Nuclear Security Administration through the Nuclear Science and Security Consortium under Award Number DE-NA-0003180, and in part by the Defense Threat Reduction Agency grant number HDTRA 1-18-1-005.

Poster I - New Radiation Detectors - Tuesday 3:00 - 4:00 pm in Ballroom with Mark Hammig

Effect of Li^+ codoping on $(Lu_{0.75}Y_{0.25})_3Al_5O_{12}:Pr^{3+}$ single crystal scintillators

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Aliovalent codoping of garnet scintillators is known as a method to improve scintillation properties either by altering the valence state of the activator or by affecting the trapping behavior within the lattice. Recent reports have described the scintillation performance of cerium doped garnets codoped with monovalent ions, such as Li^+, Na^+, and K^+. Compared to cerium, activation with praseodymium can be utilized to provide faster and shorter wavelength scintillation. To study the impact of monovalent ions on the scintillation efficiency of praseodymium doped scintillators, single crystals of the composition $(Lu_{0.75}Y_{0.25})_3Al_5O_{12}$ activated with 0.2 at% Pr and codoped with varying concentrations of Li were grown via the Czochralski (CZ) method. Scintillation and optical properties were measured and the results were compared to a lithium-free LuYAG: 0.2% Pr single crystal. The results show the effect of lithium codoping on the scintillation performance. We observed a significant improvement in the primary scintillation decay constant while the light yield was significantly decreased. A better understanding of the role of lithium on the scintillation mechanism of praseodymium doped garnet scintillators is developed.

Poster I - New Radiation Detectors - Tuesday 3:00 - 4:00 pm in Ballroom with Mark Hammig

Sensitivity and Linearity of Optical Fiber Type Neutron Detector Using a Small Piece of ^{6}Li-Based Scintillator

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Neutrons are widely used in various fields, such as material and medical science. To assure the absolute intensity at neutron irradiation fields is quite important. The counting type detector showing a peak structure in a signal pulse height spectrum are considered to be ideal to determine the neutron intensity. Our group has been developing optical fiber type neutron detectors using a small piece of transparent Li-based scintillator. In this paper, we used Eu:$LiCaAlF_6$ crystal and LiF/Eu:CaF_2 eutectic as transparent Li-based scintillators. Since these scintillators have quite high light yield more than 10,000 photons/neutron, they can show the spectra with a peak shape even using the optical fiber light guide. The neutron detectors should have an appropriate sensitivity. To adjust the sensitivity, we control lithium-6 amount in a small scintillator. We fabricated a number of optical fiber type detectors using Eu:$LiCaAlF_6$ and LiF/Eu:CaF_2 scintillators with various lithium-6 amount. In this paper, we confirmed the relationship between the neutron sensitivity and lithium-6 amount. We confirmed that the lithium-6 amount evaluated with a high precision balance can be a good index for the neutron sensitivity of the small detector. We, additionally, checked the linearity of the sensitivity of the detectors at relatively high flux field using an accelerator-based neutron source. Although the detectors show saturation at high count rate regions, we can cover relatively wide dynamic range by combining multiple detectors with various lithium-6 amounts.

Poster I - New Radiation Detectors - Tuesday 3:00 - 4:00 pm in Ballroom with Mark Hammig

Development of a compact high-sensitivity SrI_2(Eu)-based detector module

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Europium-doped Strontium Iodide (SrI_2(Eu)) gamma detectors have a very high light output ranging from 80,000-100,000 ph/MeV and energy resolutions as good as 2.9% at 662 keV. A high density of 4.6 g/cc in combination with $Z_{effective} = 49$ and absence of internal activity makes SrI_2(Eu) a very attractive sensor material for compact spectroscopic radiation devices. In this paper, we present our recent development and performance evaluation of a compact 30x30x40 mm^3 detector module based on 6.5 cm^3 SrI_2(Eu) crystal and R11265U metal PMT from Hamamatsu. The presentation will discuss light collection optimization strategies, sensitivity, energy resolution, max count rate capabilities and temperature dependence of performance. A side by side comparison of SrI_2(Eu) detector module with a commercial 15x13x5mm^3 CZT sensor will be presented and discussed. Results of recent improvements in detector fabrication techniques will be also discussed. This work has been supported by the U.S. Department of Homeland Security, Domestic Nuclear Detection Office, under competitively awarded contract HSHQDN-16-C-00026. This support does not constitute an express or implied endorsement on the part of the Government.

Poster I - New Radiation Detectors - Tuesday 3:00 - 4:00 pm in Ballroom with Mark Hammig

Pulse Shape Discrimination in Organic Scintillators The Role of Intersystem Crossing

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In this work we experimentally characterize the pulse shape discrimination (PSD) capabilities of two well-knonw PSD-capable crystals: solution-grown stilbene and p-therphenyl. We then focus on one of the light-production processes occurring upon ionizing radiation interaction with the crystal and use state-of-the-art Time-Dependent Density Functional Theory (TD-DFT) and a quantum-mechanical Fermis Golden Rule approach to investigate the role of intersystem crossing (ISC) in the two materials. We found that the ISC rates are of the order of 10^6 s^{-1}; this value is approximately two orders of magnitude lower than the prompt fluorescence signal. Therefore the ISC is perhaps only one of the factors contributing to the material PSD properties. Although PSD phenomena were discovered and demonstrated in the late 1950s and several authors have studied factors affecting PSD, including the effect of varying concentrations of impurities in the material, it is still unclear to what extent the scintillator molecular properties affect their PSD. With this work, we introduce a rigorous approach to better understand the relationship between molecular relaxiation processes and functional properties of materials as radiation detectors.

Poster I - New Radiation Detectors - Tuesday 3:00 - 4:00 pm in Ballroom with Mark Hammig

Growth and scintillation properties of Cs_2LiYCl_6 crystals doped with different Ce_{3+} concentration

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The Cs_2LiYCl_6:Ce (shorten as CLYC) crystal is regarded as a kind of promising scintillator to identify -rays and fast/thermal neutrons. Anhydrous CsCl, LiCl, YCl_3 and $CeCl_3$ beads with 4N high purity were used as starting raw materials to carry out crystal growth. Several $Cs_2LiY_{1-x}Cl_3$:Cex crystals doped with different Ce (x=0, 0.001, 0.01, 0.02) were grown by Vertical Bridgman method. The crystals were cut and polished into two samples with size of 2510mm and 10105mm and then they packaged into aluminum can with a glass window. The crystal structure was analyzed with powder X-Ray Diffractionmeter and proved to be composed of single phase of CLYC with elpasolite structure and cell constants of a=1.0481nm and V=1.1515nm^3. Two strong optical absorption bands, 220nm and 350nm can be observed in the absorption spectra, which are corresponding to the transition of electrons from 4f-5d of Ce ions. In the X-ray excited luminescence, a strong emission band between 350-450nm can be fitted into two peaks, 374nm and 397nm, which are corresponding to the transitions of electron from $5d^1$-$2F_{5/2}$ and $5d^1$-$2F_{7/2}$ of Ce^{3+} respectively. In addition, a very weak luminescence band around 300nm was also observed and is suggested to result from the core-valence luminescence (CVL). It was found that that the luminescence intensity of CVL and the emission wavelength of Ce^{3+} are affected by the concentrations of Ce ions in the crystals. The overlap between PLE and PL spectra demonstrated that self-absorption effect exists in Cs_2LiYCl_6:Ce^{3+} single crystal. Of all samples doped with different Ce concentration, the best energy resolution, 5.9%@622keV was achieved at a concentration of 0.1mol%Ce^{3+}. Three different luminescence decay component: CVL, direct electron-hole capture by Ce^{3+}, binary Vk and electron diffusion could be identified. The scintillation decay time of direct electron-hole capture by Ce^{3+} decreasing with increasing Ce^{3+} concentration proved Ce^{3+} concentration quenching effect in Cs_2LiYCl_6 crystals.

Poster I - New Radiation Detectors - Tuesday 3:00 - 4:00 pm in Ballroom with Mark Hammig

Temperature Response and Radiation Damage Effects on Potassium Strontium Iodide

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$KSr_2I_5:Eu^{2+}$ (KSI) is a new scintillator under development at the University of Tennessee Knoxville. KSI possesses a high light yield (94,000 photons/MeV at 662 keV), low non-proportionality (2%) and good resolution (2.4% at 662 keV). The inclusion of potassium in the crystalline matrix introduces an intrinsic background of ~ 6.4 Bq/cm^3. This paper will discuss characterization efforts for KSI with particular attention given to the comparison of KSI to other existing scintillators standard in the field, NaI and SrI. The discussion will include scintillator response versus temperature, as well as radiation hardness of KSI.

Poster I - New Radiation Detectors - Tuesday 3:00 - 4:00 pm in Ballroom with Mark Hammig

Alkali-Free Ce-Doped and Co-Doped Fluorophosphate Glasses for Future HEP Experiments

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We report current status of alkali-free cerium-doped and co-doped fluorophosphate glasses as a potential inorganic scintillator for future HEP experiments. Optical and scintillation properties, such as emission, transmittance, light output, decay time and their degradation after gamma-ray irradiations, are measured for glass samples produced at AFO Research Inc. Further developments are needed for this potential cost-effective glass scintillator to be used for the HHCAL detector concept.

Poster I - New Radiation Detectors - Tuesday 3:00 - 4:00 pm in Ballroom with Mark Hammig

Picosecond absorption spectroscopy of self-trapped excitons and Ce excited states in $La_{(1-x)}Ce_xBr_3$ for x = 0.004% to 100%

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Picosecond time-resolved optical absorption spectra induced by two-photon interband excitation of $LaBr_3$, $LaBr_3$:Ce(4.4% and 22.2%), and $CeBr_3$ are reported. The spectra are similar in general characteristics to self-trapped exciton (STE) absorption previously measured in alkali halides and alkaline-earth halides. A broad ultraviolet absorption band results from excitation of the self-trapped hole within the STE. A series of infrared and red-visible bands results from excitation of the bound outer electron within the STE similar to bands found in alkali halides corresponding to different degrees of "off-center" relaxation. Induced absorption in cerium-doped $LaBr_3$ after band-gap excitation of the host exhibits similar STE spectra, except decaying faster on the tens-of-picoseconds scale in proportion to the Ce concentration. This is attributed to dipole-dipole energy transfer from STE to Ce^{3+} dopant ions, and the measurements yield the concentration-dependent dipole-dipole transfer rate. The absorption spectra were also measured after direct excitation of the Ce^{3+} ions in $LaBr_3$:Ce with sufficient intensity to drive 2- and 3-photon resonantly enhanced excitation. In this case the spectrum attributed to STEs created adjacent to Ce^{3+} ions decays in 1 picosecond, attributed to dipole-dipole transfer from the nearest-neighbor separation. A transient absorption band at 2.2 eV growing with Ce concentration in $LaBr_3$ is found and attributed to a charge-transfer excitation of the Ce^{3+*} excited state responsible for scintillation in $LaBr_3$:Ce crystals. This study concludes that energy transport resulting in scintillation of $LaBr_3$:Ce proceeds mainly by STE rather than sequential trapping of holes and electrons on Ce^{3+} ions. While the time scale of these induced absorption measurements is shorter than the scintillation measurements in $LaBr_3$:Ce made by Bizarri and Dorenbos [1], the results are complementary and seem in basic agreement. We suggest that dipole-dipole transfer from STEs at their point of creation (i.e. before hopping) is the main part of the "Prompt transfer" process identified in Ref. [1]. Furthermore the temperature-dependent change of emission/absorption overlap determining dipole-dipole transfer rate probably accounts for the "Fast Process II" of temperature-dependent STE/Ce transfer in the immediate neighborhood of Ce, having activation energy different from Slow Process II associated with STE diffusion [1]. With extension of the picosecond absorption measurements to $CeBr_3$, we have data to motivate contemplation of what happens when the activator becomes identical with the cation consitituent of the crystal in which the STE is still observed. On what time scale are STEs associated with a hole in the topmost filled halogen band, or the topmost filled Ce(4f) band? At what rate do they communicate? This is similar to the situation encountered and discussed earlier in LaF_3 and CeF_3 including their mixture [2]. In that time there were no picosecond absorption measurements in the subject system, but now there are in the bromide sister system. [1] G. A. Bizarri, P.. Dorenbos, Phys. Rev. B 75, 184302 (2007). [2] A. N. Vasilev, Proc. SCINT99, ed. V. Mikhailin, Moscow State University, 43-52 (2000).

Poster I - New Radiation Detectors - Tuesday 3:00 - 4:00 pm in Ballroom with Mark Hammig

High photoluminescence quantum yield and fast radiative lifetime from Cs_4PbBr_6 with $CsPbBr_3$ nano-inclusions prospects and issues as a scintillator

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With high mass density and high effective Z, direct band gap of 2.3 eV, resistivity up to $= 10^{11}$ -cm, and mobility-lifetime product in the range of $= 10^{-3}$ cm^2/V, melt-grown single crystals of $CsPbBr_3$ are under active development as a semiconducting detector of gamma radiation at Argonne National Laboratory, for example. However, light emission from bulk semiconducting $CsPbBr_3$ is very weak, so it has not generally been considered prospective as a scintillation detector. It has shallow excitons that are ionized to free carriers at room temperature, so energy transport occurs mainly by free and shallow-trapped carriers. Bimolecular radiative recombination is too slow at usual excitation densities to compete effectively with deep trapping of carriers. Nikl et al showed early on that nanocrystals of $CsPbBr_3$ precipitated in CsBr host emit green band-edge luminescence with much higher quantum efficiency than the bulk semiconductor, and with a very fast radiative lifetime. However, the low solubility of Pb ions in CsBr limited the achievable nanocrystal content to 0.2% of the host. The next step toward bright room-temperature luminescence of cesium lead bromide composites started approximately with the dramatic successes of hybrid organic-inorganic perovskites including particularly lead halides for photovoltaic cells and light-emitting devices during roughly 2011 to the present. From roughly 2015 onward, the use of all-inorganic cesium lead halide perovskites yielded promising results for photoluminescent and electroluminescent devices. Our work at Wake Forest University on light emitting diodes using films of solution-grown cesium lead bromide studied photoluminescence kinetics, electroluminescence, and its connection with the composite nanostructure of $CsPbBr_3$ islands in Cs_4PbBr_6 host [1]. We conclude that quantum confinement enforces first-order radiative kinetics to overcome the bimolecular bottleneck and out-compete deep traps, leading to photoluminescence quantum efficiency (PLQY) up to 70% and photoluminescence exponential decay time of 345 picoseconds measured in our work. PLQY up to 97% from similar $Cs_4PbBr_6/CsPbBr_3$ nanocomposites has recently been reported by Chen et al. Photoluminescence quantum yields and radiative lifetimes of these

magnitudes awaken interest in whether a scintillation radiation detector could, after all, be based on the cesium lead halide nanocomposites. This is what we have begun to address in the present work. Though there have already been reports of x-ray imaging plates using cesium lead halide scintillating nanocomposites, there has been no demonstration of an energy-resolving gamma scintillation detector using perovskite lead halides that we are aware of. In addition to results on crystal growth and characterization, PLQY and picosecond kinetics, and efforts to pin down the correct attribution of bright green emission from Cs_4PbBr_6 material, we report initial experiments on gamma-excited light emission and time-resolved emission under picosecond x-ray pulses. Re-absorption of emission due to small Stokes shift from the semiconductor inclusion band edge is a challenge that one needs to deal with in bulk scintillators based on this material. [1] Xu, J. et al., Imbedded Nanocrystals of $CsPbBr_3$ in Cs_4PbBr_6 Enhanced Oscillator Strength, Kinetics, and Application in Light Emitting Diodes, Adv. Mater. 29(443), 1703703 (2017).

Poster I - New Radiation Detectors - Tuesday 3:00 - 4:00 pm in Ballroom with Mark Hammig

Crystal growth and scintillation performance of Cs_2_HfCl_6

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Cesium hafnium chloride (CHC, Cs_2HfCl_6) is a recently-discovered material with superior radiation detection properties relative to the incumbent detectors NaI(Tl) and CsI(Tl). Advantages of CHC include: an excellent energy resolution, no self-absorption, no self-radioactivity, and non-hygroscopicity. Our first-grown crystals were measured to have a light yield of 30,000 ph/MeV and an energy resolution of 3.3%. With a decay time close to 4 microseconds, CHC is well-suited to most low-count scenarios encountered in homeland security applications. This presentation will address techniques for charge purification and preparation, crystal growth by the Bridgman technique, as well as the challenges associated with this line compound. Finally, we will discuss the use of alloying to reduce the decay time to 2 microseconds. This work has been supported by the U.S. Department of Department of Energy, Office of Science, under competitively awarded contract DE-SC0015733. This support does not constitute an express or implied endorsement on the part of the Government.

Poster I - New Radiation Detectors - Tuesday 3:00 - 4:00 pm in Ballroom with Mark Hammig

Picosecond absorption spectroscopy of excited BaBrCl with Eu and Au dopants

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Picosecond absorption spectra of undoped BaBrCl, BaBrCl:Eu, and BaBrCl:Eu:Au following band-gap excitation by two-photon absorption of a 279-nm, 300-fs laser pulse are reported. The goal of this work is to provide information on the interactions of host crystal excitations, transient defects, Eu activator, and Au codopant on a very early time scale when many of the important trapping and transport processes for scintillation are taking place. The motivation for interest in the Au co-dopant is the discovery at LBNL that it causes significantly increased light yield for a given Eu concentration. Thus BaBrCl:Eu:Au joins other scintillators where co-doping significantly increases light output. The physical reasons are not yet fully known in many systems, so time-resolved measurements with and without co-dopant should be helpful. There has not been previous transient absorption spectroscopy on BaBrCl, so a challenge is to identify and understand the transient excited states and altered charge states that are produced on a picosecond time scale. We find it useful to look at the transient absorption spectroscopy of self-trapped excitons (STE) in another barium di-halide, BaF_2. In non-defective BaF_2, it is found that 100% of excitons will decompose into a close defect pair of H center (interstitial halogen) and F center, which is just called STE in the AEF_2 system. In undoped BaBrCl, electron-hole excitation mainly produces STEs looking like F_{Cl} centers with absorption peak near 1.8 eV. Based on the BaF_2 STE model, we suggest that they are the F_{Cl} part of close F-H pairs created with almost 100% efficiency. The time-resolved spectra show that the F-H pairs annihilate each other in 1.8 ns at room temperature, simply because there was nothing intentionally doped to capture either the H-center hole and/or the F-center electron to prevent them from annihilating. In BaBrCl:Eu, the spectrum is similar and we could identify it as mainly F_{Cl} or as STE. But now it does not decay in 1.2 ns. In fact, it seems to grow a bit over that time. We suggest therefore that it is not STE, which would annihilate by F-H recombination at room temperature in that time, but rather it is probably stable F_{Cl} centers, with the corresponding H centers having been removed or at least their holes removed. The holes apparently find their way to Eu, because this material produces intense Eu scintillation. When Au co-dopant is added, the time-resolved spectra show that the F_{Cl} and/or STEs are not formed at all! It suggests that somehow the presence of Au disrupts the association of electrons and holes to form STEs (then F-H pairs). One of the simplest explanations would be if Au is a very good electron trap not necessarily deep, but having a high capture rate. This work was supported by the US Department of Energy/NNSA/DNN R&D and carried out at Lawrence Berkeley National Laboratory and Wake Forest University under contract No. AC02-05CH11231.

Poster I - New Radiation Detectors - Tuesday 3:00 - 4:00 pm in Ballroom with Mark Hammig

Scintillation properties and alpha-ray detection capabilities of thin-film plastic scintillators

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Plastic scintillators have long been used for radiation detection as they exhibit fast-decay scintillation and are appropriate for use at high counting rate detection unlike inorganic scintillators. The low atomic numbers of constituent elements (C, H, O, etc.) in plastic scintillators lead to low interaction probability with high-energy photons, resulting in detection capabilities of high-energy charged particles with a low gamma-ray background. The workability and plasticity of plastic scintillators enable their fabrication into desired shapes. Thin-film plastic scintillators, whose thickness is in the tens of microns or less, offer new opportunities. In this study, the scintillation properties of the thin-film plastic scintillators are characterized and their application to high-energy charged particle detection is examined for alpha-ray detection. The XRL spectra of the thin-film scintillators were measured and it was found that the emission wavelength was consistent with BC400. In the scintillation temporal profiles, a fast component having a decay time constant of 1.8 ns was dominant although a slight contribution of a long component ($\sim$ 10 ns) was also observed. For a sample of 5-μm thick, a longer component was observed on the order of 100 ns. For the 22-μm sample, no such component was observed. In the pulse-height spectra of the scintillation detectors equipped with the thin-film scintillators for 5.4-MeV alpha-rays from ^{241}Am, clear peaks were observed at 130 and 150 channels for the 5- and 22-μm thick samples, respectively. On the basis of the peak channels and in comparison with the channel of the full-energy peak for GSO, the light yields of the 5- and 22-μm thick samples are estimated to be 540 and 670 photons/5.4-MeV alpha particle. Considering the large difference in thickness of the samples and the deposited energy by an alpha-particle, the light yield of the 22-μm thick sample was significantly lower. The lower light yield is partly owing to the quenching at high linear energy transfer in the 22-μm thick sample.

Poster I - New Radiation Detectors - Tuesday 3:00 - 4:00 pm in Ballroom with Mark Hammig

Growth and Characterization of Cesium Hafnium Bromochloride Free of Cracking and Coring

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There is a need for the discovery and development of new metal halide scintillators for use in detection and identification of potential radiological or nuclear threats. For gamma spectroscopy, users need a high density, high-Z, high light yield, non-hygroscopic, and high energy resolution scintillator. One possible candidate is cesium hafnium bromochloride (CHCB). This material shows the potential to outperform NaI(Tl) in all of said criteria. One issue with this material is, up until this point, all published examples of this crystal have had cracking or coring. The goal of this research is to identify growth parameters that will allow for uniform, uncracked, single crystals of CHCB. In this work, we were able to produce a 22 mm diameter crystal of CHCB that had no coring or cracking. The material used was synthesized at Lawrence Livermore National Laboratory and grown successfully at the University of Tennessee. In order to achieve a proper purity, it then had to undergo a purification process that included a pre-melt step, a filtering step, and then a growth step. We were able to produce both cored and uncored crystals. The defect-free crystal was grown with a thermal gradient of 84 degrees Celsius per centimeter with a translation speed of 1 millimeter per hour. The crystal had an energy resolution of 4.7 percent and a light yield of 30,000 Photons per MeV. Photoluminescence and radioluminescence properties were also measured.

Poster I - New Radiation Detectors - Tuesday 3:00 - 4:00 pm in Ballroom with Mark Hammig

Optimizing europium concentration in Cs_4SrI_6 and Cs_4CaI_6 Scintillators

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High light yield, good energy resolution, and a proportional response to different energies of ionizing radiation are some of the primary requirements of scintillators for gamma-ray detection in homeland security applications. Recently discovered scintillators Cs_4SrI_6:Eu and Cs_4CaI_6:Eu have shown promising scintillation properties for such applications, with <4% resolution (at 662 keV) and light yields above 50,000 ph/MeV [1]. However, a thorough investigation of the effects of europium concentration has not yet been conducted. In this work, Eu^{2+} concentration was varied from 0.5 mol% to 7 mol%, and single crystals were grown from the melt via the vertical Bridgman method. Scintillation performance was evaluated to determine the optimal amount of Eu^{2+}. The observed trend was that energy resolution and light yield both improved with increasing Eu^{2+} concentration. The best results were a 3.4% resolution with 65,000 ph/MeV light yield for Cs_4SrI_6:Eu 7% and a 4.2% resolution with 55,000 ph/MeV light yield for Cs_4CaI_6:Eu 7%.

Poster I - New Radiation Detectors - Tuesday 3:00 - 4:00 pm in Ballroom with Mark Hammig

Optical Properties and Emission Mechanism in TLYC Scintillator

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RMD has been at the forefront of the elpasolite scintillator development and recently has started to investigate a new family of scintillators by replacing the Cs in elpasolites with the isovalent Tl ions. Since the atomic number (Z) of Tl (81) is very high compared to Cs (55), Tl replacement increases the density and effective Z, which in turn increases gamma detection efficiency. Tl_2LiYCl_6 (TLYC) is one such scintillator that has shown excellent gamma and neutron detection properties. We have grown TLYC crystals up to 1-inch diameter sizes and have measured the density to be 4.5 g/cm3. These crystals show an energy resolution of $\sim$ 4% at 662 keV and the thermal neutron peak position due to neutron capture by ^{6}Li appears at $\sim$ 2 MeV. Under X-ray excitation we found that the emission shows a broad band with a single peak between 430 nm to 450 nm for all crystals independent of Ce concentration. The shape and location of the peak differs from typical Ce^{3+} emission in elpasolites that show the characteristic doublet emission due to 5d->4f transitions. Therefore, to understand the emission mechanism in TLYC we performed optical spectroscopy measurements. The optical excitation spectra for emission at 450 nm show a peak at 240 nm that is assigned to an exciton creation. The emission spectra for excitation at 240 nm show a broad emission between 350 nm and 600 nm with its peak around 445 nm. We also observe additional emission with a peak at 390 nm, when excited at 290 nm. This emission is not observed in an undoped crystal. Our results indicate that the main emission around 440 nm arises from Tl^+, while Ce^{3+} transfers energy to Tl ions, resulting in cross-relaxation. The optical properties of TLYC along with a discussion on the scintillation mechanism will be presented.

Poster I - New Radiation Detectors - Tuesday 3:00 - 4:00 pm in Ballroom with Mark Hammig

Structural characterization of La_2O_3 and Nb_2O_5 doped CeO_2 simulant for UO_2 towards solid-state direct-conversion neutron detectors

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Proposed uranium-based solid-state direct-conversion neutron detectors offer a unique benefit due to the high fission fragment energies produced from neutron collision events thus providing an increase in e-h pair production. Uranium dioxide, UO_2, is the most well-studied uranium oxide with respect to its electrical properties but a lack of understanding still exists understanding how to capably lower the leakage current improving the signal-to-noise ratio required by semiconductor neutron detector applications. One proposed method of doing this is by co-doping with materials that provide larger grain sizes to improve the carrier mobilities and also increase oxygen vacancies. Specific requirements for conducting experimental research on radioactive materials make essential fabrication and characterization methods difficult to perform. By utilizing a non-radioactive simulant, our understanding of UO_2 can be enhanced without the extensive overhead of working with radioactive materials. CeO_2 is both a structural simulant (a = 5.411) and a small polaron ionic semiconductor like UO_2. This work endeavors to evaluate the closeness in behavior by co-doping CeO_2 with La_2O_3 and Nb_2O_5 to the effects observed in UO_2.

Poster I - New Radiation Detectors - Tuesday 3:00 - 4:00 pm in Ballroom with Mark Hammig

Evaluation of LiCAF for neutron spectroscopy using SiPMs and portable electronics

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Lithium Calcium Aluminum Fluoride (LiCAF) doped with Europium was evaluated for the purpose of neutron detection. Wafers 0.5 cm thick, consisting of LiCAF crystals in a rubberized matrix, were embedded with wavelength shifting fibers (WSF) and mated to silicon photo-multipliers (SiPMs) in order to measure the photon response in a flux of neutrons from a D+D neutron generator. Excellent discrimination was achieved between the neutrons and gammas by applying a low-pass filter to the SiPM signal then applying a threshold level to the remaining pulse. Custom electronics were built to bias the SiPMs, then amplify, filter, discriminate, and digitize the LiCAF scintillation photons, resulting in a digital pulse that can easily be counted with any micro-controller or field programmable gate array. A significant advantage of LiCAF is that it can be fabricated into any shape/size, and the light output and transparency is sufficient to allow for thicker scintillators which enables detection of both thermal and epithermal neutrons. The compact size of the circuit, low power requirement, and simple count output enables an alternating arrangement of LiCAF and neutron moderating material for the construction of a compact neutron spectrometer.

Poster I - New Radiation Detectors - Tuesday 3:00 - 4:00 pm in Ballroom with Mark Hammig

Advancements in Gd-based neutron detection: γ-γ quasi-coincidence approach

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IN THE FRAME OF THE INTER-MINISTERIAL CBRN-E PROGRAM, CEA LIST (France) is working of the development of a high-sensitivity thermal neutron counter, based on the insertion of gadolinium (Gd) in spherical plastic scintillators. The concept of the said detector was patented and the first theoretical and experimental studies have shown the deployment potential of the concept, as well as the necessary incremental improvements for the definition of a consolidated technological solution. As the radiation sensor comprises one or several volumes of scintillating polymers, it is, by nature, sensitive to both neutron and gamma radiations. This property allows the development of a versatile detector, provided that it is possible to algorithmically separate the signature of both types of radiations. The technologically building brick is, moreover, to be implemented in a transportable (<15 kg) system, handled by a first intervention task force on an exposed area. The aim of this paper is to study, both through Monte Carlo simulation and experimentally, an algorithmic architecture of the measurement chain discriminating neutron and gamma events. In the original, modeled, assembled and tested prototype, neutron detection was based on the signature of gamma rays with energy above 5 MeV, emitted in the radiative cascade following the capture of a thermal neutron by a Gd nucleus. This signature is thus isolated via a mere pulse height discrimination (PHD). The estimated neutron sensitivity, of the order of 1 cps/(n.cm-2.s-1), was found compatible with Special Nuclear Material detection issues. The false count rate evolution, however, highlights a vulnerability to cosmic rays (muons) and high-energy gamma rays (fission), which may severely impact neutron detection limits for average dose rates (10-100 Sv.h-1). The presentation will be subdivided in three main sections: - a comparative study between the outputs of a numerical modelling tool, developed to simulated the total response of the sensor to varying radiation sources and the results of a series of experiments carried out in a controlled environment; - the building and numerical pre-validation of a simulation code dedicated to the study of consolidated algorithmic architecture, namely - quasi-coincidence on two adjacent plastic scintillators; - an experimental study of - quasi-coincidence, Gd-based neutron detection and a comparison between the results and the estimated of the numerical study. We shall conclude with the presentation of first estimates of neutron sensitivity (7 c.nSv-1, Cf-252), gamma-background vulnerability (7 c.nSv-1, Na-22 at 14 Sv.h-1) and n/ discrimination ratio (150, Cf-252/Na-22) for the scaled and assessed, material and algorithmic architectures: - two 10 10 10 cm3 EJ-200 plastic scintillators with a 250-m natural Gd converter in-between; - counting over a 531 keVee energy threshold, quasi-coincidence filtering over both channels.

Poster I - New Radiation Detectors - Tuesday 3:00 - 4:00 pm in Ballroom with Mark Hammig

Basic study on a LiF-Eu:CaF_2 mixed power neutron scintillator

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Neutrons are widely used in various fields. Neutron detection technology is one of the key issues in neutron applications. As a novel neutron detection material, we are developing the mixed powder neutron scintillator. The LiF-Ag:ZnS mixed powder has been used as a famous neutron scintillator. However, since this type of a scintillator is opaque due to extremely high refractive index of the Ag:ZnS, the scintillator thickness is limited. Consequently, it is difficult to increase the detection efficiency of this type of a neutron scintillator. If a mixed powder neutron scintillator can be roughly transparent, we can freely change the scintillator composition, especially for lithium content, and easily increase the scintillator thickness. Additionally, we can choose a scintillator material with various properties, such as fast decay, high light yield etc. In this paper, we attempt to use LiF-Eu:CaF_2 mixed powder to demonstrate a roughly transparent mixed powder neutron scintillator. Although the LiF-Eu:CaF_2 mixed powder was opaque, it can be translucency by filling the void space of the powder with liquid glass resin as a refractive index buffer. As a result, we can see a peak shape in the pulse height spectrum obtained from the LiF-Eu:CaF_2 mixed powder neutron scintillator filled with the liquid glass resin under neutron irradiation.

Poster I - New Radiation Detectors - Tuesday 3:00 - 4:00 pm in Ballroom with Mark Hammig

Component Characterization for a Compact, Optically Segmented Neutron Double Scatter Camera

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Neutron double scatter cameras are powerful instruments for directional detection of MeV scale neutrons. Next generation scatter cameras propose to substantially increase the efficiency of this technique by moving from an array of widely separated interaction cells to one where the scintillating elements are closely packed, dramatically increasing the acceptance for a second neutron scatter after the first. We describe characterizations of plastic scintillator that are being conducted in preparation for building such a device. Scintillator geometries under consideration are long, square cross-section bars suitable for tiling into a dense array that can be instrumented on both sides using pixelated photodetectors. We report properties of commercially available plastic scintillators in this form factor, including EJ-200, EJ-230, and EJ-232. Properties under consideration are timing and spatial resolution, energy resolution, and photon detection efficiency. We also study the prospects for wrapping such materials in optically reflective material to increase the number of photons propagated to the end of each bar. This is compared to the performance of the unwrapped bars, where only total internal reflection is used to retain light.

Poster I - New Radiation Detectors - Tuesday 3:00 - 4:00 pm in Ballroom with Mark Hammig

DEVELOPMENT OF A SOLID-STATE POSITION SENSITIVE NEUTRON DETECTOR PROTOTYPE BASED ON ^{6}Li - GLASS SCINTILLATOR AND DIGITAL SIPM ARRAYS

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Over the last years, photomultiplier tubes (PMT) have been intensively used as the photodetector of choice in a scintillator-based cold and thermal neutron detector application. Development of new technologies and various limitations of PMT based scintillation neutron detector such as sensitivity to magnetic fields, limited photon detection efficiency and high voltage power supply, have triggered to search for alternative photodetectors for this application. One possible solution is silicon photomultiplier (SiPM), which is a solid-state photodetector based on Geiger mode avalanche diode technology. Thanks to the technology, a SiPM, utilizes lower operating voltages compared to PMTs, is insensitive to a magnetic field, requires low production costs and is capable of higher readout rates. Mentioned above advantages make SiPM a very appealing candidate for single photon detection applications. Currently, we are developing a novel SiPM based scintillation neutron detector prototype. The prototype with an active area of 13cm13cm will be equipped with 6Li glass scintillator and 22 digital SiPM modules from Philips Digital Photon Counting. The main goal is to achieve a two-dimensional spatial resolution of 1mm1mm and a neutron counting rate of 20Mcps/m^2. The final detector is aimed to be used in the future at the TREFF instrument of the Heinz Maier-Leibnitz Zentrum (MLZ) in Garching, Germany for neutron reflectometry (NR). This work presents the design of the detector prototype, characterization of the optical front-end based on the simulation results using Geant4 along with the preliminary position reconstruction algorithm for tracing neutron event by analyzing the light distribution pattern using the SiPM array.

Poster I - New Radiation Detectors - Tuesday 3:00 - 4:00 pm in Ballroom with Mark Hammig

The potential of real-time, fast neutron and γ radiography to low-mass, solid-phase media

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Most techniques that are used for imaging with ionising radiation use X-rays. X-rays have the advantage of providing quick, high-resolution images with a relatively small dose of radiation. However, they also have the disadvantage that their penetrating power can be limited in some forms of matter. This can make the discrimination of materials with a low atomic number particularly challenging. Of specific interest in this regard is the need to screen a diversity of manmade items, that are heterogeneous with a tendency to have many interfaces between components that can comprise a diversity of low-mass elements and compounds. These items tend to have a compact geometry and a high density of components which can make them less easy to image quickly and effectively with X-rays. This limit of current screening technology can necessitate further stages of examination reducing the ease with which this is done for manufacturing and quality assurance applications. The results presented in this paper demonstrate that, either via fast-neutron radiography or tomography, the potential exists to discern a variety of low-A compounds from one another. Monte Carlo simulations have been performed, using the technique presented in [1]. It will be shown that, with fast-neutron radiography with a portable, isotopic radiation source (californium-252), absorption by the doped polymeric materials yields a degree of distinction from other substances. Considering these results, the state-of-the-art of the technique leading to the realization a combined, real-time fast-neutron and γ-ray radiography system will also be presented. The spontaneous fission of californium-252 yields a mixed radiation field of neutrons and γ rays which can be collimated towards the devices being analysed. A product under scrutiny will be scanned in different positions by a single organic liquid scintillation detector. This is located after the sample to detect the neutrons and γ rays after their interaction with the device, by means of a real-time pulse shape discrimination system [2]. Both γ rays and neutrons are thus retained to provide transmission information about the product being assessed and thus constituting the basis for a real-time, combined, fast-neutron and γ-ray tomography modality. This technique has the potential to provide information rapidly about the products(s) under scrutiny, particularly for manufacturing and quality assurance applications. It also has the potential to be coupled with existing, non-intrusive characterisation systems, improving their detection performance and reducing the time necessary for the assessment of complex, multi-material items. [1] M. Licata and M. J. Joyce. Concealed nuclear material identification via combined fast-neutron / gamma-ray computed tomography (FNGCT): a Monte Carlo study. Journal of Instrumentation. Jan 2018, 13 PO2013. 16 p. [2] M. J. Joyce, S. Agar, M. D. Aspinall, J. S. Beaumont, E. Colley, M. Colling, J. Dykes, P. Kardasopoulos, K. Mitton. Fast neutron tomography with real-time pulse-shape discrimination in organic scintillation detectors. Nuclear Instruments and Methods in Physics Research A. 834 (2016) 3645.

Poster I - New Radiation Detectors - Tuesday 3:00 - 4:00 pm in Ballroom with Mark Hammig

Development of hot pressed lithium indium selenide for use as a ceramic radiation detector

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Lithium based chalcogenides are studied because of their many uses in the nuclear science field. $^{6}LiInSe_2$ has been researched extensively because of its ability to operate in both scintillator and semiconductor modes. These two modes allow the crystal to be used in applications including nuclear material detection for national security, space applications, and medical imaging. Traditionally, $^{6}LiInSe_2$ has been used as a single crystal for scintillator or semiconductor measurements. As a single crystal $^{6}LiInSe_2$ is capable of detecting radiation but in some applications growth and fabrication costs are a concern because it takes upwards of 40 days to synthesize a charge, grow a crystal and fabricate a detector. Ceramics are a solution for this long route of preparation. This work will show that in the case of $^{6}LiInSe_2$ using a ceramic instead of a single crystal decreases the forty-day time frame to five days. This work will show that within five days, a ceramic pellet can be formed using a mechanical press equipped with a heating attachment. Finally, this work will demonstrate that the resulting ceramic $^{6}LiInSe_2$ pellet performs similarly to a slow-growth single crystal and can serve as a suitable alternative. Creating a ceramic radiation detector as an alternative will be accomplished in three stages starting with fabrication. The fabrication step involves changing a number of variables acting on the $^{6}LiInSe_2$ powder including the applied force, temperature, ramp rate, the amount of material, wait time, and the diameter of the die. To find the optimal conditions, the ceramic will undergo numerous characterization techniques. These techniques include light transmission, decay time, and most importantly radiation testing. The radiation experiments serve as stage two for the project. The ceramics are exposed to alpha, gamma, and thermal neutron radiation. A $^{6}LiInSe_2$ single crystal serves as the standard. Count rate, color change, and recrystallization of the ceramic will be compared to the single crystal. There will be a response from alpha, gamma, and thermal neutron radiation. Due to the inherent scattering properties of a ceramic, this response should be less than the crystals response. The final stage of this project is increasing the radiation response of the ceramic. Unlike a single crystal, polycrystalline ceramics contain grains and grain boundaries which can scatter light. Limiting these grain boundaries will lead to an increase in radiation response. SEMCathodoluminescence (SEM-CL) will be used to check the distribution of point defects at grain boundaries and also to characterize the grain size, and orientation. Once the characterization is complete, the variables in the fabrication step will be changed to maximize the radiation response signal.

Poster I - New Radiation Detectors - Tuesday 3:00 - 4:00 pm in Ballroom with Mark Hammig

Thin-Film Neutron Detector Based on CdTe and Li-6 Layers

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We have developed an innovative, low-cost, solid-state neutron detector based on the technology of thin-film CdTe solar cells activated with layers of isotopically enriched metallic Li-6. The technology leverages recent advances in thin-film solar-module manufacturing and lithium sources for electrochromic window fabrication. Our detector avoids the use of expensive and rare He-3 gas; it inherently has very high rejection of gamma events in contrast with many scintillator materials that require pulse-shape discrimination against gammas; it is readily scalable in size from personal radiation monitors to radiation portal monitors. Of the isotopes with large neutron cross sections, such as He-3, Li-6, B-10, and Gd-157, the Li-6 isotope is particularly attractive because of the high kinetic energy of the reaction products, ^{3}H and ^{4}He. This facilitates, in a planar configuration, the transport of the charged particles out of the Li-6 sensitizer layer and into the CdS/CdTe detector diode. Although the thermal neutron cross section is not as large as that of He-3 or B-10, the planar geometry and thin-film structure of the Lithium Innovations design facilitates multi-layer stacking for enhanced sensitivity. In this presentation, we provide results of testing of our LiNDA^{TM} detector stack with Cf-252 and other spontaneous fission sources. Some of the data were obtained as part of a recent test sequence at the Pacific Northwest National Lab and other data were obtained with our own Cf-252 source. We find that the thermal neutron response of a double detector stack is competitive with and/or exceeds responses reported for other portable detectors such as a small He-3 tube, a CLYC-based scintillator, or a microstructured semiconductor detector. The planar geometry of our detector leads naturally to a very high gamma rejection ratio ($>10^{7}$) and also to strong directional sensitivity. This work was supported in part by the U.S. Department of Homeland Security, Domestic Nuclear Detection Office, under competitively awarded contract #s HSHQDC-16-C-00042 and HSHQDCN-16-C-00010. This support does not constitute an expressed or implied endorsement on the part of the Government.

Poster I - New Radiation Detectors - Tuesday 3:00 - 4:00 pm in Ballroom with Mark Hammig

Hot pressed UO_3 as candidate material for direct conversion solid-state neutron detector

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Solid-state neutron detection typically utilize a neutron reactive layer paired with conventional semiconductor materials that measure a signal from neutron reaction products. Uranium oxides have a large neutron cross section, can undergo neutron induced fission, and are available in abundance in addition to being semiconductors. As candidate materials for both layers of a detector device, heterostructure geometries are simplified. For this work, UO_3 pellets were uniaxially hot pressed, using variation in sintering time, pressure and temperature to vary microstructure. Stoichiometric variations of starting powder were produced using a heated gas flow with changes to oxygen content. Changes to electrical resistivity and band gap for these fabrication conditions were measured for part of ongoing work into design of uranium-based neutron detectors.

Poster I - New Radiation Detectors - Tuesday 3:00 - 4:00 pm in Ballroom with Mark Hammig

Design and construction of sandwich pixelated detector prototype for dual-particle spectroscopic radiography

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One of the most persistent challenges in nuclear security is the detection of special nuclear materials (SNM) in the presence of shielding. Spectroscopic radiography that employs high-energy photons can provide the means for detecting SNM objects, but is limited by the similarity in transmission profile between SNM and other high-Z materials. Dual-particle (gamma/neutron) transmission radiography has a potential to provide improved material discrimination, including isotope sensitivity. Radiography further typically benefits from imaging with high spatial resolution. However, most radiation detectors are not efficient or capable of spectroscopy for both gammas and neutrons, especially at the small size required for high-resolution imaging. To address this challenge, we propose a sandwich dual-particle imaging (SDPI) system design based on an array of organic plastic scintillators and Cherenkov plate detectors. Through simulation, we demonstrate the feasibility of such a system to perform spectroscopic radiography over a wide range of neutron and photon energies. We further present the results of preliminary tests of several SDPI components.

Poster I - New Radiation Detectors - Tuesday 3:00 - 4:00 pm in Ballroom with Mark Hammig

Low-cost, high quality growth and characterization of $MAPbBr_3$ perovskite single crystals

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In this report, we examine the impact of growth conditions on methylammonium lead bromide ($MAPbBr_3$), as well as interfacial interactions for device fabrication. $MAPbBr_3$ single crystal growth conditions are studied, as well as post-growth treatments and interfacial layers. Current results show changes in electronic properties due to these changes in growth, treatments and interfacial layers.

Poster I - New Radiation Detectors - Tuesday 3:00 - 4:00 pm in Ballroom with Mark Hammig

Gamma spectrum acquisition with Halide Perovskite

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Easily accessed from low-cost raw material, organic-inorganic halide perovskites (OIHPs) come as a promising gamma radiation detection material with their large mobility-lifetime product, low charge trap density and defect-tolerant nature. Among OIHPs, the dopant-compensated $CH_3NH_3PbBr_{2.94}Cl_{0.06}$ has bulk resistivity up to 3.610^9 *cm and a high mobility-lifetime product of 1.810^{-2} cm^2V^{-1}, which are promising for the acquisition of gamma spectrum. In order to acquire gamma induced signals from the $CH_3NH_3PbBr_{2.94}Cl_{0.06}$ perovskite crystal, we have designed a guard ring structure electrode on the surface of the crystal aimed at reducing surface leakage current. Because of a high mobility-lifetime product and a relatively smaller thickness (4-5mm) of the device, a small voltage of 10-v was applied to achieve the best signal-to-noise ratio. $CH_3NH_3PbBr_{2.94}Cl_{0.06}$ detector was connected to a charge sensitive preamplifier (Ortec-142A) and the signals were processed with a DSP (Ortec DSPEC 50). A 5 microCi Cs-137 source was utilized as gamma source. A series of devices were tested and different Spectrums were acquired. It is confirmed that the $CH_3NH_3PbBr_{2.94}Cl_{0.06}$ perovskite crystal is able to give response to a Cs-137 gamma source. Photopeak and Compton edge can be identified from the spectrums, to support the previously reported best energy resolution (6.5%). In conclusion, the successful acquisitions of the Cs-137 gamma spectrum consistently with $CH_3NH_3PbBr_{2.94}Cl_{0.06}$ detectors verify the predicted stability of $CH_3NH_3PbBr_{2.94}Cl_{0.06}$ for gamma radiation detection.

Poster I - New Radiation Detectors - Tuesday 3:00 - 4:00 pm in Ballroom with Mark Hammig

Spectroscopic Radiation Detection Using Methylammonium Lead Iodide Perovskite Single Crystals Grown from Solution

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While spectroscopic radiation detectors have a multitude of applications, ranging from defense and non-proliferation to medicine and non-destructive testing, production costs and operating condition requirements curtail the use of these detectors. Lower-cost scintillator-based detectors have relatively poor energy resolution, which limits their utility, while higher-resolution semiconductor detectors are often prohibitively expensive for many applications, and may additionally require active cooling, further reducing their mobility and potential applications. Here, we demonstrate a semiconductor detector capable of high-resolution detection at room temperature using methylammonium lead triiodide perovskite single crystals. The fair mobility ($\sim$ 150 cm^2 / Vs), long carrier lifetimes (>100 μs), and low density of defects (10^{10} / cm^3), in addition to its high radiation cross-section (comparable to cadmium zinc telluride "CZT" single crystals), make perovskite one of the most promising materials for radiation detectors. Grown by low-temperature, solution-based crystallization methods, perovskite crystals have been measured to have energy resolutions under 10% for an 81 keV ^{133}Ba peak, for point-contacted devices using an aluminum ground plate and aluminum probe tip. Further testing showed this value to be comparable to a bare CZT crystal when tested in the same setup, and considerably better than CsI scintillators (with silicon photomultiplier "SiPM" readouts), which had a resolution of 15% for the same 81 keV peak. Additional peaks of 303 and 356 keV could also be seen from the perovskite crystal when tested with a contact-to-contact electric field strength of under 160 V / cm. In fact, the perovskite required less than one tenth the bias voltage to produce spectra of similar resolution. The facile nature of the crystallization method, combined with the high earth abundance of the precursor materials, results in production costs between 50 to 100 times less than standard semiconductor detectors, as well as an order of magnitude less than scintillation-based detectors. Crystallization process control and surface passivation techniques hold promise to further boost the energy resolution of perovskite detectors to approach and possibly surpass commercial CZT detectors, the current state of the art room-temperature semiconductor radiation detectors. With better control of the crystallization process as well as improvements in the surface quality of the perovskite crystals, the energy resolution of spectral measurements as well as the consistency of spectral measurements between multiple crystals can be greatly improved.

Poster I - New Radiation Detectors - Tuesday 3:00 - 4:00 pm in Ballroom with Mark Hammig

Methylammonium lead bromide: a low-cost organometallic semiconductor for radiation detection

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This paper presents recent radiation measurement data collected with methylammonium lead bromide perovskite semiconductors ($MAPbBr_3$). $MAPbBr_3$ detectors were used to measure fast neutrons and alpha particles. The temporal stability of $MAPbBr_3$ was investigated while applying a constant bias across the detector. Current results for neutron and alpha response as well as device stability are presented.

Poster I - New Radiation Detectors - Tuesday 3:00 - 4:00 pm in Ballroom with Mark Hammig

Development of large area Neganov-Luke phonon amplified light detectors for dark matter experiments

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In direct dark matter detection experiments, low temperature thermal detectors have played a major role because of their extreme energy sensitivity and background rejection capability. The thermal detectors having scintillating crystal as a target material can realize a simultaneous detection of heat (phonon) and light (scintillation) signals from the crystal. Heat signals may give accurate information about the amount of energy transferred into the absorber target. The relative amplitudes of heat and light signals provide a crucial feature to reject background signals. The light yield of scintillating crystals is typically a few percent. Only a small portion of the amount of the energy deposited in the crystal is visible in the light sensor. Here we developed a light detector with phonon amplification by Neganov-Luke effect. On one side of a silicon wafer served as a light absorber a pair of comb-shaped electrodes are fabricated to apply an electric field. Electron-hole pairs generated by light absorption in silicon drift to the electrodes while garnering Luke phonons. A phonon collector film evaporated on the back side of the wafer is thermally connected to a metallic magnetic calorimeter served as a sensitive thermometer. The Neganov-Luke light detector (NLLD) has the active area of 9 x 9 mm^2 between the electrodes. Clear amplification on the light signals was measured with a voltage applied to the electrodes with no change on heat signals. An amplification factor on the light signals was as large as 7 with 80 V bias voltage.

Poster I - New Radiation Detectors - Tuesday 3:00 - 4:00 pm in Ballroom with Mark Hammig

Compact phonon-scintillation detection system for rare event searches at low temperatures

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We have developed a compact cryogenic measurement system for simultaneous detection of heat (phonon) and light (scintillation) signals. It employs a 1 x 1 x 1 cm^3 scintillating crystal with heat and light sensors based on metallic magnetic calorimeter (MMC) readouts. This system yields not just high energy resolution but also clear particle identification by pulse shapes and relative ratios of phonon and scintillation signals. Using the phonon-scintillation detection system, we investigated several scintillating crystals which are possible candidates of target material for neutrinoless double beta decay ($0\nu\ \beta\ \beta$) experiment. Details on phonon signals and relative light yields of the crystals are presented with discussion on $0\nu\ \beta\ \beta$ application.

Poster I - New Radiation Detectors - Tuesday 3:00 - 4:00 pm in Ballroom with Mark Hammig

Silicon carbide stability for alpha particle detection at high temperature: A comparative approach

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Silicon carbide (SiC) is attractive for radiation detection due to its hardness as well as wide operational temperature range, which cannot be overemphasised. This makes it an important candidate in radiation detection precisely where temperature is an issue. One among other challenges of radiation detection at high temperature, is oil and gas exploration. Because of extinction of the oil and gas reservoirs, the depth of investigation increases. This increase in depth leads to the increase in temperature exposure. Therefore, the possibility of damaging a sensing element is high in this environment. Lack (or shortage) of Helium-3 causes additional difficulty for the provision of neutron detectors. In this paper, the stability of SiC devices for charged particle spectroscopy was studied in order to evaluate their potential for thermal neutron detection at high temperature using converter layers. All epitaxial SiC devices studied have an active area of approximately 10 mm 10 mm. They were subjected to temperatures up to 500 K. Dark current, capacitance and spectroscopic behaviours were observed. The increases in leakage current and changes in dopant profile, evaluated by the capacitance data show variations depending on the manufacturer and device structures. Nevertheless, on the whole, all the three devices show excellent stability of their output spectroscopy signals, for extended period of application up to 24 hours. This indicates their potential use for alpha and related spectroscopic applications at high temperature. The authors would like to thank PTDF Nigeria for sponsoring this research. The support provided by John-William Brown, Robert Derham and Simon Barnes is much appreciated.

Poster I - New Radiation Detectors - Tuesday 3:00 - 4:00 pm in Ballroom with Mark Hammig

Discriminating nuclear recoils from alpha particles using acoustic signatures in γ / β -blind tensioned metastable fluid detectors

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Metastable fluid detectors have been utilized extensively in the particle and high energy physics community for over 60 years since their discovery by Glaser in 1952. Recently, there has been a resurgence in their use for dark matter searches due to their superior ability to detect low energy interactions while remaining completely insensitive to photons. Currently several collaborations are utilizing superheat metastable fluid detectors in their search for weakly interacting massive particles (WIMP) as evidence for dark matter. WIMPs undergo elastic scattering with detector nuclei producing recoil nuclei with energy in the range of 10-100 keV (similar to the signal from 50-500 keV neutrons). Metastable fluid detectors are essential for WIMP detection due to their very low energy recoil threshold, good separation of different types of background, γ insensitivity, and ^{19}F-rich detection media (resulting in the coherent enhancement in the WIMP interaction cross section). Unfortunately, there are several major drawbacks of superheat metastable fluid detectors. Their main disadvantages are the strong temperature dependence (change in sensitivity of several % per C), shock sensitivity (as many as $\sim$ 15% of signals are due to human activity) and long dead time (up to 60 min.) associated with resetting the detectors. Tensioned metastable fluid detectors (TMFD), undergoing development by Sagamore Adams Laboratories, LLC and the Metastable Fluids Research Lab at Purdue University, retain all of the advantages of superheat metastable fluid detectors, but offer significantly improved temperature stability (compensated from 0C-40C), high effective sensitive volume, shock insensitivity, and reset times on the order of milliseconds to seconds. TMFDs have previously been successfully commercialized for applications in the nuclear security (passive and active interrogation for SNM detection) and health physics industries (neutron dosimetry and spectroscopy), however, applications in rare particle searches have not yet been fully investigated. While evidence of dark matter has remained elusive, several key developments have resulted from the renewed focus on superheat metastable fluid detector systems. One important advancement is the tantalizing possibility of utilizing the acoustic signatures from cavitation in metastable fluid systems to discriminate nuclear recoils from alpha particles. This work presents the ongoing progress in the development of the nuclear particle discrimination capabilities provided by acoustic signatures in TMFDs which could provide an avenue for the suppression of background signals (α vs. n) caused by Rn seepage or U in the detectors walls and potentially provide direct α / n spectroscopic information. Experimental evidence will be presented demonstrating the development of these capabilities using ^{222}Rn, Am-Be and ^{252}Cf sources. Additionally, the potential impact these advances in the nuclear recoil discrimination capabilities of TMFDs will have on the existing portfolio of TMFD sensors developed and in use in nuclear security and health physics applications will be discussed.

Poster I - New Radiation Detectors - Tuesday 3:00 - 4:00 pm in Ballroom with Mark Hammig

The realization of high uniformity drift electric field with a compact field cage

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Abstract: A thermal neutron detector design with a boron-lined honeycomb as the neutron converter was proposed, which can be probably a ^{3}He alternative detector used in the neutron scattering. This detector requests for a high uniformity drift electric field due to the introduction of electron migration process, which simplifies the detector structure and improves the detector robustness. To research the influencing parameters to the drift electric field, the Garfield and Maxwell 11 simulations were carried out. The simulation results demonstrated that both the field-cage pitch and the width of field strips determined the uniformity of drift electric field and the electric distortion area near the field-cage. The field-cage with optimized structure for the boron-lined honeycomb neutron detector was also designed, with 2 mm pitch, 1.5 mm width of inner field strip and 0.5 mm width of outer mirror field strip. This field-cage design can suppress the unnegligible electric distortion within 3 mm from the field-cage, and reduce the complexity of the field-cage, as well as its manufacturing difficulty. Key word: field cage, drift electric field, field distortion

Poster I - New Radiation Detectors - Tuesday 3:00 - 4:00 pm in Ballroom with Mark Hammig

Commissioning run of the Solenoid Spectrometer for Nuclear Astrophysics (SSNAP) at Notre Dame

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The development of the Solenoid Spectrometer for Nuclear Astrophysics (SSNAP) has been progressing to facilitate the study of nucleon transfer reaction studies at the University of Notre Dame. The study of nucleon transfer reactions gives us information about many astrophysical processes, such as novae bursts. As a helical orbit spectrometer, it will enable the study of transfer reactions with greater selectivity and efficiency. SSNAP will provide quick, accurate measurements of many nuclear properties, such as nuclear cross sections, branching ratios, and spectroscopy. Recently a commissioning run of ^{12}C(d,p) was performed in normal kinematics. The data and preliminary results of this measurement will be discussed. This work is supported by the National Science Foundation and the Joint Institute for Nuclear Astrophysics.

Poster I - New Radiation Detectors - Tuesday 3:00 - 4:00 pm in Ballroom with Mark Hammig

The Neutron Induced Fission Fragment Tracking Experiment: Precise Measurements of Fission Cross Section Ratios in a Time Projection Chamber

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The Neutron Induced Fission Fragment Tracking Experiment (NIFFTE) has built a fission Time Projection Chamber (fissionTPC) designed to precisely measure fission cross section ratios. Using a pulsed neutron beam at the Los Alamos Neutron Science Center (LANSCE) impinging on an actinide target we observe fission fragments ejected into the drift chamber. High resolution track information enables excellent particle identification and allows us to make an in-situ measurement of the beam profile and actinide distribution. Much of our effort has been focused on making measurements with sub-1% uncertainties of the ^{238}U(n,f)/^{235}U(n,f) and ^{239}Pu(n,f)/^{235}U(n,f) cross section ratios. We are now preparing to measure ^{235}U(n,f) and ^{239}Pu(n,f) in reference to the well-known ^{1}H(n,el) cross section. In this presentation we will summarize our analysis of the relevant systematic uncertainties, highlight the cross section ratio results, and discuss the developments toward making a ratio measurement referenced to the ^{1}H(n,el) cross section.

Poster I - New Radiation Detectors - Tuesday 3:00 - 4:00 pm in Ballroom with Mark Hammig

Simulation and fabrication of a scCVD diamond as a radiation detector and vacuum window

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We describe the simulation and fabrication for a super-thin single crystalline (sc) chemical vapor deposited (CVD) diamond membrane, intended to act as a radiation detector and a vacuum window in the McMaster University biological microbeam facility. The ultimate goal is to deliver very accurate and controlled doses to cellular targets through single-particle alpha irradiation. To study the options of the material and detectors, MCNP6.1 Monte Carlo code was used to simulate the energy loss and beam broadening of different materials and configurations, including vacuum window, air gap, and petri dish. A transmission-type detector based on a super-thin diamond membrane was selected because of the minimal energy loss and beam broadening. A 3 mm 3 mm 0.3 mm optical grade scCVD diamond membrane was thinned with Ar/O2 plasma etching and the surface roughness was examined by a light microscope. Then the diamond membrane was provided with aluminum contacts through physical vapor deposition. The performance of the detector will be presented.

Poster I - New Radiation Detectors - Tuesday 3:00 - 4:00 pm in Ballroom with Mark Hammig

Operation of Microhexcavity Plasma Panels Detectors in Geiger and Avalanche Mode

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The microHexCavity Panel (μHex) is a novel gaseous micropattern particle detector. Based on an earlier microcavity detector, the μHex is comprised of a dense array of close-packed pixels, each operating as an independent detection unit for ionizing radiation. Devices were fabricated as 16 by 16 arrays of 2 mm diameter, 1 mm deep hexagon cells embedded in a thin 1.5 mm wafer. Cell walls are metalized cathodes, connected to high voltage bus lines through conductive vias. Anodes are small discs (400 μm) or pins positioned on the primary cavity axis. The detectors are filled with an operating gas to near 1 atm and then closed off with valves. They have been operated as both Geiger mode and avalanche mode, producing volt to mV level signals, respectively. Geiger mode discharge is enabled by high impedance quench resistors at each pixel site. Initial results indicate high single pixel intrinsic efficiency to both betas from radioactive sources and to approximately minimum ionizing cosmic ray muons, with few ns level timing response. We will report on device construction, operation and present performance results.

Poster I - New Radiation Detectors - Tuesday 3:00 - 4:00 pm in Ballroom with Mark Hammig

Diamond detectors for directly-imaged, high-speed proton radiography

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We have made preliminary measurements to determine the suitability of high quality single-crystal CVD diamond sensors as nanosecond-resolution direct imaging detectors at the Los Alamos National Laboratory Proton Radiography facility. A radiographic detector must be linear in response to mono-energetic protons, have high detector quantum efficiency, and be radiation hard. These initial experiments indicate that diamond is a promising material for an integrated, high-resolution, large area direct proton imaging sensor.

Poster I - New Radiation Detectors - Tuesday 3:00 - 4:00 pm in Ballroom with Mark Hammig

Aramid-based nanocomposites for portable ionizing radiation detection

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Existing materials in the field of ionizing radiation detection are predominantly single-crystalline semiconductors or scintillators, which are limited in their application due to poor efficiency, high cost, or logistical burden. The goal of this project is to develop novel materials for radiation detection that can achieve high-resolution detection in a low-cost portable device. In this project, we employ the aqueous synthesis of colloidal semiconducting nanoparticles in order to provide a cost-efficient solution to this material problem. The multiple-exciton generation exhibited in quantum dots reduces the information loss in the form of optical phonons, the tunable band gap can be employed to achieve room temperature detection, and the aqueous synthesis provides a reduction in the fabrication cost. Cadmium Telluride [CdTe] nanoparticles were synthesized with various short-organic ligands (thioglycolic acid, 1-thioglycerol) and incorporated into a matrix of aramid nanofiber [ANF] to form a nanocomposite device for radiation detection. ANFs are the nanofibers obtained by dissolving Kevlar (Poly(paraphenylene terephthalamide))), and thus provide a lightweight fiber matrix that exhibits superior mechanical properties. The chemical structure of ANF contains repeating carbonyl and amide groups that act as sites for hydrogen bonding for the organic ligands on the CdTe nanoparticles. Vacuum-assisted filtration is utilized to incorporate the quantum dots into ANF hydrogels, with the goal of constructing a continuous pathway of nanoparticles along the nanofiber backbone for efficient charge transport through the composite material. The performance of these devices was evaluated by measuring the detection from both an Americium-241 alpha particle source and a Barium-133 gamma ray source. The nanocomposites displayed spectroscopic performance, with the deficiencies attributed to incomplete loading of nanoparticles within the film and insufficient detector thickness for the case of gamma rays. The inclusion of citrate-stabilized silver nanoparticles has been investigated as a method to improve the connectivity along the fiber backbone. While the count-rate for gamma rays remained constant, the addition of silver nanoparticles resulted in an improvement in the energy resolution due to the decrease in the resistance to charge transportation. Current research is looking to improve the hydrogen-bonding interactions between the quantum dots and the ANF to achieve effective self-assembly of the nanoparticles into the composite radiation detector.

Poster I - New Radiation Detectors - Tuesday 3:00 - 4:00 pm in Ballroom with Mark Hammig

Ultrafast Waveguiding Quantum Dot Scintillation Detector

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High-efficiency, picosecond scintillation detectors are critical in the fields of high-energy physics and medical imaging. Historically, direct bandgap semiconductor scintillators were valued for their light yield, however they have limitations that make them unsuitable for many applications: high self-absorption, low material density and high refractive index. We propose a semiconductor scintillator composed of InAs Quantum Dots (QD) as radiative recombination centers in a GaAs stopping medium/waveguide, integrated with an epitaxially grown InGaAs p-i-n photodiode; this structure [1] could circumvent many semiconductor-related problems even at room temperature. InAs QDs in a GaAs matrix have appealing potential scintillation properties including high light yield ($\sim$ 240,000 photons/MeV) and fast capture of electrons (2-5ps) [1]. Additionally, the high refractive index of GaAs (n=3.4) ensures light emitted by the QDs is waveguided within the matrix. The QD waveguide (WG) structure was grown using Molecular Beam Epitaxy. It has a thick GaAs layer with embedded sheets of modulation p-type doped InAs QDs for fast electron capture, and an InGaAs photodetector tuned to QD emission wavelength. An AlAs sacrificial layer is grown between the waveguide and the substrate for epitaxial lift-off to separate the scintillator film and transfer it to a foreign substrate such as glass slide. We used a femtosecond Ti-sapphire laser to measure the timing properties of QD structure. The light pulse excites electrons in the structure above the GaAs bandgap, and pickup is done with a 100x100 micron$\hat{2}$ photodiode fabricated on top of the WG. The QD response shows a lifetime of $\sim$ 0.6 ns and mostly RC-limited rise-time of 100 ps at the highest bias. A small initial bump corresponds to direct laser light absorption in the PD and a second peak to a response of the PD to scintillation, with a timing delay of $\sim$ 30ps, characteristic of QD electron capture and light emission. Absorption within the WG is measured on a structure with the PD etched off and transferred to glass, which is then excited with a 50mW red laser. Spectra are measured at regular intervals as the excitation point is moved away from the fiber. There is a distinct red-shift of the spectra due to self-absorption in the QDs, but after light travels over 1mm in the WG, the spectrum shape and low self-absorption stabilizes. The lowest attenuation coefficient of 3.4 cm$\hat{}$1 was observed in a 20 micronthick WG with as low as 50 QD layers to reduce accumulated strain in the WG and eliminate dislocation formation. Timing characteristics of a scintillation detector ware evaluated using 5.5MeV alpha particles. The scintillation response has shown 80ps noise-limited time resolution and decay time of 0.6ns. The histogram of integrated charge shows an average of 8.4 x10$\hat{4}$ electrons corresponding to collection efficiency of about 7%. The data confirms unique potential properties of this scintillation detector. [1] S. Oktyabrsky, et al. IEEE TNS, 63, 656 (2016).

Poster I - New Radiation Detectors - Tuesday 3:00 - 4:00 pm in Ballroom with Mark Hammig

Material defect study of thallium lead iodide ($TlPbI_3$) crystals for radiation detector applications

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$TlPbI_3$ is a promising semiconductor material for fabricating room-temperature radiation detectors, which have wide applications in national security, medical imaging, astrophysics research, industrial process monitoring and environmental survey. $TlPbI_3$ has a large energy bandgap at 2.3 eV, a high density (6.04g/cm3) and high concentrations of the high atomic number elements Tl and Pb. Such physical properties offer great potential to use $TlPbI_3$ to detect gamma-ray at room temperature with high detection efficiency. In this work, we used the positron annihilation lifetime spectroscopy (PALS) measurement and infrared transmission microscopy to study the material defects in bulk $TlPbI_3$ crystals. For the PALS measurements, we used the positron experimental setup at North Carolina State Universitys PULSTAR reactor facility. The test results show that the dominating positron lifetime in $TlPbI_3$ is 393 ps and its intensity is more than 92%. This component is typically attributed to some vacancy type (or more likely, vacancy cluster) positron trapping sites. In addition, there could be a hint of nanovoids indicated by an o-Ps lifetime. The associated intensity is 0.75%, which is more robust than that purely due to an artifact and thus excludes such a possibility of fitting artifact. If this is actually related to nanopores, the average pore size would be $\sim$ 0.57 nm.

Poster I - New Radiation Detectors - Tuesday 3:00 - 4:00 pm in Ballroom with Mark Hammig

Using the Formation Mechanism of 2-D Superlattices from PbSe Nanocrystals and Nanocrystal Attachment to Improve Charge Carrier Transport of Semiconductors

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Despite quantum dot (QD) solids bringing in a new class of materials for semiconductor devices, the key to achieving better QD optoelectronic devices consists of the fabrication of QD solids with low defect concentrations and efficient charge carrier transport. With a heavy reliance on the hopping mechanism that dominates the charge transport in QD solids, significant work must be devoted to minimizing defect densities, lower non-radiative recombination losses and reduce interparticle spacing. We report the development of thin-film microstructures which have achieved microstructural transformations within the particle monolayer. These transformations have partially optimized the charge carrier transport with the usage of oriented attachment for nanocrystals (NCs) to find their optima position and orientation. This may provide better understanding of how to fine-tune optoelectronic devices and optimize NC monolayers. Efforts to harness this quantum tunability of semiconductor NCs has and will continue to lead many successes in optical and optoelectronic applications.

Poster I - New Radiation Detectors - Tuesday 3:00 - 4:00 pm in Ballroom with Mark Hammig

A New Semiconductor Radiation Detector $CsPbBr_3$

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The wide band gap solid state semiconductor, $CsPbBr_3$, has been investigated for room temperature radiation detection. $CsPbBr_3$ has a direct band gap (2.25 eV), high density (4.85 g/cm^3), and high resistivity $\sim$ 109 Ωcm. We developed new processes for synthesis, purification, and crystal growth to achieve highly pure $CsPbBr_3$ crystals with reduced defects. The precursors CsBr and $PbBr_2$ were prepared in aqueous HBr solution using binary salts and the follow-up purification was performed by sublimation, bromination, and melt filtration. Large single crystals were grown by the vertical Bridgman and electro dynamic gradient (EDG) methods and the crystals of $CsPbBr_3$ obtained express the resistivity (ρ) and mobility-lifetime product () in the order of $10^{-9} \sim 10^{-10}$ Ωcm and $10^{-4} \sim 10^{-3}$ cm^2/V for electrons and holes, respectively. These crystals display a significant photo response on the γ-ray sources including ^{241}Am, ^{57}Co, and ^{137}Cs with $\sim$ 4% energy resolution for each characteristic -peaks which is comparable to that observed from the benchmark material, cadmium zinc telluride (CZT), at the same measurement conditions. The results from all characterization including optical, charge transport, photoconductivity, and γ-ray spectroscopy from the new single crystals of $CsPbBr_3$ will be presented.

6.2.4 Semiconductor Detectors I (Tuesday 4:00 - 5:30 pm in Mendelssohn with Alan Janos)

Semiconductor Detectors I - Tuesday 4:00 - 5:30 pm in Mendelssohn with Alan Janos

High performance CdZnTe for security applications - requirements for high volume production and experience Curve effects for improved cost competitiveness.

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Over the past 10 years, thousands of Redlen CZT detectors have been deployed into the field aimed at identifying radiological sources. The detection of high energy photons requires very thick up to 15 mm CdZnTe (CZT), and exceptional homogeneity throughout the bulk is required to facilitate discrimination of all the different photon energies present. Previously, the supply of high performance CZT was limited due to unreliable yields and consistency on performance, as all the necessary conditions for growth and fabrication needed to be determined, along with additional improvements to attachment, electronics designs and low-noise signal processing. Optimal conditions for the production of these devices are now better understood, and as more experience continues to be gained, economies-of-scale from higher volume production and Experience Curve effects will continue to improve performance, quality, and to lower manufacturing costs. We will review the technical obstacles to high-quality growth and fabrication, and address analytical protocols and findings that facilitate higher volume manufacturing, and the future for the production of much larger volume (40mm x 40mm x 15mm) high-performance CZT detectors.

Semiconductor Detectors I - Tuesday 4:00 - 5:30 pm in Mendelssohn with Alan Janos

Temperature based gamma-ray event reconstruction in 3-D position-sensitive CdZnTe detectors

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Maintaining good energy resolution in 3-D position-sensitive CdZnTe detectors without temperature regulation requires several self-calibration measurements at various ambient temperatures. However, required calibration times and storage space for calibration data increase linearly with working temperature range. In this experiment, gamma-ray interactions were measured by 3-D, position-sensitive CdZnTe detectors read out via VAD_UM v2.2 ASICs at various ambient temperatures. Physical causes of changes in detector behavior were studied. A proposed method to reconstruct events using only one complete self-calibration measurement, and several fast measurements at different ambient temperatures is discussed.

Semiconductor Detectors I - Tuesday 4:00 - 5:30 pm in Mendelssohn with Alan Janos

Halide Perovskite for New Generation X-ray and ray Detectors

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Organic-inorganic halide perovskites (OIHPs), which have made significant successes in the applications of solar cells, light emitting diodes, and photodetectors, are showing great promise as a new generation of radiation detection materials. In addition to their large product, these materials in a single crystal form have a low charge trap density and defect-tolerant nature, making them particularly attractive for radiation detection. High quality perovskite single crystals can be grown from solution processes at room temperature with low cost raw materials. The high atomic number (Z) of Pb, I and Br as well as the relatively large material density of ca. 4.0 g/cm^3 enables respectable attenuation of high-energy photons. We reported the large product of methylammonium lead triiodide ($MAPbI_3$) single crystal and its application in gamma-ray energy harvest with a 4% efficiency operated in a gammavoltaic mode. Further $CH_3NH_3PbBr_3$ single crystals X-ray detectors studies were shown to have a high sensitivity of 80 C Gy^{-1} $_{air}$ cm^{-2} to 50 keV X-rays with the lowest detectable dose rate of 0.5 Gy_{air} s^{-1}, which is already several times more sensitive than the commercial amorphous selenium (-Se) X-ray detectors. The integration of perovskite single crystals with silicon substrates has been demonstrated, which not only further enhanced the sensitivity to 2.110^4 C Gy^{-1} $_{air}$ cm^{-2} under 8 keV X-ray radiation, but also allowing a direct signal read-out with silicon based circuits. The demonstrated X-ray imaging capability at extremely low dose rates of 36 nGy_{air}/s may find its application in medical imaging devices to minimize the X-ray dosage to which patients are exposed. The X-ray imaging resolution can reach 10 line pairs per millimeter (lp/mm) under 8 keV X-ray radiation, and X-ray imaging capability under higher energy photon irradiation such as 120 keV is undergoing. We also found that $CH_3NH_3PbBr_3$ and $CH_3NH_3PbCl_3$ single crystals are p-type and n-type doped, respectively, whereas dopant-compensated $CH_3NH_3PbBr_{2.94}Cl_{0.06}$ alloy has over ten-folds improved bulk resistivity of 3.6109 Ω cm. Alloying Cl$^-$ ions into $CH_3NH_3PbBr_3$ also increases the crystal hole mobility to 560 cm^2 V^{-1} s^{-1}, yielding a high mobility-lifetime product of 1.810^{-2} cm^2 V^{-1}. The use of a guard ring electrode in the detector reduces the crystal surface leakage current and device dark current. A distinguishable ^{137}Cs energy spectrum with best photopeak resolution of 6.5% is collected at room temperature, comparable or even better than standard scintillator detectors made by NaI(Tl). All these exciting results demonstrate the promising commercialization capability of halide perovskite materials as low cost ionization radiation detectors.

Semiconductor Detectors I - Tuesday 4:00 - 5:30 pm in Mendelssohn with Alan Janos

$^6LiInSe_2$ Semiconductor Neutron Detector

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We developed a neutron detector based on $^6LiInSe_2$ semiconductor material due to a number of promising properties, such as efficient thermal neutron detection, direct conversion of neutron capture to electrical signal, and excellent separation between gamma rays and neutrons. The high thermal neutron efficiency is due to the concentration of Li-6 atoms in the solid-state detector. The gamma neutron separation benefits from the large signal produced by the large Q value (∼ 4.8 MeV) of the n-alpha reaction in Li-6. $^6LiInSe_2$ has a wide bandgap for low noise operation and high sensitivity neutron detectors. The stopping power within $LiInSe_2$ for thermal neutrons is very high, requiring only ∼ 1.5 mm of 95%-enriched crystal to become 80% efficient. Thus, a solid-state thermal neutron detection detector based on $^6LiInSe_2$ would be a major breakthrough over conventional He-3 thermal neutron detectors and other neutron detection technologies. The recent advances of the crystal growth, material processing, and detector fabrication technologies at RMD Inc. allowed us to fabricate large detectors with 100 mm2 active area. The synthesis, crystal growth, detector fabrication, and characterization are reported in this paper This work has been supported by the US Department of Homeland Security, Domestic Nuclear Detection Office, under competitively awarded contract No. HSHQDC-16-C-00001. This support does not constitute an express or implied endorsement on the part of the Government.

Semiconductor Detectors I - Tuesday 4:00 - 5:30 pm in Mendelssohn with Alan Janos

Resonant two-photon mapping of defect states in TlBr during aging under applied voltage

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TlBr is a promising semiconductor radiation detector that is beginning to make the transition to implementation in commercial detectors. A recurring issue has been high ionic conductivity which leads to sample polarization and degeneration over time. Bias switching has recently been shown to dramatically increase the lifetime of these detectors, although the fundamental mechanisms underlying this effect have yet to be fully understood. We have developed a technique using a two-photon photocurrent microscope to map the concentration of mid-gap defect states in TlBr. Using this tool, we can examine the spatial and temporal evolution of mid-gap defect states in TlBr under applied voltage and with bias switching. In a run extending for three weeks under an applied field of 1000 V/cm we observed the photocurrent response and the deduced concentration of mid-gap defects increasing near the negative electrode. Switching polarity caused a sudden decrease in the accumulated defects followed by a gradual increase back up to a level of saturation. Auxiliary measurements are being used to try to identify the defect responsible for the mid-gap state. WFU acknowledges support of DNDO-ARI DHS-2014-DN-077-ARI077-05. This support does not constitute an express or implied endorsement on the part of the government.

Semiconductor Detectors I - Tuesday 4:00 - 5:30 pm in Mendelssohn with Alan Janos

The p-type point contact germanium detectors in CDEX experiments

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The p-type point contact germanium detectors with excellent energy resolution, ultralow energy threshold and low background radioactivity have been adopted to search light dark matter in recent years. Two of the detectors with mass of 1 kg have been designed and achieved an energy threshold of 400 eVee and 160 eVee, respectively, by the CDEX-1 experiments at China Jinping Underground Laboratory. The arrayed detectors with a total mass of about 10kg are ongoing research. The structure of detectors shielding, electronics system, data analysis methods and some key performances of these detectors are described.

6.2.5 Neutron Facility, Characterization, Detectors and Generators (Tuesday 4:00 - 5:30 pm in Hussey with Mark Wrobel)

Neutron Facility, Characterization, Detectors and Generators - Tuesday 4:00 - 5:30 pm in Hussey with Mark Wrobel

New Neutron Beam Facilities Developments at the Penn State Breazeale Reactor (PSBR)

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Summary INTRODUCTION The Penn State Breazeale Reactor (PSBR), the centerpiece of the Radiation Science and Engineering Center (RSEC). An upgrade in reactor power and a change in fuel type made in the 1960s left only one of seven beam ports aligned with the centerline of the reactor core. The others are significantly below the cores centerline. This inherent design issue has greatly limited the utilization of the neutron beam capabilities of the PSBR. A significant change of the core-moderator assembly, reactor core upper and lower grid plates, safety plates, reactor tower structure and new and geometrically aligned neutron beam ports are being installed. The project will be completed in summer 2018. After this upgrade and improvements, full use of the PSBRs capabilities and the establishment of state-of-the-art neutron beam facilities will be possible. Five new neutron beam ports were designed and being installed at the PSBR facility. New beam ports are geometrically aligned with the new core-moderator assembly for optimum neutron output. A mesitylene-based cold neutron source with three supermirror neutron guides will be installed. Four new experimental techniques: triple-axis spectrometer, conventional and time-of-flight neutron depth profiling, neutron powder diffraction, and prompt gamma activation analysis will be added to the existing neutron imaging and neutron transmission facilities. The geometrical configurations along with the filter and collimator system designs of each neutron beam port were selected based on the requirements of each experimental facility. After installation of new core-moderator and neutron beam ports, new research projects will be available for the development of cold neutron beam and neutron guides as well as nuclear energy-related research and development. Some of the new techniques that will be implemented for research at the RSEC are: Cold Neutron Source: Most of the neutron beam applications can be enhanced by using subthermal, "cold," neutrons. Cold neutrons have longer wavelengths and lower kinetic energies than thermal neutrons, allowing an increased size scale for structure research and better energy resolution in the study of molecular motion. The PSBR cold neutron source will be a third generation university reactor cold neutron facility in the USA. The cooling of the moderator chamber will be handled by a circulating helium line attached to the cryorefrigerator. This will be improvement from previous cooling systems used at the Cornell University Reactor or at the University of Texas at Austin reactors. Three supermirror neutron guides will be installed at the PSBR facility to provide cold neutron beam to new PGAA, NDP, and NPD facilities. Prompt Gamma Activation Analysis (PGAA): PGAA is a rapid, nondestructive technique used for trace and major component analysis of various elements. It is based on the detection of gamma rays emitted by a target material while it is being irradiated with neutrons. PGAA is most applicable in the determination of nonmetals, which are usually found in the common matrices as an impurity or major element (H, C, N, Si, P, S), or trace elements with high thermal capture cross sections (B, Cd, Gd). The analysis of these elements is usually marginal when other techniques are used. Neutron Powder Diffraction (NPD): Neutron diffraction is one of the best ways to obtain detailed atomic-level structural information for many different materials. The recent development of instrumentation and data analysis techniques have made it possible to obtain precise structural information (as in single crystals) from neutron diffraction experiments on powder samples. NPD is now feasible for low- and medium-power research reactors due to developments of position-sensitive detector systems and focusing monochromators. Time-of-Flight Neutron Depth Profiling: Neutron depth profiling (NDP) is a near-surface analysis technique to measure the spatial distribution of certain light isotopes of technological importance in substrates with low neutron affinity. Upon neutron absorption, certain light isotopes emit a charged particle, either a proton or alpha depending on the isotope, and a recoil nucleus. As the charged particle and the recoil move in the substrate they lose kinetic energy through nuclear and coulombic interactions with host atoms. The amount of energy loss can then be correlated to the distance traveled by the particles, which is an indication of the depth at which the particles are created. Conventional NDP is based on the direct measurement of particle energies by charged particle detectors, mostly by silicon semiconductor detectors, passivated implanted planar silicon (PIPS) detectors or PIN photodiodes. Proportional to the advances in scientific and technological applications, depth profiling with higher resolutions has become a necessity. Neutron depth profiling has reached the limits of resolution that can be attained by conventional techniques, limited by the use of charged particle semiconductor detectors. This limitation can be overcome, however, through a technique called time-of-flight neutron depth profiling (TOF-NDP). TOF-NDP eliminates the semiconductor detector and employs micro channel plates for particle detection in time-of-flight configuration.

Neutron Facility, Characterization, Detectors and Generators - Tuesday 4:00 - 5:30 pm in Hussey with Mark Wrobel

Fission Neutron Angular Correlation Measurements and MCNP6.2 Simulations

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Neutrons emitted in the fission process are correlated both in energy and their relative angles, properties which may be useful in the design and testing of nuclear instrumentation for homeland security, safeguards, and nonproliferation applications. MCNP6.2 includes the fission event generators FREYA and CGMF, which can be used to simulate the correlation of neutrons emitted in the fission process. This presentation and full paper will describe a relatively simple arrangement of scintillator detectors used to measure neutron correlations. This arrangement includes up to six EJ-301 detectors placed 1 m from a Cf-252 source and with relative detector angles from 30 180. Cf-252 spontaneous fission neutrons were recorded over a duration of several weeks in detector arrangements intended to minimize room return and detector cross talk. Measurements have been compared to MCNP6.2 simulations using the CGMF and FREYA fission event generators, and a custom internal build utilizing events generated by Lestones correlated fission model .

Neutron Facility, Characterization, Detectors and Generators - Tuesday 4:00 - 5:30 pm in Hussey with Mark Wrobel

Fabrication and experimental evaluation of microstructured ^{6}Li silicate fiber arrays for high spatial resolution neutron imaging

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This research presents the fabrication and experimental evaluation of instrumentation designed to enable higher spatial resolution neutron radiography for users at neutron scattering facilities. The properties of novel X-ray opaque materials, like those used energy storage systems, precision manufacturing technologies, aerospace components, and metallic additive manufacturing, are often described using simulation tools lacking experimentally grounded models, and are based on first-principle calculations and theoretical assumptions alone. Thus, ongoing material characterization relies on neutron scattering instrumentation to verify performance predictions and add structure to future models. Despite the successes that neutron scattering science facilities have achieved in recent years, even higher-impact research into microstructure evolution, thermodynamic, and mechanical properties of advanced materials is limited by the current spatial resolution of neutron sensing instrumentation. Herein, we describe a proof-of-concept array of microstructured silicate fibers with ^{6}Li doped cores that shows progress towards micron resolution neutron radiography. The multicore fiber was fabricated by drawing stacked unit elements of Guardian Glass (Nucsafe Inc., Oak Ridge, TN, USA), a ^{6}Li scintillating core glass, and a silicate cladding glass. These structured fibers function as an array of sub-10-micron waveguides for scintillation light. Measurements have shown a significantly increased integrated charge distribution in response to neutrons, and the spatial resolution of the radiographs is described by edge response and line spread functions of 48 2 m and 59 4 m, respectively.

Neutron Facility, Characterization, Detectors and Generators - Tuesday 4:00 - 5:30 pm in Hussey with Mark Wrobel

Experimental and Predicted Performances of the Micro-Layered Fast-Neutron Detector

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An enabling technology for high-efficiency fast-neutron detection for the Transient Reactor Test (TREAT) Facility hodoscope is presented. The current technology employed at TREAT for fast-neutron detection suffers from low detection efficiency (0.4%) for neutrons with energies above 0.1 MeV, Cherenkov background in the detector light-guides, and non-linear signal output at high power levels. To overcome these challenges, a novel design of alternating layers of hydrogenous material and a scintillating medium has been constructed, with the light collected by a photomultiplier tube (PMT). Poly-methyl methacrylate (PMMA) was used as a proton radiator because of its transparency to light and minimal autofluorescence, while Ag-doped ZnS was selected as the scintillation medium owing to its high light yield for heavy charged particles, and its intrinsic ability to discriminate between heavy ionizing particles in an intense gamma-ray background. An output pulse can be generated if a fast neutron elastically scatters in the PMMA volume to produce a recoil proton. The recoil proton can intersect and excite scintillation molecules, subsequently emitting photons that can be measure by a photomultiplier tube (PMT). The Micro-Layered Fast-Neutron Detector (MLFD) consists of alternating ultra-thin layers of PMMA and ZnS:Ag, stacked up to a desired length. This design enables incorporation of a large amount of scintillation medium without compromising light transparency. Because of the layered construction, background radiations produce a much smaller amount of scintillation light than recoil protons. Consequently, pulse height discrimination adequately separates neutron-induced events from gamma-ray events. The light-collection device is attached to one side face of the MLFD, thereby eliminating the need for extraneous light guides, and subsequently reducing Cherenkov contribution significantly. A Lambertian reflector was coated on all faces of the device except for the face attached to the PMT. The design results in a greater registration of fast-neutron counts along with reduced counts from Cherenkov radiation and gamma-rays. Currently, a 25.4-mm long MLFD yields a fast-neutron detection efficiency of 1.01%, while a 43-mm long MLFD has 1.39% detection efficiency when irradiated with a ^{252}Cf source. There are discrepancies in count rate trends between the experimental and simulated models, which are currently under investigation. The most fascinating aspect of the MLFDs is that, according to numerical modeling, the detection efficiency can be scaled up to 6% with longer detector lengths up to 20 cm.

Neutron Facility, Characterization, Detectors and Generators - Tuesday 4:00 - 5:30 pm in Hussey with Mark Wrobel

Inverse Problem Approach for the underwater localization of Fukushima Daiichi fuel debris with fission chambers

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FUEL DEBRIS LOCALIZATION forms a critical step in the decommissioning road map of damaged nuclear power plants, as illustrated by the necessity to remove melted nuclear fuel from the Fukushima Daiichi units. Despite its high intensity, gamma radioactivity does not provide a relevant signature for the localization of fuel debris in the Primary Containment Vessel (PCV). Indeed, the position of volatile fission products is not bound to the position of uranium or plutonium isotopes. On the contrary, fuel debris have a distinct neutron signature that can be detected to locate fuel debris. Neutron measurement in a damaged PCV environment is submitted to severe deployments constraints, including a high dose rate gamma background and limited available space, which narrows the range of useable technological solutions. Given these, the study of principle was oriented towards small fission chambers (FC), with U-235-enriched active substrates. To study the expected performance of FC in various irradiation conditions (neutron activity, surrounding environment, and distance), a numerical model of the detector head was built. We describe the elaboration of the numerical model and the Monte Carlo study of the fission rate inside U-235 coatings per generated neutron. To convert this fission rate into an expected count rate, we ran an experimental calibration of our code with a commercial, CFUE32 fission chamber. The evaluation of a representative calibration coefficient then allowed us to carry out a multi-parameter performance study of a FC underwater. The objective of this simulation study was to compute a relevant and explicit response function linking, on the one hand, the activity and spatial distribution of neutron emitters in a water container (representative of the bottom-floor of a water-filled PCV), with, one the other hand, expected count rates measured by a fission chamber as a function of its radial and axial position inside the water volume. We then undertook a measurement campaign on the evolution of a CFUE32 FC response _(r,z) (count rate, cps), set at different positions inside a water drum, as a function of its axial and radial distance to a Cf-252 neutron source attached at the center of the container. The experimental study of the influence of a water diffusion environment is indeed crucial, both to validate the FC underwater behavior, and to provide a first set of results in conditions as close as possible to the ones of in-situ deployment. We finally present an approach in which fuel debris localization is defined as an Inverse Problem, solvable with a Maximum-Likelihood Expectation Maximization (ML-EM) iterative algorithm. The projector matrix is built by capitalization on the results of the previous numerical studies, and the ML-EM was tested on simulated data sets with varying parameters (number of voxels, number of measurement positions). Our first results indicate that, for an axial distance z<30 cm, originating voxels are identifiable with a spatial resolution in the order of 10 to 100 cm2. Also, for a given neutron activity, the simulations allowed us to compute the acquisition time required for a localization associated with a given spatial resolution.

Neutron Facility, Characterization, Detectors and Generators - Tuesday 4:00 - 5:30 pm in Hussey with Mark Wrobel

Niowave Neutron Interrogation System

Peters, William A. (1), Bakken, Alex C. (1), Grimm, Amanda K. (1), Grimm, Terry L. (1), Johnson, Nathan C. (1), Mamtimin, Mayir (1), Odeh, Faisal Y. (1), Shannon, Kristin A. (1), Starovoitova, Valeriia N. (1), Pozzi, Sara A. (2), Sivels, Ciara (2)

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The United States Department of Homeland Security is looking to develop an active interrogation system that can quickly detect SNM, as well as other types of contraband, such as explosives and drugs. These soft targets require portable, mobile, active interrogation systems that can quickly interrogate and unveil hidden threat which can be easily shielded for passive detection methods. Recent technological advances in neutron generators and radiation detectors make compact active interrogation systems technically and economically feasible. Therefore, Niowave is developing a compact neutron generator based modular and mobile interrogation system which can detect 1 kg ^{235}U at 1 meter in less than 10 seconds, with multiple corroborating signals leading to a confidence level greater than 95%. This initial determination can then trigger a longer secondary scan to measure: SNM with $\sim$ 0.1 kg resolution, isotopic composition of object, -ray image with $\sim$ 1 cm resolution, and the k-value of the SNM assembly. Because we will be looking for multiple signals using five concurrent detection methods, this system will distinguish between shielded or unshielded ^{235}U or plutonium and other contraband. This is a distinct improvement over interrogation techniques that only rely on one or two types of signals. The entire system will use less than 5 kW of electrical power and will fit inside a standard van for discrete interrogation with removable components for pin-point interrogation or conveyor belt operation. In this talk, a portable neutron based interrogation system will be presented including system setup, shielding and collimation, detector suit, detection method and algorithm, and preliminary results from various detectors.

6.3 Wednesday

6.3.1 Neutron Detectors II (Wednesday 8:00 - 9:30 am in Mendelssohn with Donny Hornback)

Neutron Detectors II - Wednesday 8:00 - 9:30 am in Mendelssohn with Donny Hornback

Single-photon detection performance for neutron imager development

Brown, Joshua (1), Brubaker, Erik (1), Febbraro, Michael (2), Folsom, Micah (2), Hausladen, Paul (2), Mattingly, John (3), Steele, John (1), Weinfurther, Kyle (3), Ziock, Klaus (2)

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Single optical photon detection is a challenging regime for nuclear instrumentation, especially when high spatial and temporal resolution are required. Performance is determined by the characteristics of both the photodetector and the readout electronics. We will present experimental results for single-photon detection performance of multiple photodetectors, including both MCP-PMTs and SiPMs. Readout electronics are based on the DRS4 fast waveform sampling chip. We study the single-photon detection efficiency, gain, and gain width, including the dependence of these quantities with position in the photodetector. Single-photon time resolution is evaluated using a 50 ps fast pulse laser. This work supports development of a new concept for compact, high-efficiency fission-energy neutron imaging, the single-volume neutron scatter camera. In this concept, scintillation light is emitted isotropically from multiple neutron interactions within one volume and collected on the boundaries of the volume. Successful event reconstruction requires detection of each individual optical photon with excellent spatial and temporal resolution.

Neutron Detectors II - Wednesday 8:00 - 9:30 am in Mendelssohn with Donny Hornback

Characterization of Deuterated-stilbene (stilbene-d_{12}) for Neutron Spectroscopy

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Organic scintillators feature a fast time response and the capability of detecting and discriminating radiation with different ionizing density, e.g. neutron-generated recoil protons and Compton electrons. Deuterated scintillators, while retaining the two above mentioned favorable properties, can also effectively provide neutron spectra by unfolding the measured light-output spectra with the detector response to monoenergetic neutrons, without the need of time-of-flight. The light output response of deuterated scintillators to monoenergetic neutrons shows a characteristic peak, corresponding to the maximum energy deposited by the recoil deuterons. Unlike recoil protons, recoil deuterons produced by elastic collisions of impinging neutrons are preferentially forward-scattered. This non-isotropic reaction results in distinct peaks in the light-output response. Deuterated stilbene (stilbene-d_{12}, $C_{14}D_{12}$) is a newly developed fast neutron detector. In this work, we characterized two deuterated crystalline trans-stilbene crystals custom-fabricated at Lawrence Livermore National Laboratory. The largest crystal has hexagonal cross-section and 32 cm^3 volume. Stilbene-d_{12} shows a superior gamma-neutron discrimination capability, compared to conventional 1H-stilbene, at the same light output. We measured the neutron light-output spectra emitted by several nuclear reactions, including spontaneous fission, d(d,n)^{3}He, d(t,n)^{4}He, etc. Using pulse shape discrimination to separate recoil deuterons, as expected stilbene-d_{12} shows a distinct peak in the light-output response to 2.5 MeV and 14.1 MeV neutrons. We will determine the response matrix of deuterated stilbene to monoenergetic neutrons using an intense ^{252}Cf source and the time-of-flight technique and then use the derived response matrix to unfold neutron spectra from several sources, including ^{252}Cf, PuBe and from other (d,n) binary reactions produced at a Van de Graaff accelerator. Being solid-state, non-toxic and non-hygroscopic, deuterated stilbene crystal is well suited to be used in the field for many applications, including nuclear security, nuclear non-proliferation, and nuclear physics measurements.

Neutron Detectors II - Wednesday 8:00 - 9:30 am in Mendelssohn with Donny Hornback

Directional fast neutron detection based on neutron time projection chamber and plastic scintillation detectors

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Neutron scatter camera and neutron time projection chamber (TPC) were developed in the past decade to realize directional fast neutron detection, which is very useful in the detection of special nuclear material. We propose a new directional fast neutron detection method based on a neutron TPC and position-sensitive plastic scintillation detectors to enhance the angular resolution of the neutron TPC. The effective event is a two-order one: the first scattering takes place in the neutron TPC which can record the track of the recoil proton; the scattered neutron then interacts with one of the plastic scintillation detectors which can provide the t_0 for the TPC and determine the direction of the scattered neutron together with the TPC using the position information. The effective event can be selected by the fact that the track of the scattered neutron is perpendicular to that of the proton. According to the simulation results, angular resolution of 8 degree (FWHM) can be achieved for fission neutrons (^{252}Cf). The efficiency is estimated to be 2.7x10^{-4} with 20 scintillation detectors surrounding the neutron TPC. A detector prototype is being developed. The neutron TPC has an effective volume of 10x10x50 cm^3 filled with 1 atm Ar:C_2H_6 (50:50), which is readout by a triple-GEM detector with 2-D pads connected to 36 pieces of 16-ch ASIC board. Each channel is sampled by a 25 MHz FADC. The gain calibration of the neutron TPC has been done using cosmic rays. The position sensitive plastic scintillation detector is realized by double-side PMT readout. It has been tested using a ^{137}Cs source. The position resolution is 23 mm @ 400 keV (σ). The neutron imaging experiment will be carried out using a ^{252}Cf source. The design, simulation and experiment results will be presented.

Neutron Detectors II - Wednesday 8:00 - 9:30 am in Mendelssohn with Donny Hornback

Demonstration of coded-aperture fast neutron imaging based on Timepix detector

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Localization of radioactive hot spots is an important issue for nuclear industry (decommissioning, waste management and radiation protection) as well as for Homeland Security applications (non proliferation of special nuclear material). For gamma-radiation or X-radiation, industrial imaging systems are currently available, as for example iPIX, Polaris-H, ASTROCAM 7000HS, while for fast neutron, efficiency or portability improvements are still in development, as for example CLYC RadCam 2. The specific fast neutron emission is of great interest for detecting plutonium isotopes. One of the potential benefits is to overcome some limitations of gamma imaging due to specific configurations; for instance, when the presence of gamma shielding, such as leaded glass, hinders the localization of gamma source. To track down this specific fast neutron emission, a neutron imaging system must have a neutron sensitivity in the 0.1 to several MeV energy range (the average energy of prompt neutrons is about 2 MeV for plutonium isotopes). The main purpose of this work is to develop a portable neutron imager whose performance is compatible with the previously mentioned applications. The technological solution selected to locate the fast neutron source is based on two key building blocks: a modified version of the Timepix detector and a coded aperture enabling to locate the neutron source. Timepix is a pixelated readout ASIC which provides a matrix of 256256 (65536) pixels having a pitch of 55 μm. The full sensor sensitive area is 14.08 mm14.08 mm (1.98 cm^2). Neutron detection is obtained by adding a specific conversion layer on the detector. The converter used is a layer of around 1 mm of paraffin paper; therefore, in our case, the charged particles detected were protons. Coded aperture imaging is a technique widely utilized in X-ray and gamma-ray cameras and telescope. This approach employs masks containing multiple apertures with different pixel shapes arranged in unique patterns. In our case, we selected a MURA (Modified Uniformly Redundant Array) pattern, based on CEA LIST knowledge following the development of the GAMPIX gamma camera, presenting the following specifications: rank 3, surface area of 28.16 mm28.16 mm, 5 cm thick, polyethylene. In this article, we describe the work carried out to develop and characterize the main building blocks of the neutron imager prototype. Then we present experimental measurements obtained with a d-t neutron generator emitting 14 MeV neutrons. Finally, we expose future developments planned in the next months.

Neutron Detectors II - Wednesday 8:00 - 9:30 am in Mendelssohn with Donny Hornback

A comparative study of scintillators for ultracold neutron detection

Wang, Zhehui (1), Hoffbauer, M. A. (1), Li, X. (1), Makela, M. (1), Morris, C. L. (1), Pattie, R. W. (1), Wolfe, B. T. (2), Cude-woods, C. (1), Saunders, A. (1)

Los Alamos National Laboratory (1), Collaboration university (2)

A new type of ultracold neutron (UCN) detector based on Boron-10-coated plastic scintillator is described. The characteristic decay time of the scintillator is less than 10 ns and shorter than earlier detectors based on ZnS:Ag. The light yield within the first 10 ns compares favorably with polycrystalline ZnS:Ag and crystalline LutetiumYttrium Oxyorthosilicate (LYSO). The efficiency of each detector is cross-calibrated against ZnS:Ag using various charge particle sources. Several light coupling and photodetector schemes are evaluated. Plastic scintillator-based detectors are useful options for high-rate, large-area UCN detection applications.

Neutron Detectors II - Wednesday 8:00 - 9:30 am in Mendelssohn with Donny Hornback

Improved Manufacturing and Performance of the Microstructured Semiconductor Neutron Detector

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In a bid to find suitable replacements for aging and expensive ^{3}He-based neutron detectors, much research was performed in the area of solid-state neutron detectors. Solid-state detectors often require little volume (<1-mm thickness) and low operating voltages (<5V) compared to their gas-filled competitors but have historically yielded lower detection efficiency (typically <3-4% intrinsic thermal-neutron detection efficiency). To combat this shortfall, Microstructured Semiconductor Neutron Detectors (MSNDs) were developed as a low-cost, high-efficiency means of solid-state thermal-neutron detection. Trenches etched into a pn-junction diode are backfilled with ^{6}LiF neutron converting material. Neutrons absorbed within the conversion material produce charged reaction products that interact within the semiconductor substrate and generate electron-hole pairs. The electron-hole pairs are drifted to the contacts via the applied bias, thereby, generating an electronic pulse. Commercially available single-sided MSNDs are approaching their realistic maximum detection efficiency with devices nearing ϵ_{th} 35% and represent an order-of-magnitude improvement over common thin-film-coated thermal-neutron detectors. However, ^{3}He gas-filled detectors routinely achieve ϵ_{th} >70%. MSNDs are inherently limited in their detection efficiency because of the presence of streaming paths between the trenches; incident neutrons rarely interact with the semiconductor substrate and can pass through the silicon fins without detection. Dual-side microstructured semiconductor neutron detectors (DS-MSNDs) alleviate this issue with an additional set of trenches etched into the backside of the diode. Previously reported DS-MSNDs achieved ϵ_{th} 54%, a nearly 2x improvement over MSNDs. However, the improvements reported here have increased the detection efficiency of a single device through device redesign, controlled junction forming, and better neutron conversion material backfilling. These changes have produced a substantial improvement to the DS-MSND thermal neutron response at ϵ_{th} = 69.2 +/- 0.8%, a new record in solid-state thermal-neutron detection.

6.3.2 PET, SPECT and Other Medical Imaging Techniques (Wednesday 8:00 - 9:30 am in Hussey with Kanai Shah)

PET, SPECT and Other Medical Imaging Techniques - Wednesday 8:00 - 9:30 am in Hussey with Kanai Shah

Trends and opportunities in nuclear medicine imaging

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Semiconductors, both as gamma cameras and photodetectors, have had widespread impact in both PET and SPECT. In particular, their compatibility with magnetic fields has facilitated the development of hybrid PET-MRI and SPECT-MRI systems. The use of modular detectors with good energy and spatial resolutions has yielded improvements in cardiac SPECT and other task-specific systems. Further improvements in sensitivity, timing resolution, energy resolution, and spatial resolution still are needed to enhance image quality while lowering radiation dose to subjects. Germanium detector technology offers the potential to finally make multi-isotope SPECT studies practical. The detection of Cherenkov radiation offers new possibilities for imaging, while the increasing interest in radionuclide therapies is creating new demands for imaging at different gamma-ray energies. The relationship between technical developments and patient care will be explored.

PET, SPECT and Other Medical Imaging Techniques - Wednesday 8:00 - 9:30 am in Hussey with Kanai Shah

The Hybrid Cerenkov-Charge Induction Readout TlBr Detector

Ario-estrada, Gerard (1), Mitchell, Gregory S. (1), Du, Junwei (1), Kwon, Sun Il (1), Kim, Hadong (2), Cirignano, Leonard J. (2), Shah, Kanai S. (2), Cherry, Simon R. (1)

Department of Biomedical Engineering, University of California Davis, Davis, CA (1), Radiation Monitoring Devices, Inc., Watertown, MA (2)

We report on the performance of the first ever thallium bromide (TlBr) detector that combines the conventional charge induction readout of semiconductor detectors with Cerenkov light detection readout for fast timing to be used in applications as time-of-flight positron emission tomography (TOF-PET) and prompt gamma timing (PGT). This hybrid TlBr detector consists of a silicon photomultiplier (SiPM) optically coupled to one of the faces of a TlBr detector that also has electrodes for conventional charge readout. This hybrid TlBr detector has the potential to achieve excellent energy resolution (using the charge induction readout), sub-nanosecond timing resolution (using the Cerenkov readout), and fine 3-D segmentation (using small pixels and obtaining depth-of-interaction information (DOI)). Moreover, TlBr has a better detection efficiency than the scintillator bismuth germanate (BGO) in the energy range of above 100 keV. The hybrid TlBr detector consists of a 3 x 3 x 5 mm^3 TlBr sample with electrodes on two opposite 3 x 5 mm^2 faces and an SiPM (NUV-HD SiPM, FBK, Povo, Italy) coupled to one 3 x 3 mm^2 face. A test board with several filter stages and a charge sensitive preamplifier CR-110 (Cremat, Watertown, MA) was used to readout the charge induction signal. The output of the CR-110 was coupled to a spectroscopy amplifier 2021 (Canberra, San Ramon, CA) for further shaping. The hybrid TlBr detector was biased at -900 V and operated in coincidence with a reference detector, which consisted of an LFS crystal coupled to an SiPM. Waveforms of the reference detector signal, optical Cerenkov signals from the SiPM, and the charge signal from the TlBr preamp output, and spectroscopy amplifier output were acquired with a DPO7254 digital oscilloscope (Tektronix, Beaverton, OR) for coincidence events. The oscilloscope images showed a good time overlap between the Cerenkov output peak and the start of the charge collection of the preamp signal. The preamp signal showed a drift time of approximately 4 s, which is within the expected range for a 3-mm thick TlBr detector biased at 900 V. Timing resolution based on the Cerenkov readout output was evaluated using nuclear instrumentation modules (NIM) and a desktop digitizer DT5740D (CAEN, Via Reggio, Italy). The hybrid detector was operated in coincidence with the reference detector. This setup recorded, for each event, i) the detection time between the reference detector and the Cerenkov output of the hybrid detector, ii) the energy deposited in the reference detector, and iii) the energy deposited in the hybrid detector using the charge induction readout. By gating on events around the 511 keV photopeak, a timing resolution of 625 ps FWHM was achieved. Future work will include the characterization of timing resolution for different energies and the measurement of the drift time of electrons using both readouts of the hybrid detector to i) measure the depth of interaction in the drift direction and ii) correct for the energy degradation due to charge trapping.

PET, SPECT and Other Medical Imaging Techniques - Wednesday 8:00 - 9:30 am in Hussey with Kanai Shah

Development of a MR insert PET detector using strip-line signal readout

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We present our development of a MR insert PET system using SiPM for small animal imaging. In the detector, the strip-line based multiplexing method is adopted for SiPM signal readout, which we have developed for efficient electronic channel reduction; multiple SiPM outputs in a row share a common strip-line to digitizing electronics, and position information of a hit SiPM is encoded in the signal propagation time difference along the strip-line. In strip-line readout, signal digitization electronics is accomplished remotely from detection module, and this feature is advantageous for building PET operating inside a MR scanner; the detection module within MR is kept minimal and compact, and interference between two systems can be minimized accordingly. The prototype MR insert PET is comprised of 14 detector modules; each detector module consists of a strip-line board and 8x4 LYSO scintillator array (each LYSO 3x3x10mm^3). Two units of Hamamatsu S13361-3050NE-04 MPPC array (4x4, 3.2 mm pitch) are used in each detector module, and 32 SiPMs output signals are routed in 2 strip-lines so that 16 SiPM signal outputs share a common strip-line for readout. The detector modules are installed inside a plastic supporting structure with 60 mm of inner diameter and 115 mm outer diameter. The axial field of view of the detector is 25.6 mm. Various experimental tests have been conducted to evaluate the detector performance. A resolution phantom and mouse imaging have been carried out with the insert PET. The effects on MR image due to the PET are also studied. Preliminary test results are very promising and demonstrate that detector design based on strip-line signal readout is suitable for PET/MR system.

PET, SPECT and Other Medical Imaging Techniques - Wednesday 8:00 - 9:30 am in Hussey with Kanai Shah

System Modeling and Evaluation of a Prototype Inverted-Compound Eye

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We have previously reported the design of the MRC-SPECT-II system based on the inverted-compound-eye (ICE) gamma camera concept to offer an >1% detection efficiency while maintaining a sub-500 m imaging resolution [1]. One of the key challenges of using the ICE camera for SPECT imaging is whether one could develop an accurate gamma ray response function (GRF) for the ICE-cameras, given its super-complex compound-eye aperture design. In this work, we will discuss (I) a combined experimental and analytical approach for deriving the precise GRF, and (II) an experimental imaging study to demonstrate the feasibility of using the ICE-camera for acquiring high-performance SPECT images. These studies would help to overcome one of the major hurdles for actually implement ICE-cameras for practical SPECT imaging.

PET, SPECT and Other Medical Imaging Techniques - Wednesday 8:00 - 9:30 am in Hussey with Kanai Shah

A Broadband X-ray Fluorescence Emission Tomography Imaging System Utilizing Small-Pixel Ultra-High Resolution CdTe Detectors

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This work examines recent efforts in developing a broadband X-ray fluorescence emission tomography (XFET) imaging system for monitoring the delivery and stimulation of X-ray induced photodynamic therapy (X-PDT) nanoparticles as well as visualizing the distribution of metalssuch as hafnium, platinum and gadoliniumthat are introduced to living subjects as contrast media or therapeutic agent. A technique inspired by SPECT, XFET is approached as a stimulated emission tomography by utilizing collimation apertures coupled to high-resolution X-ray imaging detectors. The latest iteration of the XFET system incorporates a novel high spectral resolution CdTe detector for fluorescent X-rays of energy between 5 keV and 100 keV. This study examines the feasibility XFET system to monitor the delivery of nanoparticle-mediated X-ray induced photodynamic therapy (X-PDT), but can easily be applied to a large array of other applications as well. In X-PDT, a collimated external X-ray beam irradiates a target region filled with nanoparticles capable of producing localized therapeutic effects. During the X-ray stimulation process of X-PDT, the incident X-rays, which interact with metal atoms contained within the PDT agents, could generate fluorescence X-rays. Detection of fluorescent X-rays would allow the construction of a precise 3D distribution of a specific metal within the target area and provide confirmation of therapeutic delivery. This work focuses on the delivery of therapeutic agents containing high-Z metal elements, such as Au, Hf, La, Pt, and potentially Gd. Such high-Z elements would selective absorb the incoming excitation X-rays, and also emit higher-energy fluorescence X-rays (68.8 keV for Au K, 43 keV for Gd K, 33.4 keV for La-K, and 55.8 keV for Hf K) that could penetrate a substantial thickness tissue, allowing for deeper XFET imaging. This presentation will demonstrate the use of a multi-detector XFET imaging system that utilizes low energy X-ray sources (17.4 keV monochromatic and 50 kVp polychromatic) as well as the higher energy X-ray source found in the Xradia Bio MicroCT (MicroXCT-400) system (operable up to 120 kVp). Detailed studies to assessing the spectroscopic capabilities of the detector for identifying XF photons, as well as the tomographic imaging performance of XFET system will be presented.

PET, SPECT and Other Medical Imaging Techniques - Wednesday 8:00 - 9:30 am in Hussey with Kanai Shah

Edge-illuminated semiconductor x-ray and gamma-ray detectors for medical imaging

Barber, William C. (1), Wessel, Jan C. (1), Kuksin, Evgeniy (1), Hartsough, Neal E. (1), Iwanczyk, Jan S. (1), Morton, Ed (1)

Rapiscan Systems Inc. (1)

We have fabricated direct conversion silicon (Si) and cadmium telluride (CdTe) semiconductor detectors for use in x-ray and gamma-ray imaging respectively using custom application specific integrated circuits (ASICs). The Si detectors are optimized for digital mammography (DM) and breast computed tomography (BCT) and the CdTe detectors are optimized for molecular breast imaging (MBI). Both technologies use a modular edge-illuminated strip detector geometry and can be tiled into long one dimensional (1D) panels which can be stacked into a two dimensional (2D) field of view (FoV) with small gaps. The ASICs are mounted behind and within the active area of the detectors in the incident direction with a common printed circuit board (PCB) for both the sensors and ASICs. This geometry simultaneously provides a high detective quantum efficiency (DQE) and rapid complete charge collection. Placing Si in an edge-illuminated geometry enables spectral photon counting DM and BCT, which use X-ray beam energies of $\sim$ 30kVp and $\sim$ 65kVp respectively, at high flux and with good energy resolution. For DM, 1D panels tiled in a half fan beam array suitable for mammography have been stacked where each panel contains four tiled Si strip arrays. For BCT, 1D panels tiled in a full fan beam array suitable for tomography have been stacked using similar Si strip arrays. The tiling allows each strip of the Si sensor to point to the X-ray focal spot for the particular beam geometry in DM and BCT. The Si strip detectors have either a 50 m or 100 m pixel pitch in the tiling direction and are collimated in the stacking direction with slit widths between 100 m and 500 m. At the highest intrinsic spatial resolution the maximum output count rate (OCR) for the Si strip detectors is 200 Mcps/mm2 when integrated vertically with a photon counting ASIC with four energy thresholds. Si detectors with 6 mm and 10 mm active depth in the incident direction have been tested. The full width at half maximum (FWHM) energy resolution has been determined to be $\sim$ 2 keV between 22 keV and 60 keV, and is mostly due to the electronic noise of the system. Placing CdTe in an edge-illuminated geometry enables MBI, using primarily 140 keV Gamma-rays from technetium 99m (99mTc), with good energy resolution. For MBI, twenty-two 1D panels have been stacked in a flat panel array where each panel contains a CdTe strip array suitable for scintigraphy with radionuclides with Gamma-ray emission up to $\sim$ 200 keV. The tiling allows each strip to be co-registered with collimator septa for MBI. The CdTe strip detectors have a 1 mm pitch in both the tiling and stacking direction. CdTe detectors with 3 mm and 4 mm active depth in the incident direction have been tested. The maximum OCR for the CdTe strip detectors is 200 kcps/mm2 when integrated vertically with a spectroscopic ASIC with up to 16,384 energy bins. The FWHM energy resolution has been determined to be 1.6 keV at 22 keV and 2.2 keV at 140 keV.

6.3.3 Poster II - Radiation Measurement Techniques (Wednesday 9:30 - 10:30 am in Ballroom with Shaun Clarke)

Poster II - Radiation Measurement Techniques - Wednesday 9:30 - 10:30 am in Ballroom with Shaun Clarke

Experimental Validation of a Scintillator-Based, Cosmic-ray Muon Tomography Proof-of-Concept System for Dry Nuclear Fuel Storage Cask Monitoring

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Oregon State University (1), University of Tennessee, Knoxville (2)

Because of the growth of the nuclear power industry in the United States and the policy to ban reprocessing of commercial spent nuclear fuel, the spent fuel inventory at commercial reactor sites has been increasing. With the Yucca Mountain project on hold, more spent fuel is expected to be stored in dry storage casks (DSC) at independent spent fuel storage installation (ISFSI) for extended periods of time. These fuel assemblies are practically inaccessible for inspection purposes, as reopening a DSC would require special facilities and be tremendously expensive. There is currently no practical method to verify the content of a DSC once continuity of knowledge is lost, but cosmic ray muon imaging is under development as a method that could meet this need. The cosmic ray muon flux reaching the surface of the Earth is about 10,000 muons/(min*m$\hat{2}$), which makes muons the most abundant cosmic-ray particles at sea level. Imaging with these muons has been demonstrated to be a viable non-destructive assay method for high-Z materials, such as those inside used nuclear fuel assemblies. Most often a gas-based detector system has been used. In this work, we report on a proof-of-concept muon tomography system made out of plastic scintillator and wavelength shifting (WLS) fibers. The design, calibration and experimental validation of this system are described.

Poster II - Radiation Measurement Techniques - Wednesday 9:30 - 10:30 am in Ballroom with Shaun Clarke

Shielding a Monoenergetic Photon Source for Nonproliferation Applications Analysis

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Near-monoenergetic photon sources inherently solve many problems with using broad-band bremsstrahlung sources in nonproliferation applications. A laser plasma accelerator based Thomson scattering near-monoenergetic photon source is under development at the Lawrence Berkeley National Laboratory. The use of a laser plasma accelerator offers electrons at the very high energy needed for multi-MeV Thomson sources in a compact form factor. Since these electrons are of energies up to 0.5 GeV a large number of energetic photons and neutrons are created as they are dumped out of the beam line. This creates challenges for performing experiments to demonstrate the advantages of such a photon source for nonproliferation applications in the short term, until effective methods for decelerating the electrons are developed. To mitigate these background particles for laboratory measurements a system of beam dumps and secondary collimators has been designed. Once background flux is reduced to the lowest practical level, it is compared to the expected flux created by the source photon beam on a lead target. This simulation mimics a nonproliferation application by predicting measured flux off-axis from an interrogated high-Z object as a surrogate for special nuclear material. While source shielding mitigation alone successfully limits photon flux below signal levels, background neutrons require additional reduction. This will be accomplished through detector shielding, energy thresholding, and time gating. Combined, these approaches enable an experimental setup for assessing the benefits of a near-monoenergetic photon source over broad-band bremsstrahlung sources for nonproliferation applications can be demonstrated.

Poster II - Radiation Measurement Techniques - Wednesday 9:30 - 10:30 am in Ballroom with Shaun Clarke

Characterization of Rotating Scatter Mask Designs for Novel Applications in Photon Detection

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The Rotating Scatter Mask (RSM) system, which consists of a NaI detector, plexiglass mask, and a small motor, is a low cost directional radiation detection system with a nearly 4π field-of-view over a broad range of photon energies. However, the current mask design is limited by similarities in the directional modes of the detector response, causing potential misidentification errors when locating a source. A new class of RSM designs were simulated using MCNP and compared to the current mask design using the modal assurance criterion to characterize differentiability between directional modes. These masks were shown to successfully decouple the angular components of the source's direction, improving the average criterion value by up to 83% and limiting the directional uncertainty to the order of the physical system's angular resolution. Correlation between the geometry of the mask and the detector response for this new class of designs also presents an improved method for determining source direction. Finally, the new designs drastically improved the system's efficiency, reducing the time to identify the source by up to two orders of magnitude.

Poster II - Radiation Measurement Techniques - Wednesday 9:30 - 10:30 am in Ballroom with Shaun Clarke

FRAMv5.2 Estimation of Plutonium and Uranium Isotopics using Digitized 3-D Position-Sensitive CdZnTe Detectors

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Verifying plutonium and uranium isotopics is important for international safeguards due to their potential use in nuclear weapons. Recently developed digitized, 3-D position-sensitive CdZnTe systems are promising for nuclear safeguards, offering larger active volumes and better energy resolutions than current IAEA CdZnTe systems. FRAMv5.2, commercial software used to estimate plutonium and uranium isotopics from high-purity germanium gamma-ray spectra, can be used directly on spectra from high resolution digitized CdZnTe. Plutonium and uranium isotopics were estimated across a wide range of material grades using digitized, 3-D position-sensitive CdZnTe systems and FRAMv5.2. Utilizing FRAMv5.2, plutonium isotopics were estimated to within less than 3σ statistical measurement uncertainty across weapons to reactor grade samples while lowly and highly enriched uranium were easily distinguished. As a result we demonstrate that current, digitized CdZnTe systems offer attractive, room-temperature safeguards capabilities with high energy resolution spectra that are readily compatible with the commercial software FRAMv5.2.

Poster II - Radiation Measurement Techniques - Wednesday 9:30 - 10:30 am in Ballroom with Shaun Clarke

Measurement and Analysis of Beta-ray Spectra at CANDU Reactors

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With the recent International Commission on Radiological Protection recommendation of lowering the dose limit for the lens of the eye, an accurate beta-ray source term information is required to ensure the radiation safety of nuclear workers. In this work, we present beta-ray spectral measurements at several Canada Deuterium Uranium (CANDU) reactors in Ontario, Canada. The beta-ray spectrometry system consists of a plastic scintillator and a digital pulse processing system. The detector response was characterized by Monte Carlo simulations and verified experimentally using calibrated sources at fixed geometries. The spectral data were analyzed using a linear decomposition method and an iterative unfolding method, after subtracting gamma-ray contributions. Based on these preliminary results, we are developing an improved beta-ray spectrometer system than will reject gamma-ray events using coincidence detection.

Poster II - Radiation Measurement Techniques - Wednesday 9:30 - 10:30 am in Ballroom with Shaun Clarke

Study, fabrication and test of a special cooling system for targets submitted to intense ion beams

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DISAT - Politecnico di Torino, Torino, Italy (1), INFN - Sezione di Torino, Torino, Italy (2), LPC Caen, Normandie Universit, ENSICAEN, UNICAEN, CNRS/IN2P3, Caen, France (3)DISAT - Politecnico di Torino, Torino, Italy (1), INFN - Sezione di Torino, Torino, Italy (2), LPC Caen, Normandie Universit, ENSICAEN, UNICAEN, CNRS/IN2P3, Caen, France (3)

In Nuclear Physics, the cross section measurement of rare reactions requires very intense beams, which deposit large amount of heat inside the target. Sometimes, the target material chosen for a given reaction has poor thermal properties; therefore, the heat produced by the beam inside the target must be efficiently dissipated. In the present work, the use of pyrolytic graphite as a support for the target is proposed. Its high thermal conductivity allows to quickly transfer the heat to the cold sample holder. The case of the NUMEN project, which will use very intense ion beams on thin targets, is considered. The temperature distribution inside both the target and the graphite has been calculated for sevral materials. A numerical technique was used to evaluate the time and spatial distribution of the temperature in the system. A MATLAB code, tested in some analytical cases, has been implemented. Using this code, the dependence of the maximum temperature on several parameters has been evaluated. The surface of the deposited films of Sn and Te has been characterized by FESEM analysis. An experimental test of the cooling efficiency of the samples, using a LASER beam, has been planned in the next future.

Poster II - Radiation Measurement Techniques - Wednesday 9:30 - 10:30 am in Ballroom with Shaun Clarke

Double Photon Emission Coincidence Imaging with GAGG-SiPM Compton Camera

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A Compton camera is a promising gamma-ray imaging method for sub-MeV gamma ray because of high probability of Compton scattering. Several Compton cameras have been utilized for visualizing nuclides in medical and environmental applications. Three-dimensional gamma-ray imaging is also required for these applications, however, it is still difficult to fully apply Compton camera for 3-D imaging of distributed sources, because of its low signal-to-noise ratio caused by Compton cones. To solve this problem, we have developed double photon emission coincidence Compton imaging method called DPECT (Double Photon Emission CT) using cascade gamma-rays. Here we show experimental results of DPECT for cascade photon emission nuclides, such as ^{134}Cs and ^{22}Na. As a Compton camera, two layers of 88 array of GAGG (1010 mm^2) coupled to SiPMs as scatter and absorber, and dynamic Time-over-Threshold signal processing circuit are used for parallel event detection. Two Compton cameras are synchronized with an external clock for coincidence detection. Point source image and multiple source image of ^{134}Cs and ^{22}Na are acquired by single Compton imaging and double-photon emission imaging for comparison. Both of those dataset indicated the drastic improvement of SN ratio and point spread function by using double-photon emission imaging method.

Poster II - Radiation Measurement Techniques - Wednesday 9:30 - 10:30 am in Ballroom with Shaun Clarke

Design of a photoneutron source for Bragg edge transmission imaging

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Abstract: To realize the Bragg edge transmission (BET) imaging that can be used to analyze the stress state of samples, a neutron source with large enough cold neutron flux ($\sim 10^3$ n/cm^2/s), continuous energy spectrum and good energy resolution ($\sim$ 3%) should be available. A photoneutron source based on the 10 MeV/20 kW e-linac is proposed in Tsinghua University to meet these requirements. The heavy water is used to convert the bremsstrahlung to intense photoneutrons. The water and the solid methane of 10 K temperature act as the pre-moderator and the main moderator, which finally moderate fast neutrons to cold neutrons. The size of this photoneutron source is researched by simulation to strike a compromise between the neutron yield and the energy resolution. The simulation results show that the cold neutron flux is 2.69*10^3 n/cm^2/s @10 m, and the energy resolution is less than 4%. Keyword: photoneutron source, moderator, the BET imaging, TOF

Poster II - Radiation Measurement Techniques - Wednesday 9:30 - 10:30 am in Ballroom with Shaun Clarke

Gamma-Ray Yield Measurement of ^{12}C(p,p')^{12}C at E$_p$=19.5 - 30 MeV: Preliminary Results from NaI(Tl)

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Passive detection of the presence of special nuclear materials is difficult due to the inherently low rate of spontaneous emission, the presence of shielding, and the fluctuating and frequently overwhelming background. Active interrogation refers to the use of external radiation to increase the emission rate of measurable signatures and has long been proposed as the practical approach to uncover shielded special nuclear materials. Current active interrogation systems use bremsstrahlung beams that deliver high radiation doses. To overcome this issue, low-energy nuclear reactions that provide multiple monoenergetic photons may be used. For example, the ^{12}C(p,p')^{12}C reaction provides strong gamma rays at 4.4 MeV and 15.1 MeV and should not directly produce neutrons when the proton energy is below $\sim$ 19.5 MeV. Further, the 15.1-MeV gamma line is well matched to the photofission cross section of ^{235}U and ^{238}U. We present the preliminary results of the measurement of thick-target yields at 4.4 and 15.1 MeV from the ^{12}C(p,p')^{12}C reaction over the energy range 19.5 <E_p <30 MeV. Measurements were made with a NaI(Tl) detector placed at 0^0. We observe an increase in the production rate of gamma rays when compared to ^{11}B(d,n)^{12}C reaction measured at 90^0 angle with 3 MeV deuteron energy.

Poster II - Radiation Measurement Techniques - Wednesday 9:30 - 10:30 am in Ballroom with Shaun Clarke

Production and Detection of Radioxenon for Nuclear Explosion Monitoring

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There is a worldwide need for improved nuclear explosion monitoring capabilities, including for the US Office of Nuclear Detonation Detection, to support verification of the Comprehensive Nuclear-Test-Ban Treaty. Measuring ratios of radioxenon activity from a combination of four xenon nuclides can distinguish between nuclear power plants, fission-based medical isotope facilities, and nuclear explosions. This requires sensitive - coincidence radioxenon detectors that currently need special coatings which degrade their resolution. Niowave, in partnership with University of Michigan, is working to produce samples of radioxenon in order to calibrate and characterize a new radioxenon detector we will develop, that does not need a special coating. This effort will capitalize on Niowaves existing assets, established by our radioisotope program, with facilities and an NRC license to operate a subcritical assembly and perform nuclear fuel reprocessing. Niowave has a gas extraction module to extract gaseous fission products from our subcritical uranium assembly using a cryogenically-cooled condenser cup. Because the independent and cumulative fission yields for important xenon nuclei are so different, we can drastically change their relative intensities in a sample by adjusting our irradiation time and extraction method to mimic different sources. These samples can be used to calibrate new or existing radioxenon detectors and determine their ability to effectively distinguish between different sources of radioxenon. The University of Michigan, Department of Nuclear Engineering and Radiological Science, is developing stilbene detectors that exhibit properties desirable for an improved radioxenon detector. The problem with existing - coincidence detectors, caused by xenon diffusion into the plastic charged-particle detector, is eliminated by using organic stilbene crystal that is impervious to xenon diffusion. The inherent energy resolution of stilbene is also an improvement over plastic scintillators. Preliminary results of extracted noble gases from pressed fuel pellets in Niowaves uranium target assembly and recent tests of stilbene - detection will be presented.

Poster II - Radiation Measurement Techniques - Wednesday 9:30 - 10:30 am in Ballroom with Shaun Clarke

Elemental and Structural Characterization of Scale Deposition in Oil Pipes using X-Ray Microfluorescence and Computed Microtomography

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The occurrence of scales in pipes and equipment has been reported since the 30s and consists in one of the most relevant problems in the oil prospecting field. The formation of scales (metal sulphates, calcium carbonates and silicates) occurs when incompatible types of water (injected sea water and formation water) are mixed in the reservoir, unavoidably undergoing chemical interaction followed by mineral precipitation. Scales limit and sometimes block oil and gas production by plugging the oil producing formation matrix or production lines and equipment, consequently impairing fluid flow. Due to that, there is a need for determining the way such materials are deposited with in the piping system, as well as its chemical elements constituents. The purpose of this work is to analyze the elemental and structural composition of scale samples from obstructed oil pipes through X-Ray Microfluorescence (μXRF) and computed microtomography (microCT) techniques. The samples were extracted from scales found in steel and composite pipes. Using the μXRF technique, the elements S, Ca, Mn, Fe, Sr and Ba were found in the samples and the 2D distribution map of each element were acquired. In the scale samples extracted from steel pipes, the element Cr was also present due to its utilization to inhibit corrosion. It was possible to observe that the elements S, Sr and Ba were found in very well-defined layers, pinpointing the deposition points for $BaSO_4$ and $SrSO_4$. Calcium was also found in high intensities in the samples extracted from composite pipes, showing that a scale containing this element is predominant for this type of pipe and its application. Through the microCT results it was possible to distinguish the various layers with different densities that compose the samples, showing variations in the structural composition of the scales found in composite and steel pipes and in the way that they were deposited inside the tube. Through the elemental and structural characterization of scales it is possible to predict what kind of scaling will likely be formed in different types of pipes, thus allowing the optimization of prevention and removal methods of such materials.

Poster II - Radiation Measurement Techniques - Wednesday 9:30 - 10:30 am in Ballroom with Shaun Clarke

EMISSION AND TRANSMISSION TOMOGRAPHY SYSTEM APPLIED TO ANALYSE INDUSTRIAL PROCESS INSIDE CHEMICAL REACTORS.

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The radiotracer techniques for industrial processes evaluation have been indicated as the most promising in order to evaluate the kinetic properties along all process. It is capable to obtain measurements in real conditions without interrupting the operation and non-invasive sampling. The radiotracer techniques are widely used in many industries, such as: chemical, food pharmaceutical and oil sectors, in order to diagnose and identify failure in their industrial process. This paper describes a device type double tomographic system capable to generate images of inner products of a chemical reactor, using 40 GBq of Ga-67 citrate as radiotracer to obatain emission images and five Cs-137 external sources for transmission tomographic images. The industrial tomography comprises 70 NaI(Tl) radiation detectors with multichannel input board placed around the chemical reactor. The AnaComp program (Compartmental Analysis) is a computational code designed for the analysis of kinetic data in terms of models. It allows the simulation and the fitting of experimental data using an iconographic language that translates to the symbology of the compartmental analysis. In this work the pathway of the chemical product and the kinetics parameters were evaluated in a laboratory chemical reactor settled in our laboratory, using 40 GBq of Ga-67 citrate as radiotracer and the 70 NaI(Tl) radiation detectors around the chemical reactor for tomographic purposes capable to show the internal structure of the reactor. The AnaComp code allowed estimating the reaction yield showing a value of 87% at 30 minutes of substrate reactions using a safe and non-invasive methodology

Poster II - Radiation Measurement Techniques - Wednesday 9:30 - 10:30 am in Ballroom with Shaun Clarke

Standoff Enrichment Analysis of UF_6 Cylinders

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We address using standoff measurements of UF_6 cylinders for applications such as safeguards verification of facility operations. Existing enrichment analysis techniques are performed by an inspector near the surface of a cylinder where excellent statistics and experimental controls are available. This approach, however, requires significant inspector effort, as well as detailed facility-provided knowledge about the container, fill level, and/or UF_6 cylinder and sample history. In general, enrichment measurements are also complicated by systematic variability of the radiation signatures, likely caused by the cylinder history, $^{234}U/^{235}U$ ratio differences, and spatially heterogeneous "heels" material deposited on the cylinder walls. We describe here an investigation of an unattended multi-sensor radiation system enrichment-measurement concept. Such an approach could be used to verify that shipments entering and leaving a facility are consistent with declared operations for future safeguards and nonproliferation needs. We investigated the use of an array of stationary sensor units to detect and characterize nuclear material in a vehicle moving at 5 to 30 mph at standoff distances of 5 to 10 m. The array consisted of three nodes separated by 5 meters. The center node consisted of two 4"x16" NaI(Tl) gamma-ray detectors, large moderated 3He neutron detectors, magnetometers, an ultra-wide band impulse radar, optical cameras, and a LIDAR to measure different characteristics of the vehicle and any nuclear material it is carrying. The other two nodes consisted of similar gamma-ray and neutron detectors, and a single optical camera. Measurements were conducted at the Framatome Nuclear Facility in Richland, WA. These included several configurations of UF_6 cylinders: stationary measurements at a standoff distance, single cylinders driven slowly by the detector array, and truck shipments of multiple cylinders measured from the side of the road. We measured 30B cylinders with and without overpack varying from depleted to 4.95 wt.% enrichment. We observed increased rates of gamma-ray and neutron signatures from UF_6 cylinder truck shipments despite the thick overpack shielding, several meter standoff distance, and 30 mph speed of the truck. From the cylinders driven by on forklifts at 5-10 meter standoff, we observed the 186 keV gamma signature and neutron rates increasing with enrichment, despite considerable signature variance. We also found that the signal-to-noise ratio of the gamma-ray signatures increases when vehicle tracking information is included in analysis. This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

Poster II - Radiation Measurement Techniques - Wednesday 9:30 - 10:30 am in Ballroom with Shaun Clarke

Transfer of the Oak Ridge Enge Split-Pole Spectrograph to Notre Dame

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University of Notre Dame (1)

Light-ion transfer reactions have been used for many years to study the structure of exotic nuclei. Recently there has been a renaissance of such studies to the application of nuclear astrophysics. In particular, knowledge of the structure of proton-rich exotic nuclei can be used to estimate the astrophysical rates of proton-induced reactions in explosive hydrogen burning. Such studies require the extraction of reaction ejectile energy and angular distributions, and the use of Enge split-pole spectrographs have traditionally provided a good combination of the required resolution and acceptance. Recently the Department of Energy has approved the transfer of the Oak Ridge Enge split-pole spectrograph to the University of Notre Dame Nuclear Science Laboratory (NSL) in order to study transfer reactions of astrophysical interest. Light ion reactions [such as (^{3}He,d), (^{3}He,t), (^{3}He,^{4}He), (^{6}Li,d), and (^{7}Li,t), for instance] will be used to study the structure of the exotic nuclei produced by bombarding stable targets. The spectrograph has been disassembled at Oak Ridge and shipped to Notre Dame. Detailed plans for installation and the status of the project will be discussed. This work is supported by the National Science Foundation and the University of Notre Dame.

Poster II - Radiation Measurement Techniques - Wednesday 9:30 - 10:30 am in Ballroom with Shaun Clarke

Non-destructive Inspection of laminated joints of pipe in polymeric composite material reinforced by fiberglass

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The objective of the present study is to apply the Digital Radiography and Computed Microtomography (microCT) technique to the inspection of laminated joints of pipe in polymeric materials reinforced by fiberglass. The study comprises structural assessment, defects characterization and void distribution of each sample. Non-destructive testing using X-ray is increasingly present in composite material analyses, and has advantages over other laboratory techniques since it is non-invasive and allows 2D/3D visualization of inner structures without previous preparation. The results showed that the techniques detected the intentional void defects inserted, besides others not provided void defects. The Digital Radiography made possible an extension defects measurement. The microCT quantified volumetrically these defects, as well as the reinforcement and matrix layers. Keywords: Microtomography; Radiography; Laminated Joints; Fiberglass.

Poster II - Radiation Measurement Techniques - Wednesday 9:30 - 10:30 am in Ballroom with Shaun Clarke

Evaluation of root canal retreatment quality through of microCT

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The aim of this study was to value the root canal treatment quality using microCT technique. The microCT is a powerfull non-destructive technique that is capable to analyze inner structures without previous manipulation. To realize the instrumentation, the dental file used were reciproc and protaper universal retreatment. After that, the teeth were acquired in original form, instrumented and retreated. The volume was calculated for image segmentation and it was possible to value the volume increased by instrumentation and the residual material percentage after the retreatment . It was possible to conclude that the microCT is a powerful image technique to analyze roots canal and their quality treatment with qualitative and quantitative tools.

Poster II - Radiation Measurement Techniques - Wednesday 9:30 - 10:30 am in Ballroom with Shaun Clarke

Autonomous UAV-Based Radiation Inspection and Mapping of Radiological Contamination

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To safely inspect areas after a nuclear event a system has been developed to remotely take radiation measurements using a VTOL UAV and a simple detector. The system was demonstrated in two different configurations landing at points of interest to dwell for a measurement and lowering the detector from a tether and hovering at the points of interest. The hardware for the system was a small hexacopter equipped with a low-cost flight controller a bGeigie Nano radiation detector. The system had a flight time of 15 to 20 minutes as configured. The system is controlled through mission control software on a laptop that issues autonomous waypoints. To demonstrate the use of the system ten point sources were placed in the test environment to simulate the pattern of a radiation plume. The strength of the sources decreased as the distance from the starting location increased. For the first test the bGeigie was mounted to the landing gear of the UAV. The system was given ten points to search. At each location the UAV would land and collect data for one minute. For the second test the bGeigie Nano was attached to a servo-controlled tether. At each of the ten points the bGeigie was lowered and data was collected for one minute. The hard mounted system had the benefit of longer operation time since the measurement dwells were completed while the UAV was on the ground. This however has the disadvantage that the UAV could become contaminated by the environment. The second configuration eliminated this concern by keeping the UAV in the air and lowering the detector with a tether. The tether detector could also be dropped after data collection was complete. The UAV localization was accurate enough to get close to the sources placed in the environment and the data collected showed the sources. The system demonstrated how a low-cost UAV and detector could be used to collect measurements autonomously.

Poster II - Radiation Measurement Techniques - Wednesday 9:30 - 10:30 am in Ballroom with Shaun Clarke

Continuous and Unattended Spectroscopic Operation and Analysis with the Mirion Data Analyst

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A number of applications benefit from continuous and repeated gamma ray spectral acquisition, analysis, and reporting. These applications include the measurement of fluid or gas flowing through a pipe, material on a conveyor belt, a detector in a free air plume, as well as nuclide mapping by detectors attached to drones. In these cases, important criteria include: no lapses in data acquisition during monitoring, full data analysis and reporting can be applied in real time, the spectra and results are stored for post analysis review, and notifications are available when concentration levels rise above predetermined limits. The Data Analyst is a small device designed to accommodate these needs and provide the flexibility needed to configure measurement, data collection, and data analysis for a variety of applications. Continuous acquisition is accomplished with novel software and hardware which allows for unattended acquisition, analysis, and storage of data over multiple measurement workflow definitions. Each workflow is an independent analysis stream where acquisition time, analysis algorithm parameters, and reporting options may be configured. Since multiple averaging times are allowed for a single data stream it is possible to attain swift reaction times in parallel with very low minimum detectable concentrations. As a direct result of the multiple averaging times, the dynamic range of the applied system may cover eight orders of magnitude depending on the intrinsic range of the radiation detector being utilized. The analysis protocol leverages existing Genie 2000 analysis algorithms and applies them in real time to each workflow as it completes an averaging interval. When one or more intervals are complete the device automatically starts a new interval without the loss of data. The device also accommodates the use of analog inputs, GPIO communication, GPS location, and either wired or wireless communications. The features and capabilities of the device as well as a number of applications will be discussed.

Poster II - Radiation Measurement Techniques - Wednesday 9:30 - 10:30 am in Ballroom with Shaun Clarke

Artificial Neural Network Algorithms for Classification and Recovery of Piled-up Pulses in Active Interrogation of Special Nuclear Material

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We use a new artificial neural network (ANN) algorithm to calculate the rate of neutron multiplets detected by a fast-neutron multiplicity counter (FNMC) performing the non destructive assay of uranium oxide samples in active interrogation mode. The ANN algorithm performs pulse shape discrimination (PSD) and identification of piled-up pulses produced by organic scintillators. We tested the algorithm on a dataset measured by a single detector at a high acquisition count rate of 100,000 counts per second, in the presence of a gamma-to-neutron ratio of approximately 400 to 1. In these conditions, the ANN algorithm exhibits 3, 14, and 11 lower misclassification rates for neutron, gamma, and piled-up pulses, respectively, compared to traditional PSD and pile-up discrimination (PD) approaches. Therefore, the ANN algorithm is suitable for safeguards applications, where neutron coincidence and multiplicity counting is performed in the presence of a high gamma-ray background to estimate the fissile mass of unknown samples. In this work, we use the ANN algorithm to quantify the neutron count rate emitted by uranium oxide certified reference material (CRM) actively interrogated by two ^{241}AmLi sources at Idaho National Laboratory (INL). Two sets of CRM samples were characterized at INL. The ^{235}U enrichment of the first set is constant at 93.2 wt%, and the UO2 mass ranges between 0.5 and 4 kg. The second set includes samples of increasing enrichment (from 20 wt% to 97 wt%) and constant UO2 mass of 230 g. The maximum detected gamma-ray/neutron ratio was 400 to 1 at an overall count rate of 100,000 counts per second. The accuracy of fissile mass estimate relies on the reliability of the PSD algorithms because the time-correlated neutron counts are used to estimate the ^{235}U mass of the uranium oxide samples. The bias error and statistical uncertainty on the estimated ^{235}U mass using the ANN-based method are compared to those obtained with standard PSD-charge integration and fractional pile-up discrimination approaches. The ANN algorithms are implemented in a scalable fixed-point framework and can be implemented on field programmable gate arrays and therefore process the FNMC pulses in real-time.

Poster II - Radiation Measurement Techniques - Wednesday 9:30 - 10:30 am in Ballroom with Shaun Clarke

Effects of Clutter During Radiation Measurements

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There are many challenges to overcome during nuclear nonproliferation measurements, including a wide variety of clutter sources that may be introduced into a scene during acquisition. The ability to understand how the dissimilarity of various objects, or clutter, obscures a detector's field of view and affects the measured response of the detector improves the input to detection alarm and nuclide identification algorithms. Additionally, having the capability to input clutter variation into radiation transport models would allow for more real-world scenarios to be modeled and understood. Efforts at Oak Ridge National Laboratory have been exploring the ability to determine specific natural background radiation contributions from surroundings, such as buildings, soil, asphalt, and concrete, and utilize those source terms in large scale ($100+m^2$) models. This allows for a model test bed reflecting realistic scenarios to be modeled, such as city streets, and for source injections to be performed for algorithm response testing. The capability to quantify different clutter terms, ranging from humans to large vehicles, allows researchers to inject realistic noise into these models. This work seeks to explore the effects that clutter introduces to quantify the expected signal variation inherent to both controlled and uncontrolled scenarios, specifically how the introduction of clutter into a scene introduces a variation in signals due to the attenuation of naturally occurring radioactive material distributed within the scene or by introducing non-threatening radioactive materials into the scene. Controlled measurements aim to quantify how different types of clutter of varying size and composition affects the response of a radiation detector. Persistent measurements are also being performed on the Oak Ridge Reservation with a 2 in. 4 in. 16 in. NaI(Tl) detector, a 3 in. 3 in. NaI(Tl) detector, and a neutron detector to observe the daily response and subsequent changes in signal detected within a dynamic environment. Various contextual sensors are also collocated with the radiation detectors, and data from devices such as weather stations, LIDAR, and cameras are stored within a correlated database that allows data fusion techniques to be used to help identify the presence of clutter. Using results from various controlled tests and data from months of persistent monitoring systems in a dynamic scene, the systematic effects of clutter and its effect on radiation readings is analyzed.

Poster II - Radiation Measurement Techniques - Wednesday 9:30 - 10:30 am in Ballroom with Shaun Clarke

Detector Characterization for Quantitative Spectral Radiography of Uranium Powder Samples

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The International Atomic Energy Agency (IAEA) is responsible for verifying the mass of elemental uranium in various forms (powders, pellets, scrap) as part of inspections at nuclear fuel fabrication facilities. Current methods require in-field dissolution chemistry, which is time consuming and imposes operational challenges. A rapid, nondestructive assay method would streamline inspections. We present a method which uses spectral x-ray radiography for material quantification with a CdTe High-Energy X-ray Imaging Technology (HEXITEC) detector. This detector provides high energy-resolution at the energies of interest (30-200 keV), high stopping power, and count-rate capability suitable for use with an x-ray generator. The detector measures the energy spectrum of x-rays transmitted through a sample over an array of 80 x 80 pixels with a 250 m pitch. The detected spectra are processed with a PNNL algorithm that uses knowledge of the detector response and an inverse problem algorithm to calculate the elemental mass of the uranium in a powder sample (e.g., UO_2). In this paper, we present a characterization of the HEXITEC detector that was used to generate a high-fidelity detector response model to be supplied to inverse algorithm. We also present the first experimental results of the algorithm performance on surrogate samples.

Poster II - Radiation Measurement Techniques - Wednesday 9:30 - 10:30 am in Ballroom with Shaun Clarke

Development of a Gamma-ray/Neutron Dual-particle Imager based on a CLYC-based Rotational Modulation Collimator (RMC) System

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The development of dual-particle imagers has become a popular research topic in nuclear security field thanks to the complementing nature between gamma-ray and neutron measurements. Among various modalities of dual-particle imaging, rotational modulation collimator (RMC)-based imaging is considered as a promising imaging method with little complexity in the system composition. Recently, we have suggested an RMC imaging system combined with the pulse shape discrimination (PSD) capable Cs_2LiYCl_6:Ce (CLYC) scintillation detector as a dual-particle imager. Based on the Monte Carlo simulations performed to investigate the feasibility of developing CLYC-based RMC system and the imaging reconstruction methodology developed implementing maximum-likelihood expectation-maximization (MLEM) method, measurement experiments were conducted for the CLYC-based RMC dual-particle imager. We, first, checked the reproducibility of our imaging system using a gamma-ray source. A 10.64 uCi Ba-133 source (R-type, Eckert & Ziegler, Germany) was positioned on the mounting unit, of which the location can be precisely controlled by the program. Measured modulation patterns showed good reproducibility and well matched MCNP6 simulation results. Reconstructed images also made good estimations on the radiation source location. Subsequently, we also conducted experiments with a neutron source. A 90 uCi Cf-252 source (A3014-01 capsule type, Eckert & Ziegler, Germany) was kept in the cabinet to simulate the scenario in which a radioactive material contained in a box is involved. The reconstructed image of thermal neutron also estimated the location of the Cf-252 neutron source correctly. The experiments gave promising results on utilizing CLYC-based RMC for nuclear material monitoring and detection. In this study, it was shown that both gamma rays and neutrons can be visualized to estimate the source location of radioactive materials utilizing a CLYC-based RMC system. This result demonstrated the feasibility of the CLYC-based RMC system as a dual-particle imager. In the following study, we plan to characterize the device and further evaluate our dual-particle imager with more complex scenarios involving multiple sources and mixed radiation environment that includes neutrons and gammas at the same time.

Poster II - Radiation Measurement Techniques - Wednesday 9:30 - 10:30 am in Ballroom with Shaun Clarke

Gamma-Ray Spectroscopy via Measurement of Angular Distribution of Compton Scattering

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We present a novel method to perform gamma ray spectroscopy suitable for extreme pileup situations, wherein traditional pulse-height spectroscopy is not feasible. One example of such application is spectral characterization of intense laser-based radiation sources that employ laser wakefield acceleration, in which a large number of photons can be produced in a well-collimated beam on a sub-ps timescale. The method relies on the measurement of the angular distribution of Compton scattering, in which an integrated energy measurement is sufficient. The probability for a photon to undergo Compton scattering into a given solid angle is a function of its energy. By first Compton-scattering a beam of photons and then measuring the total energy deposited in an array of detectors placed at various angles of scatter, it is possible to reconstruct incident beam energy spectrum without the need to resolve individual photon interactions. We demonstrate the technique experimentally with a monochromatic beam of 662 keV gamma rays.

Poster II - Radiation Measurement Techniques - Wednesday 9:30 - 10:30 am in Ballroom with Shaun Clarke

Optimization of a $LaBr_3$(Ce) spectrometer for high rate gamma-ray spectrometry at CANDU reactors

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The International Commission on Radiological Protection has recently recommended that the new annual dose limit for the lens of the eye be 50 mSv, rather than 150 mSv. As a result of the new recommendation, the information on the spatial distribution of the gamma-ray field at nuclear power plants is of great importance for the radiation safety of nuclear reactor workers, particularly during the maintenance periods. To this end, gamma-ray spectra were measured in the maintenance areas of CANDU nuclear reactors using a 2" by 2" $LaBr_3$(Ce) detector and digital pulse processing system. Owing to the input count rate of $1x10^5$ cps or higher, the shaping parameters of the pulse processing system were optimized for high rates. The angular and energy responses of the $LaBr_3$(Ce) detector were simulated using the MCNP6 Monte Carlo code in order to analyze the data. The gamma-ray fluence rate spectra measured at Bruce Power and Darlington CANDU reactors will be presented.

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A neural network approach for identification of gamma emitting radionuclides with silicon photomultipliers

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This paper presents a neural network approach for identification of gamma emitting radionuclides measured with Silicon Photomultipliers (SiPMs). SiPMs have wide-ranging applications in field of radiation monitoring and medical imaging due to its high quantum efficiency, high gain, and compactness. For better accuracy on measured information, however, we should consider the disadvantages: dark count rate, optical crosstalk, and temperature sensitivity. Regarding temperature dependencies, conventional approaches are mainly focused on compensating gain variances against temperature by adding circuits or calibrating signals. In contrast with previous works, we propose a new approach exploiting a 2-layer fully connected neural network with SiPMs for identification of gamma emitting radionuclides. The neural network is composed with Rectified Linear Unit (ReLU) layers and a softmax layer. A Saint-Gobain Lutetium-yttrium oxyorthosilicate (LYSO) and a SensL MicroFJ SiPM combined with a Charge sensitive amplifier (CSA) circuit were used in the data acquisition to detect ^{137}Cs and ^{152}Eu. The decreasing logistic regression cost function shows that the proposed neural network is converging to a global minimum, verifying the possibility of distinguishing Cesium from Europium in the mixed radioactive environment.

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A Comparison of Machine Learning Methods for Automated Gamma-ray Spectroscopy

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Pattern recognition algorithms such as artificial neural networks (ANNs) and convolution neural networks (CNNs) are prime candidates to perform automated gamma-ray spectroscopy. The way these models train and operate mimic how trained spectroscopists identify spectra. These models have shown promise in identifying gamma-ray spectra with large calibration drift and unknown background radiation fields. In this work, two algorithms for mixtures of radioisotopes based on ANN and CNN are presented and evaluated.

Poster II - Radiation Measurement Techniques - Wednesday 9:30 - 10:30 am in Ballroom with Shaun Clarke

Quantification of the Systematic Uncertainty in Measuring a Chance Coincidence Background

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Modern advances in waveform digitizers allow coincidence experiments to be performed by record- ing singles data, and identifying coincidences in a later software analysis. It has been shown that for such data the coincidence background can be obtained with unprecedented statistical precision. This method is especially attractive for experiments with complicated backgrounds (i.e. not amenable to analytic or even a detailed Monte Carlo analysis). Many neutron detection experiments fall into this category, such as the Chi-Nu experiment to measure the prompt fission neutron spectra of the major actinides While one may also assert an improved systematic precision of the background measured via this method, this has previously not been demonstrated. Presented here are the systematic uncertainties associated with using such a method to measure backgrounds.

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Optical and Scintillation Properties of Ultrafast Inorganic Scintillators for GHz Hard X-Ray Imaging

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Gigahertz (GHz) hard X-ray imaging for the proposed MaRIE project presents an unprecedented challenge to the front imager in both response speed and radiation hardness. Novel ultrafast inorganic scintillators are to be developed to face these challenges. An investigation on the optical and scintillation properties for a set of fast inorganic scintillators was carried out at the Caltech HEP crystal lab. Transmittance, emission, light output and decay time were measured. Based on this investigation we plan to take two approaches to develop ultrafast inorganic scintillators with sub-ns pulse width and decay time for GHz hard X-ray imaging. One is yttrium doped barium fluoride single crystals and another is based on gallium doped ZnO nano particle based films.

Poster II - Radiation Measurement Techniques - Wednesday 9:30 - 10:30 am in Ballroom with Shaun Clarke

Correlation between pulse shape and pulse height in gamma events at the same energy - prospects for improving resolution

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Alongside strictly material efforts, we want to examine whether there are cases in which one can use pulse shape information to improve energy resolution of a radiation detector. Using extra information in the pulse shape to scale or discriminate radiation interactions in different spatial parts of a detector has successfully improved resolution. For example, SrI_2:Eu suffers from self-absorption and re-emission of scintillation light. Using a digital correction based on pulse shape to distinguish depth of interaction, Beck et al. demonstrated energy resolution of 2.9% FWHM at 662 keV for a 4 in^3 SrI_2:Eu crystal. Pulse shape correction for spatially-dependent charge losses have been used to improve energy resolution and photopeak efficiency of CZT- and CdTe-based semiconductor diode detectors. Both of these resolution improvements used information in the pulse shape to correct for variations of Light Yield versus location of the gamma stopping event in the detector. But is that the only useful information carried by pulse shape? We have studied the correlation between the pulse shape and pulse height as a function of several measurement parameters and conditions such as integration gate, activator concentration, and incident gamma energy in several scintillation crystals including CsI:Tl, NaI:Tl, and CsI:Na. We wanted to see if there are correlations between pulse shape and pulse height from one gamma event to another with ostensibly the same energy. One tool is to make Pulse Shape Discrimination plots of monoenergetic gamma events comprising the detected photopeak, a γ γ-PSD plot. The curving tilt or distortion found in some cases indicates a relation between the pulse shape and the detected pulse height. In results to be presented, a mathematical correction rule was applied to remove the tilt, and the result was resolution improvement in the pulse height spectrum. We anticipate that composite scintillators with a substantial resolution loss due to random splitting of energy deposition in two components will allow for a more significant resolution improvement. Monolithic crystalline scintillators can be expected to display random variations in pulse height and pulse shape between different individual gamma events at the same ostensible total energy just due to the well-known fluctuations in energy deposition and how they interact through nonlinear terms in rate and transport equations. The measured different nonproportionality trends of different decay components in NaI:Tl and CsI:Tl establish that there are definite correlations between pulse shape and pulse height versus energy. We have used this to improve proportionality. The correlation information may be a basis for resolution improvement, but it requires more work concerning noise that accompanies assigning the amplitude of each pulse shape component. If a correlation can be found between pulse shape and pulse height and reduced to an algorithm, then pulse shape fluctuations could in principle provide the information to "compress" the photopeak, in analogy to compression of optical pulses using information in the frequency spectrum. WFU authors acknowledge support from DHS/DNDO under DHS-2014-DN-077-ARI077-05. There is no express or implied endorsement by the government.

Poster II - Radiation Measurement Techniques - Wednesday 9:30 - 10:30 am in Ballroom with Shaun Clarke

Design of a prototype radioxenon detection system using stilbene and CdZnTe

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The measurement of radioxenon isotopes has been instrumental in the effective enforcement of the Comprehensive Nuclear Test Ban Treaty (CTBT). In a nuclear weapon test lot of noble gases are produced. The unique feature about radioxenon is the coincident emission of electrons and photons making it easy to detect low concentration of radioxenon in the air. The ratios of different radioxenon isotopes act as signatures of nuclear weapon tests. In an effort to aid the CTBT, a well-type plastic-based scintillator for electron detection and a CZT based detector for photon detection was developed. This detector provided a near 4Π solid angle for electron detection but introduced the problem of memory effect. From literature review it was found that stilbene has virtually no memory effect, therefore it was decided to use a well-type stilbene detector for electron detection. For photon detection it is desired to have a high Z element, therefore, CZT was chosen for its relatively high Z, good energy resolution and room temperature operation. Therefore, for the new radioxenon detection system, it was decided to use stilbene and CZT. The CZT is placed close to the stilbene gas cell to improve absolute efficiency. For light collection from stilbene, arrays of silicon photomultiplier (SiPMs) will be used, these light collection devices bring with them low cost, compact size, and low operational voltage. The entire detector assembly will be mounted on a PCB for real-time measurements. Signals from the SiPMs are routed through the charge sensitive preamplifier and connected to one channel of the digital pulse processor. Signals from the collecting and non-collecting grids of the CZT pass through the preamplifiers followed by the subtraction circuit before being connected to the second channel of the digital pulse processor. A MATLAB interphase was developed in the PC to control the coincident time window. Plotting the 2D spectrum of the coincident pulses and identifying the regions of interests associated with the coincidence decay indicates the presence of radioxenon. The detector will be characterized using check sources and radioxenon activated at the Oregon State TRIGA reactor. The Stilbene-CZT based detector is expected to provide a cost-effective, compact alternative to the state of the art while keeping the memory effect in check and achieving the minimum detectable concentration of less than or equal to 1mBq per meter cube for ^{133}Xe.

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Image quality characterization using Presampled-MTF for a neutron imaging system composed of ^{6}Li loaded ZnS detector and CCD camera at different flux locations of the UFTR

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Experimental procedure is setup to determine the quality of transmission neutron radiography images produced at different flux locations of the 100 kW research reactor located at the University of Florida (UFTR). The system employs ^{6}Li loaded ZnS scintillation detector and CCD camera. A separate experiment on the flux characterization of the reactor beam ports has shown that the thermal and epithermal neutron fluxes decrease in different rates as the distance from the reactor core increases, the latter decreasing at higher rate. This work quantitatively determines the effect of the flux profile on the quality of transmission radiography images produced by the system. Presampled MTF is used as the characterization parameter to compare the images produced by locating the image acquisition system at different distances from the reactor core. The MTF parameter is used in this work since it combines both the resolution and contrast, which are the two parameters limiting the smallest object that can be identified with an imaging system. Multiple images of a slightly slanted target, Cd sheet with 0.02 inch thickness and 100% purity, are collected using the ImageJ software, and fed in to an algorithm built in python to determine the Presampled MTF parameter. The steps followed in the algorithm include detecting the edge using canny edge detection method, determining the orientation of the edge using Hough Transform with a precision of 0.1 degree angle and acquiring multiple oversampled edge spread functions. The average edge spread functions is then used to find the line spread function, and the Presampled MTF is eventually calculated by taking the absolute value of the Fourier transform of the line spread function.

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Development of a high frame rate neutron imaging method for two-phase flows

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A high-frame rate imaging system has been developed to image two-phase flow in an aluminum bubbler at 1-2 kfps. The imaging system utilizes a LiF/ZnS scintillator and a CMOS camera. The spatial resolution of the system allows the imaging of bubbles as small as 3-4 mm. The source is a bright neutron flash created by a pulse at the Pennsylvania State University TRIGA reactor. After post processing various properties of the bubbly flow are derived, such as, instantaneous gas fraction and gas interface velocity.

Poster II - Radiation Measurement Techniques - Wednesday 9:30 - 10:30 am in Ballroom with Shaun Clarke

Passive neutron measurement by neutron coincidence counting using neutron/gamma discriminating plastic scintillators

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Characterization of nuclear waste packages is a crucial task for the nuclear industry. Non-destructive methods are often used to characterize such packages and offer the advantage of preserving their integrity. Both passive and active non-destructive methods exist. This study deals with a passive measurement technique which consists in detecting neutrons emitted spontaneously by actinides contained in packages. This method is known as passive neutron measurement. Total neutron counting is easy to deploy but can be disturbed by spurious neutrons emitted by, e. g. (alpha, n) reactions. In order to circumvent this problem, neutron coincidence counting can be applied to detect correlated neutrons emitted by spontaneous fission. Neutron coincidence counting is a reference measurement method used in industrial setups dedicated to nuclear waste packages characterization and especially to quantify plutonium masses. The reference neutron detector is based on the use of Helium-3. Unfortunately, Helium-3 shortage lead to a significant increase in price of such detectors. Alternative neutron detectors are then required. Plastic scintillators are a solution of interest as the latter offer the advantage of being low cost and can be made in large volumes. However, in a gamma-ray background, standard plastic scintillators reach their limitations as they are sensitive to both neutrons and gamma-rays. Recent developments conducted by few laboratories including ours enabled to achieve effective neutron/gamma discriminating plastic scintillators. In this study, we evaluate performances of home-made fast neutron/gamma discriminating plastic scintillators to carry out neutron coincidence counting. A setup has been built for these experiments and a specific Matlab code has been developed to process measurement results and plot Rossi-alpha distributions. First measurements carried out with liquid scintillators enabled to validate the setup and the Matlab code. Then, measurements carried out with plastic scintillators enabled to demonstrate the potential of neutron/gamma discriminating plastics to perform passive neutron measurements by neutron coincidence counting.

Poster II - Radiation Measurement Techniques - Wednesday 9:30 - 10:30 am in Ballroom with Shaun Clarke

A Monte-Carlo simulation method for the research of self-powered neutron detectors

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The self-powered neutron detector (SPND), which plays a key role in monitoring the neutron flux of the reactor core, is a very important device for developing the nuclear power. In this research, a comprehensive method is proposed and researched to predict the performance of the SNPD that might be affected by various parameters of the detector. Compared with the methods proposed by former researchers, this method covers a more exhaustive physics process and can handle with a more complicated detector geometry and reactor conditions. The theoretical research results are compared with the experimental results, indicating a <4% relative error, which is better than the figure (>9%) of former researches.

Poster II - Radiation Measurement Techniques - Wednesday 9:30 - 10:30 am in Ballroom with Shaun Clarke

Investigation of A Model Based Reconstruction Technique for Neutron Tomography at the PULSTAR Reactor

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Thermal neutron tomography is a non-destructive technique used for the investigation of the internal structure of objects. This technique provides complementary information to X-ray tomography for a wide range of applications in science and engineering. High spatial resolution is often a desired characteristic of any imaging system. The achievable spatial resolution in neutron imaging is limited by the beam geometry and the detector system. A well collimated beam reduces geometrical blurriness but may limit the available neutron flux at the image plane. For a scintillator/CCD based detector system, a thin scintillator can improve the resolution but is limited by the range of the neutron absorption reaction products (i.e., the alpha and triton particle for ^{6}LiF:ZnS(Ag) scintillator). In this work, we have developed a model based tomography reconstruction technique to enhance the achievable spatial resolution of a neutron tomography system. The spatial resolution is improved by including the system response function in the forward projection model. The method was implemented using projection data produced with Geant4 multi-physics simulation model. The simulation model includes a thermal neutron source, a ^{6}LiF:ZnS(Ag) scintillation screen and a pixilated imaging detector. The thermal neutron source is assumed to be a beam extracted from the PULSTAR research reactor at North Carolina State University (NCSU). The projection data is obtained by simulating 25 m, 50 m and 250 m thick scintillators. The spatial resolution is characterized from the reconstructed images of a cylindrical phantom and validated with a bar phantom. The reconstruction results of the model based technique are compared with the traditional filtered back projection technique. The spatial resolution achieved with the model based technique for all scintillator screens shows an improvement of nearly 40% relative to traditional reconstruction techniques. By examining the trends in spatial resolution improvement with model based technique, a path can be envisioned for the development of a neutron micro-tomography system which includes using a thin scintillator for data acquisition and a model based technique for tomography reconstruction.

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Pulse Height Spectra Analysis of an Energy Tuning Assembly

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Neutron spectrum shaping is a novel method that can be used to generate synthetic debris for nuclear forensics applications. An energy tuning assembly (ETA) was previously designed and built for the purpose of irradiating samples with a combination of a thermonuclear and a prompt fission neutron spectrum for production of synthetic debris for technical nuclear forensics at the National Ignition Facility. Initial bench-marking of the ETA performance was performed at the Lawrence Berkeley National Laboratory 88-Inch Cyclotron using 33 MeV deuteron breakup on tantalum as the neutron source. This research analyzes detector responses collected from three EJ-309 detectors used to characterize the ETA generated neutron field. Full waveform data from the source and ETA modified field were taken. A signal processing chain was developed to reduce the waveform data into a neutron only pulse height spectrum to unfold the measured neutron energy spectrum.

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Pre-deployment characterization of large fast neutron detectors for high performance computing fault characterization

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Los Alamos National Laboratory (LANL) provides world-class high performance computing (HPC) capabilities, which is a vital resource for a wide range of science. Due to the high cost of these supercomputers, it is of vital importance that these systems are reliable and produce results that scientists can depend on. Computer electronics have long been known to be impacted by neutrons. Supercomputers can experience faults in their microprocessors in the form of data corruptions and crashes caused by the interaction of neutrons. These events are known as single event upsets (SEU). Neutrons are created by the interaction of cosmic rays in the atmosphere and can cause increased concern for computing facilities at higher altitudes. Therefore, the understanding of the neutron environment in the Strategic Computing Complex (SCC) at LANL, where the supercomputers are located is critical for understanding the risks of neutrons to the supercomputing hardware. In collaboration with the Space Science and Applications group (ISR-1) at LANL, the HPC Design Group (HPC-DES) purchased four neutron detectors to be deployed in the SCC to monitor the cosmic neutron intensity over time. Two of the detectors use plastic scintillators and two use liquid scintillators. Previous studies have investigated neutron-gamma ray pulse shape discrimination (PSD) capabilities of plastic and liquid scintillator detectors with diameters and lengths of just a few centimeters. This study investigates the PSD capabilities of two Eljen scintillator detectors; one plastic and one liquid with diameters and lengths of 12.7 centimeters. These detectors have been tested to provide a comparison in the liquid and plastic scintillator PSD capabilities. A CAEN DT5790N digitizer provided the high voltage and PSD method for this comparison. The characterization of the two detectors will provide a more complete understanding of the cosmic neutron intensity in the SCC and will help to make the vital work at the HPC more reliable.

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Experimental plan for the verification of a neutron imaging technique incorporating compressed sensing in the collimator design

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Compressed sensing theory has been applied in the signal processing stage of most current imaging system. This research attempts to incorporate compressed sensing principles in the collimator design. A physical experiment was designed to provide a proof of concept for this technique by running a series of Monte Carlo N-Particle Transport Code (MCNP) simulations to determine the height of water required to stop all neutrons from the source, the collimator array dimensions, the collimator material and the collimator size for the experiment. The simulations were run using a cylindrical water tank and an array of 2 x 2 collimator with three different materials to determine the collimator material for the experiment. An array configuration is defined as the random combination of air-filled and water-filled channels. Three hundred configurations were generated for the 23 x 23 array and 100 configurations for the 11 x 11 array. With these different configurations and the neutron counts measured with each configuration, the image of the source was constructed using compressed sensing principles by the l1-MAGIC package with MATLAB. The neutron source images produced using a 23 x 23 array of collimator and 11 x 11 array were compared and the latter was shown to yield an image that still allows for correct shape and position identification of the ring source defined in the MCNP input deck. Due to the availability of a parallelepiped water tank for the experiment, another MCNP model with a parallelepiped tank was created with an 11 x 11 array. Several images as a function of the number of measurements, K were produced for this model to observe the minimum K used that would result in significant degradation of image quality. These simulations have resulted in the decision to proceed with the assembly of an imaging system made of a 250-gallon water tank that would be filled with water with an array of 11 x 11 polyvinyl chloride (PVC) pipes of a half-inch diameter placed vertically at its center. It is found that an image that shows the correct shape and location of the neutron source at this 11 x 11 resolution can be obtained with about 58% of the total number measurements needed if the image was reconstructed using the conventional method. This technique can be proved to be useful in the localization and shape identification of a neutron source for nuclear security or comparison with image signatures of nuclear installations for nuclear safeguards.

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Neutron flux measurements in the beam ports of the University of Florida Training Reactor after the HEU to LEU fuel conversion

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After the conversion from high-enriched uranium fuel to low-enriched uranium fuel in 2006, the reactor entered a prolonged outage period in 2008 until 2015. The characterization of the irradiation beam ports of the University of Florida Training Reactor are absolutely necessary to their usage for different irradiation experiments, including thermal neutron imaging. In this work, neutron activation analysis was performed using gold foils to determine the neutron beam profile at different regions surrounding the reactor core, including separate determination of the new thermal and epithermal neutron fluxes using the cadmium ratio method. In order to improve the accuracy of the calculated neutron fluxes, three correction factors, thermal neutron correction factor, permeation correction factor and self-shielding correction factor, were used. These factors account for contribution of thermal flux, thermal neutron permeation through cadmium and absorption and scattering of neutrons within a sample, respectively. At the maximum reactor power of 100 kW, the highest thermal and epithermal fluxes for the vertical ports were recorded in the central vertical port as (1.45 0.07) x10^{12} and (4.30 0.21) x10^{11} n.cm^{-2}.sec^{-1}, respectively. The CVP is located at the center of the reactor core and ends at the reactor core mid-plane where the maximum neutron fluxes of the reactor were obtained. On the other hand, the highest thermal and epithermal fluxes for the horizontal ports were recorded in the south port as (0.79 0.03) x10^{12} and (4.25 0.21) x10^{11} n.cm^{-2}.sec^{-1}, respectively. As expected, neutron flux decreased as distance from the core increased in all of the three ports where the neutron beam profiles were determined. The thermal column had the most significant decrease in flux between the closest and farthest points from the core that were 40 cm apart, 72.50% decrease in thermal and 96.13% decrease in epithermal neutron fluxes.

Poster II - Radiation Measurement Techniques - Wednesday 9:30 - 10:30 am in Ballroom with Shaun Clarke

Design and development of an External Fast Neutron Beam Facility at The Ohio State University Research Reactor

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An external fast neutron beam facility is under construction at the Beam Port 1 of the Ohio State University Research Reactor (OSURR). Presently, OSURR utilizes Beam Ports 1 and 2 to perform research, training and experimentation. Beam Port 2 has already been developed as an external thermal neutron beam facility with structural shielding in place. The newly designed facility at the Beam Port 1 is expected to provide a collimated beam of fast neutron flux with relatively low gamma ray content for various neutron-probing applications such as fast neutron imaging, radiation damage evaluation on semiconductor and electronic devices etc. In order to perform radiation-shielding analysis of the facility, the MCNP modeling was performed for the Beam Port 1. The MCNP model of the new fast neutron beam facility consist two collimators, a beam shutter and a beam stopper for radiation shielding analysis and dose simulations. The collimators allow neutrons to penetrate the biological shield, 58 in length with an aperture of 32 mm in diameter, containing a 6 thick graphite block as a thermal neutron scatterer and a 4 thick polycrystalline bismuth as a gamma ray filter. The cylindrically shaped beam shutter utilizes high density polyethylene (HDPE) as a fast neutron absorber and lead filters as a gamma ray absorber is provided between the two collimators. The beam stopper employs borated polyethylene as a fast neutron absorber and lead as a gamma absorber. MCNP simulations were aimed to optimize the performance of shielding materials used. The MCNP simulations were performed at the neutron energy of 1.5 MeV with collimators and the beam shutter both in the closed and open position, with a 30 million-particles run, provided a neutron flux of $\sim$ 102 and $\sim$ 1.8x108 neutrons/cm2s at the collimators exit, and dose rate of $\sim$ 0.174 and $\sim$ 4.75 mrad/h at the beam boundaries, for closed and open position respectively. Next simulation utilizing 3 MeV neutron beam, with a 100 million-particles run, with the beam stop provided dose rate of $\sim$ 1 mrad/h and $\sim$ 500 microrad/h at the backside and, left and right sides of the beam stopper, respectively. The newly built beam facility will allow samples to be irradiated at the near core position, where neutron energy is expected to be approximately 1.5 MeV with the fast neutron flux of 6.5x109 n/cm2s, and gamma ray content reduced to 0.01 % of its core value.

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Neutron and gamma-ray Pulse shape discrimination of $LiAlO_2$ and $LiGaO_2$ crystals

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A scintillator is one of the luminescent materials that convert a high energy ionizing radiation photon/particle to hundreds of visible photons via energy migration from the host matrix to emission centers immediately. Recently, the shortage of 3He gas becomes a big issue in the radiation detector field, and some alternatives for neutron detectors are highly required. Recently, we find some undoped crystals such as $LiAlO_2$ and $LiGaO_2$ have a pulse shape discrimination (PSD) function, and we will report some basic scintillation and PSD properties of these crystals. In scintillation emission spectra, these two crystals had an emission peak around 330 nm, and spectral shapes were identical. In scintillation decay curves, micro-seconds order components were observed in these crystals, and the decay times were slower than typical emission center activated scintillators. When we irradiate neutrons from ^{252}Cf and gamma-rays from ^{60}Co, we found a difference of decay curves by different radiation. We made a two-dimensional histogram between the pulse height with fast integrated time window and the ratio of the pulse height under fast and slow integrated time windows of $LiAlO_2$ and $LiGaO_2$. As a result, neutron and gamma-ray events were clearly separated in the two-dimensional histogram. To the best of our knowledge, PSD function in undoped inorganic scintillators is not common, and this work opens a new possibility to search for new PSD scintillators.

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Thermal Neutron Detectors for Radiation Sensing Using UAVs

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This abstract summarizes the work to establish the Radiation Detection Technologies Inc. (RDT) Domino thermal neutron detector as a viable solution for airborne radiation detection using an unmanned aerial vehicle (UAV). The use of radiation sensors on UAVs imposes constraints on the size, weight, and power (SWAP). Both simulation and laboratory calibration data were used to (a) verify manufacturer claims of efficiency, (b) show that the Domino is flexible enough to perform with commercial-off-the-shelf (COTS) data acquisition tools, and (c) detect a range of neutron sources applicable to nuclear threat reduction scenarios. Additionally, benchmarking of a thinning algorithm was conducted in order to simulate detection of sources which may be too active to be used in a laboratory setting. Predicted counts using the thinning algorithm were in good agreement with experimentally observed results for a range of distances up to 2.5 m. Current work now focuses on testing of the detection capabilities of the sensor package in actual flight conditions.

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A review of the prompt neutron nu-bar value for ^{252}Cf spontaneous fission

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Passive neutron multiplicity counting can be used to determine the absolute emission rate of ^{252}Cf spontaneous fission sources. Such sources can then be used to characterize and calibrate instruments used to assay Pu for materials control and accountancy, nuclear safeguards, and nuclear security applications. An important contribution determining the ultimate accuracy of this technique is how well the neutron multiplicity distribution of ^{252}Cf is known. This governs how well the emission rate of the ^{252}Cf sources can be determined. Additionally because ^{252}Cf is used as a reference standard against which other spontaneously fissile systems are compared, it also governs the scaling of the ^{252}Cf characterization and calibration data to the corresponding performance estimates for the spontaneously fissile Pu-nuclides. The main scale setting parameter is nu-bar, the average number of neutrons released following fission, of ^{252}Cf. In this work we briefly review the 14 high quality absolute determinations of nu-bar and subject them to a full covariant evaluation. This is compared to several variants of weighted mean, including an extension where an allowance is made for the uncertainty in the variance on each point. The prompt nu-bar value was found to be robust to the different statistical assessment methods applied and the overall uncertainty estimates were of similar magnitude. Based on the full covariant treatment a prompt nu-bar value of (3.75730.0056) prompt neutron per fission was obtained, where the uncertainty is at the 1-σ level. This compares favorably with the value of Zucker and Holden, (3.7570.010) prompt neutrons per fission, long used in the nuclear safeguards community. The relative standard deviation of 0.15% obtained from the analysis reported here is sufficiently small that we advocate for a new high accuracy determination of the delayed neutron contribution, since this is needed to correct the Mn-bath class of nu-bar measurements. Collectively the measurements span the period 1963 to 1985. Of the 14 measurements six carry very little weight (individually 2% or less), five carry intermediate weight (individually 3% to 7 %), while three values are highly weighted (individually 15% to 32%). These have a reported relative standard deviations of between 0.2% and 0.3%. Given the small number of measurements with small reported uncertainties and the fact that the youngest such determination is over 30 years old, we also strongly suggest that new measurements of the highest currently achievable quality are overdue. In this regard a high efficiency ^{3}He based counter would remove the residual concern over -sensitivity of doped liquid scintillator tank data. Key words: nuclear data evaluation; nu-bar; ^{252}Cf spontaneous fission; ^{252}Cf source strength

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The Specific (α n) Production Rate for ^{234}U in UF_6

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Natural, depleted, and low enriched uranium hexafluoride is manufactured and transported on an industrial scale to support commercial nuclear power plant operation. One way material production and flow is verified by nuclear safeguards inspectorates is by neutron counting. The dominant neutron source term is (α,n) production due to ^{234}U which gets enriched/depleted along with ^{235}U. In this paper we describe recent efforts to accurately determine the (α,n)/s/g of ^{234}U in UF_6. This piece of nuclear data is of direct value to the nuclear safeguards community in the science based verification and assay of bulk uranium hexafluoride. It also provides a benchmark on codes that calculate yield curves from cross section data and hence provides a scale constraint on evaluated cross section data. In turn evaluated basic data allows the yield from other materials to be calculated, for instance moist uranyl fluoride which is of interest in holdup measurements. Key words: uranium hexafluoride, alpha-neutron reaction, nuclear safeguards

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Applications of C^7LYC Scintillators in Fast Neutron Spectroscopy*

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The spectroscopic capabilities of ^{7}Li-enriched $Cs_2{}^7LiYCl_6$ (C^7LYC) scintillator detectors have been explored in projects which exploit the excellent pulse-shape discrimination between neutrons and gamma rays, and the unprecedented $\sim$ 10% energy resolution for fast neutrons in the <8 MeV range, obtained through the ^{35}Cl(n,p) reaction [1]. Test experiments with SCANS (Small C^7LYC Array for Neutron Spectroscopy) [2], which is comprised of sixteen 1" x 1" C^7LYC crystals, include both elastic and inelastic neutron scattering cross-sections on ^{56}Fe at Los Alamos with a pulsed white neutron source, as well as (p,n) and (d,n) reactions on low-Z targets using mono-energetic proton and deuteron beams from the 5.5 MV Van de Graaff accelerator at the UMass Lowell Radiation Laboratory. As a long time-of-flight (TOF) arm is not necessary for obtaining good neutron energy resolution, a large gain in solid angle can be achieved by positioning the detectors close to the target, substantially offsetting the relatively low intrinsic efficiency of C^7LYC for fast neutrons when compared to traditional neutron detectors such as liquid scintillators. The incident energy from the pulsed white neutron source at Los Alamos WNR facility was measured via TOF of the beam, and the scattered neutron energy via the measured pulse height in SCANS. Our angle- and energy-resolved cross-section measurements establish the utility of this dual neutron-gamma scintillator in fast neutron spectroscopy applications. Larger C^7LYC crystals are now being produced, and measurements with the first ever 3" x 3" C^7LYC crystal (which has an efficiency close to twice the entire SCANS array) are in progress. Direct efficiency measurements have been performed using mono-energetic neutron beams generated via the ^{7}Li(p,n) reaction at the UML accelerator. The results of the spectroscopic capabilities of C^7LYC will be presented and discussed in the context of developing this emerging scintillator for targeted science applications. *Supported by the NNSA Stewardship Science Academic Alliance Program under Grant DE-NA0002932 and the Office of Science under Grant DE-FG02-94ER40848. 1. N. D'Olympia et al., NIM A694, 140 (2012); ibid., A714, 121 (2013); ibid., A763, 433 (2014). 2. N. DOlympia. Ph.D. thesis, U. Massachusetts Lowell (2014) (unpublished).

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Quantifying the determinants of leakage multiplication for large uranium objects using Monte Carlo simulations

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Leakage multiplication is a quasi-physical characteristic of fissionable uranium objects that is often assayed using active interrogation measurements. Assay of large, highly-multiplying uranium objects using coincidence and multiplicity counting is susceptible to biases due to the simplistic assumptions of point kinetics-based analysis methods. This work uses Monte Carlo simulations to quantify the sensitivity of leakage multiplication to its underlying physical characteristicsenrichment, mass, and geometry for a bare uranium metal sample under active interrogation. Nonlinear curve fits of data from over 49,000 MCNPX-PoliMi simulations are used to calculate a range of sensitivity coefficients for leakage multiplication. The effect of varying the directional distribution of the external source relative to the interrogated object is also examined. An understanding of how sensitive leakage multiplication is to changes in the underlying physical characteristics of uranium allows for potential corrections to assay results or evaluation of assay uncertainty based on prior knowledge of one or more of these physical characteristics.

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Measurement of neutron and gamma-ray cross-correlation functions with ^{4}He detectors

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For the first time, the time-dependent cross-correlation distributions of a spontaneous fission source are measured using two ^{4}He fast neutron detectors. A Struck 14-bit 250 MHz waveform digitizer is used along with its constant fraction discrimination feature to achieve a good pulse timing resolution. Charge integration based pulse shape discrimination is performed to identify the following correlated pairs: gamma raygamma ray, neutronneutron, gamma rayneutron, and neutrongamma ray. Both total and separate cross-correlation functions are determined and compared at various source-detector distances. At equal source-detector distance, the cross-correlation distributions are symmetric around time zero. When varying the source location between the two ^{4}He detectors, notable changes in the cross-correlation distributions are observed. The center position of the Gaussian fitted correlated neutron-neutron distributions shows a clear correlation with the difference of the source-detector distance. The results illustrate the implantation of the ^{4}He detectors as a potential radioactive material characterization tool, with applications to nuclear nonproliferation and homeland security.

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Multiplicity Detection of Low-Fluence Neutron Sources using CTMFDs

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This paper describes the development of a neutron multiplicity counter for low-fluence neutron sources using Centrifugally Tensioned Metastable Fluid Detectors (CTMFDs) as the detection elements. As reported in past SORMA meetings and NIMRA publications among others, TMFD technology offers a promising alternative to conventional neutron detectors across a wide array of detector missions. The ideal detector element for a multiplicity counter has the following properties: inexpensive, easy to use, large gamma rejection ratio, large neutron efficiency (preferably at both fast and thermal energies), large solid angle coverage, short time between being able to accept counts, and precise timing of neutron detection events. CTMFDs address many of these concerns. Individual CTMFD units are inexpensive; they are easily controlled via a LABVIEW interface with automatic event detection and recording via IR sensors. They have been shown to be completely gamma insensitive up to gamma fields of 700 R/h. Full spectrum Cf neutron detection efficiency for constructed CTMFD units has been experimentally tested up to $\sim$ 56% and designed units theoretically should reach $\sim$ 80% (Note: units with borated fluid should be even higher). Designs for CTMFDs in column configuration have resulted in packing efficiencies approaching that of moderated thermal neutron detectors. Until recently the two final properties, dead time and timing precision, represented a significant challenge to multiplicity counting via CTMFDs. Detailed in this paper are the efforts at the creation of acoustic shock based superior precise timing information, and the evaluation of spin algorithm and detector placement to maximize multiplicity information obtained. Previous iterations of CTMFD hardware relied solely on IR photodiodes to detect when a Cavitation Detection Event (CDE) occurred. Because of the physics of cavity expansion and vortex formation, change in IR signal caused by the CDE would not be reliably detected until hundreds of milliseconds after the event. Recently, new acoustic shock based timing for the detection of CDEs has been devised. The CTMFD enclosure was outfitted with a waveguide designed to focus the sound waves from cavitation onto a microphone. Experiments using a high-speed camera and a ns pulsed laser to initiate bubble nucleation showed that the timing accuracy of the acoustic system is improved x1,000, now on the order of fractions of a ms. Other uses for the acoustic waveform are being presented in a companion paper. Because of the $\sim$ 10s dead time for each detector between CDEs, it is vitally important to maximize opportunities for detectors to be sensitive simultaneously and thus have the ability to detect multiplicity neutrons born in the same initiating event. In order to optimize the quantity of these events, a variety of operational paradigms were investigated. In addition to optimizing the spin algorithm, the source distance and detector threshold were also optimized. CTMFDs have the ability to set the threshold at which they will be sensitive to neutron recoils. Placing the detectors optimally means finding the setting where multiple neutrons from an event are most likely to interact both spectroscopically and geometrically without saturating the detector.

Poster II - Radiation Measurement Techniques - Wednesday 9:30 - 10:30 am in Ballroom with Shaun Clarke

Development of an Ir transition edge sensor for near infrared single photon counting

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Recently high sensitivity near infrared photon detectors draw attentions of many researchers in quantum computing, telecommunications, and near infrared scintillators. We are developing a near infrared photon counting detector with energy resolution, which might be potential high-energy resolution scintillation detectors when coupled to the near infrared scintillators as well as quantum computing applications. Avalanche photodiodes (APDs) are sensitive to near infrared photons, however, they cannot detect single photons. Their quantum efficiency is very low or even zero for near infrared photons. Therefore, we focus on superconducting transition-edge sensors (TES) operating at ultra-low temperatures. TES serves as a microcalorimeter to detect photons of sub-mm to pm wavelength range. For instance, tungsten (W) and titanium (Ti) TESs with a high quantum efficiency above 95% were reported. However, the transition temperature of W is difficult to control to depend on its microstructure. Also, thermal noise of Ti-TES is insufficient for the resolving power of m wavelength photons. For fabricating TES with high sensitivity, we applied iridium (Ir) for superconducting thin film because Ir has a low bulk transition temperature and chemical stability. TES is an extremely sensitive thermometer by using its steep transition curve. The operating temperature of TES is automatically stabilized by using the negative electron-thermal feedback (ETF) method, which applies a constant voltage bias across the film for speeding up the detector. We have fabricated an Ir-TES near infrared sensor. The Ir thin metal film and Nb electrode were deposited by an RF magnetron sputtering method on the Si/SiN wafer and formed by the lift-off method. The Ir-TES was formed into the 7 m 17 m 20 nm size (7 m 7 m size of effective area). The Nb electrodes (200 nm thickness) were fabricated on the Ir film with contact area of 5 m at both edges. The cryostat is kept at the operating temperature of 100 mK by using a GM refrigerator and a mixture of ^{3}He and ^{4}He. An Ir-TES was mounted on the cold stage with a Superconducting Quantum Interference Device (SQUID) readout electronics placed on the same cold stage. It was biased in the constant voltage regime with a 20 m shunt resistance. We measured current-voltage (IV) characteristics of the Ir-TES at the bath temperature from 64 mK to 280 mK. We confirmed the ETF operation of the device because we observed the region where Joule heating of small pixel Ir-TES is constant. Although transition temperature of bulk Ir is 140 mK, the measured transition temperature was approximately 280 mK. In order to confirm single photon response, we irradiated thel Ir-TES with a 1310 nm wave-length laser which was attenuated to a level of single photon operation. We successfully observed a pulse height spectrum corresponding to a single photon detection in the 1310 nm near infrared region.

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Beta Radionuclide Identification Algorithm by Using a Phoswich Detector

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The identification of beta-emitting radionuclides has been a challenging issue because of the continuous energy distribution of their primary source spectra and the similarity of their maximum decay energies. Presently, no studies have been reported that identify radionuclides without sampling, using the spectrum measured directly by scintillators. In this paper, we propose a modified energy-weighted algorithm to identify the radionuclides for plastic beta spectra. The spectra were simulated by Monte Carlo N-Particle transport code 6.1 based on the response function of the EJ-400 plastic scintillator. The algorithm presented here could distinguish 131I and 99Mo from other radionuclides having similar spectral shapes. High uncertainty spectra generated by reducing the number of particle histories could also be identified as those radionuclides. In addition, the algorithm was validated by identifying 90Sr/Y using the spectra measured by EJ-400. The 90Sr/Y radioactivity of 0.05 Ci could be identified.

Poster II - Radiation Measurement Techniques - Wednesday 9:30 - 10:30 am in Ballroom with Shaun Clarke

Progress towards ultrafast detectors for GHz hard X-ray imaging

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High-speed imaging is one of the most important techniques and sometimes the only option to examine material properties, structures, and their functions on micro- and nano-second timescales. Higher imaging frame rate requires higher X-ray pulse repetition rate. APS-U, with 88-MHz pulse repetition with a low beam emittance and more than 10^5 X-ray photons per pulse, is anticipated in the near future. Similar capability is available at the French ESRF facility and elsewhere. To take advantages of these new source capabilities and future facilities such as MaRIE, ultrafast hard X-ray imaging capabilities with a frame-rate no less than 100 MHz is desired, which will be at least 10X faster than the state-of-the art technologies (about 10 MHz frame-rate). We report the first successful time-resolved X-ray measurements at the Advanced Photon Source (APS) 10-ID-B beam line. An ultrafast x-ray detector concept was proposed using ultrafast crystals and detectors with picosecond timing resolution. Multiple crystal and sensor pairs (LYSO, BaF_2, plastic scintillators, PMTs) as well as a standalone detector (diamond) have been tested to demonstrate the time-resolved measurements using hard X-rays at energies of 30 keV and above. The experimental results show that a number of choices exist for time-resolved high-energy X-ray beam measurement, paving the way towards ultrafast imaging technologies using hard X-rays for many applications.

Poster II - Radiation Measurement Techniques - Wednesday 9:30 - 10:30 am in Ballroom with Shaun Clarke

Simulated Spectral Responses of Thin Planar-Type Radiation Detectors by Tracking Primary Electrons from the Gamma-ray Interaction

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In the simulation of a spectral response from a radiation detector measuring gamma rays, the pulse height (f8) tally of the MCNP is often used, or the energy deposited in the detector is calculated from the energy lost by each incident gamma ray due to the interaction. However, in reality, the energy deposition to a radiation detector is indeed caused by the kinetic energy transferred by primary electrons which are generated by the gamma ray interactions and further create information carriers to create the detector signal. One may think the simulation of spectral responses of a gamma-ray detector following aforementioned approach would not cause any significant discrepancy from the reality, if the sensor volume is large enough to encompass the mean range of primary electrons. However, even in the case measuring a 137Cs source using a 1 mm-thick silicon detector. Moreover, in such cases as thin planar-type detectors like a silicon sensor or detectors with small active volume with fine pixellation or ones constructed by nanomaterials, one cannot assume that the amount of energy change between particle histories of the gamma ray will be equal to the energy that was really transferred to the detector volume. This issue can possibly make an influence on investigations on micro-dosimetry as well, because one would desire to precisely calculate the exact radiation dose given to a specific area of small volume. In this regard, we attempt to compare simulated spectra obtained for a small thin planar-type detector by tracking primary electrons with those obtained with conventional methods. We first calculated energy spectra using MCNP6 and GEANT4 codes by changing the size of the detector thickness and cutoff energy of electron transport. Spectral response simulations were performed for a cylindrical silicon detector with a radius of 2.5 cm and the thickness varying from 50 μm to 500 μm irradiated by a 662 keV point source. Each simulation was performed for 108 particle histories. Cutoff energy of electron transport was varied from 1 keV to 160 eV and 30 eV in order to see any differences in spectra, when electron tracks are traced.

Poster II - Radiation Measurement Techniques - Wednesday 9:30 - 10:30 am in Ballroom with Shaun Clarke

SiPM-based Compact Time-of-Flight Detector Using Cherenkov Glass

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Endectra LLC, in collaboration with University of Michigan, is developing a compact solid-state glass detector technology that utilizes erenkov emission (CE) following neutron interactions within the medium. When integrated with a fast silicon photomultiplier (SiPM) array, this approach is capable of efficient single-waveform detection and identification of nuclear radiation. Here we report new results demonstrating the detectors performance when measuring neutron energies using time-of-flight methods. For this purpose, a small erenkov glass faceplate was optically coupled to a light-tight silicon photomultiplier (SiPM) array and placed downstream of a spontaneous fission ^{252}Cf source. A plastic scintillator, which was used as the fission start detector, was placed on a SiPM array with the same size and backend electronics. Pulses were recorded in coincidence with a sub-nanosecond sampling time digitizer to obtain the time-of-flight spectrum. A SiPM-based Cerenkov glass detector approach described here is promising as a compact time-of-flight neutron spectrometer. Its small form factor provides a route to a novel handheld device for neutron spectroscopy. We acknowledge funding from the DTRA and NSF SBIR programs.

Poster II - Radiation Measurement Techniques - Wednesday 9:30 - 10:30 am in Ballroom with Shaun Clarke

A New, Versatile, High-performance Digital Pulse Processor with Application to Neutron/Gamma-Ray Pulse-Shape Discrimination in Scintillator Detectors

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We present a VME based, 16-channel digital pulse processing module which has been developed to be suitable for a wide range of radiation detectors and to deliver high resolution in energy and time measurement. This module delivers high performance and flexibility with ease of use. A unique concept for the online digital pulse processing firmware has been developed to combine the capabilities of digitizing data acquisition with the logic to emulate the accuracy of classic analog techniques. For use with scintillating neutron detectors, the on-board firmware includes pulse-shape discrimination (PSD) in order to allow on the fly neutron-gamma discrimination. PSD data-transfer rates are low since the particle identification is done on board. Measurements for a xylene-based EJ-301 liquid scintillator and a 4x2 Inrad Optics stilbene crystal detector will be presented. The results will compared with data derived from analog PSD techniques.

Poster II - Radiation Measurement Techniques - Wednesday 9:30 - 10:30 am in Ballroom with Shaun Clarke

Prototype Design of Pulse Digitalization Base for Photomultiplier Tube with Single Cable

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The pulse digitalization and readout electronics is important for system with photomultiplier tubes (PMT), which are popularly used in high energy physics experiments, nuclear related experiments, medical equipment and other fields. The prototype design of integrated pulse digitalization base for PMT is including the GSPS FADC, high speed buffer, clock, power management, FPGA, high voltage generator, synchronized timing and PoE power supply. There is only one CAT-5 Gigabit Ethernet cable is needed for power, data and synchronized timing. The integrated design will replace the conventional readout system with PMTs use the discrete or integrated pulse shaping circuits and FADC boards which are based on NIM or VME system to implement the data acquisition function. In many applications, there are only several PMTs used in whole system, or in some distributed applications, long distance analog cable with high voltage power cable are not applicable due to tremendous channels and enormous distributed space. The integrated digitizer base is designed for neutron scintillator detector with two PMTs used to measure the background radiation and neutrino experiments with more than 20000 PMTs aim to geometrical neutrino explorer, they all will be deployed in China Jinping underground Laboratory (CJPL). Over 800 Mbps TCP data throughput and more than 10W power can be supplied with 50ns synchronized precision. This paper will illustrate the prototype designs system architecture, hardware design, software development and preliminary test result for this integrated readout electronics.

Poster II - Radiation Measurement Techniques - Wednesday 9:30 - 10:30 am in Ballroom with Shaun Clarke

Temperature dependence of neutron detectors using $LiCaAlF_6$ scintillators

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Nuclear logging is a method for gathering information about the layers of rock drilled through. The gamma-ray and neutron scintillation detectors which operate at high-temperature are used for such application. Temperature dependence of conventional gamma-ray scintillators have already been investigated, and Tl:NaI is known to show high light output and good temperature response. The Tl:NaI scintillator is a current standard material for gamma-ray logging. A standard material for neutron logging is the Ce-doped lithium silicate glass (Li-glass) which also shows good temperature response. Many gamma-ray scintillators have been tested for this application; however, only few neutron scintillators have been tested. In the present work, we have studied the influence of temperature on the responses of Ce:$LiCaAlF_6$ and Eu:$LiCaAlF_6$ in comparison with that of GS20. Prototype neutron detectors using Ce:$LiCaAlF_6$, Eu:$LiCaAlF_6$, and Li-glass GS20 coupled with the photomultiplier tube (PMT; Hamamatsu R1288) were prepared. From the results of the temperature dependence of relative pulse heights for neutron detectors using GS20, Ce:$LiCaAlF_6$, and Eu:$LiCaAlF_6$ under thermal neutron irradiation, we confirmed that pulse heights of all the detectors tend to decrease at high temperature. Pulse heights of the neutron detectors equipped with GS20, Ce:$LiCaAlF_6$, and Eu:$LiCaAlF_6$ at 150 degrees C were approximately 40%, 70%, and 50% of those at 25 degrees C, respectively. We conclude that neutron detectors using Ce:$LiCaAlF_6$ and Eu:$LiCaAlF_6$ show good temperature responses as similar as that using GS20.

Poster II - Radiation Measurement Techniques - Wednesday 9:30 - 10:30 am in Ballroom with Shaun Clarke

Flexible silicon-based alpha particle detector

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The detection of alpha particles in the field can be challenging due to their short range in air of often only a few centimeters or less. This short range is a particular issue for measuring radiation inside contaminated pipework in the nuclear industry, for which there is currently no simple method available without cutting the pipes open. Here, we propose an approach for low cost, rapid, and safe identification of internally contaminated pipework based on a flexible 30 X 10 mm$\hat{2}$ sheet of 50 lm thin crystalline silicon. Following established fabrication steps of pn-junction diodes, we have constructed a device with a signal-to-noise ratio of >20 in response to 5.5 MeV alpha-particles using a bespoke amplifier circuit. As flexible detectors may readily conform to a curved surface and are able to adapt to the curvature of a given pipeline, our prototype device stands out as a viable solution for nuclear decommissioning and related applications

Poster II - Radiation Measurement Techniques - Wednesday 9:30 - 10:30 am in Ballroom with Shaun Clarke

Time resolved nuclear spectroscopy - exploring new dimension in scintillation characterization

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In this work we propose a new approach towards characterization of scintillation pulses in two domains simultaneously: in terms of excitation energy and time. With the proposed method we characterized several halide scintillators providing new insights on the dynamics of the scintillation process. The results enable verification of recent theoretical developments in the field and extend our state of knowledge. Our approach to nuclear data processing may enable improvements of a scintillation detector energy resolution by exploiting all available information within each scintillation pulse.

Poster II - Radiation Measurement Techniques - Wednesday 9:30 - 10:30 am in Ballroom with Shaun Clarke

Engineering of well conditions to improve the responsivity of p-on-n SiPM for blue light detection

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This paper reports electrical and optical properties of the new p-on-n SiPM developed at KAIST with a collaboration of NNFC. The overall device fabrication process flow in the new development follows that of the prototype development. Based on the previous work, several changes were applied to the new development to minimize the shooting of the leakage current at a low bias and reduce the breakdown voltage while enhancing the PDE. The modifications introduced in the new development are RTP conditions for the shallow well annealing and ion implantation conditions for the junction formation. In this work, we lay out a comparison between the new and the prototype in terms of several SiPM characteristics to underline the improvements achieved through the device modifications. In particular, we demonstrate that the reverse current has been reduced by more than a factor of 10^4 with the modified RTP condition in the new development. Likewise, we will show that the device operation voltage is reduced and that the overall detection efficiency is enhanced when compared to the prototype as a result of modifying the well conditions.

Poster II - Radiation Measurement Techniques - Wednesday 9:30 - 10:30 am in Ballroom with Shaun Clarke

Low Energy Light Yield of Fast Plastic Scintillators

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Very compact neutron imagers using double-scatter kinematic reconstruction are being designed for localization and characterization of special nuclear material. These neutron imaging systems rely on scintillators with a rapid prompt temporal response as the detection medium. As n-p elastic scattering is the primary mechanism for energy deposition by fast neutrons in organic scintillators, proton light yield (LY) measurements are needed for accurate assessment of scintillator performance and are fundamental inputs to event reconstruction algorithms. The LY of a series of commercial fast plastic organic scintillators (i.e., EJ-200, EJ-204, and EJ-208) was measured via a neutron coincidence scattering technique at the 88-Inch Cyclotron at Lawrence Berkeley National Laboratory. Using a tunable deuteron breakup neutron source, target scintillators housed in a dual-PMT coincident-trigger configuration, and an array of pulse-shape-discriminating observation scintillator cells, the fast plastic scintillator LY was measured over a broad and continuous proton energy range. These detection and analysis methods enable LY measurements down to approximately 50 keV proton recoil energy, approaching the physical threshold for light detection in these systems. This work enables the accurate assessment of scintillator properties required for utilization of these materials in emerging neutron imaging modalities.

Poster II - Radiation Measurement Techniques - Wednesday 9:30 - 10:30 am in Ballroom with Shaun Clarke

Development and Evaluation of $CeBr_3$ and GAGG array with SiPMs for Compton and PET imager

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For PET and Compton imaging applications, pixellated array with good energy resolution and fast timing resolution is required. $CeBr_3$ and GAGG are both promising scintillation detector because of its good characteristic of fast decay (19 ns and 88 ns) and high light yield (72000 ph/MeV and 56000 ph/MeV). We have developed a 8 x 8 $CeBr_3$ and GAGG array individually coupled to SiPMs (3 x 3 mm^3 / pixel). The performance of $CeBr_3$ and GAGG arrays are characterized as a pixelated detector. Also the performance as Compton imager is characterized.

6.3.4 Room-Temperature Semiconductor Detectors (Wednesday 10:30 - 12:00 pm in Mendelssohn with Mac Black)

Room-Temperature Semiconductor Detectors - Wednesday 10:30 - 12:00 pm in Mendelssohn with Mac Black

Development of position-sensitive virtual Frisch-grid CdZnTe detectors

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Arrays of position-sensitive virtual Frisch-grid CdZnTe (CZT) detectors offer an economical approach to make high-efficiency and high energy-resolution gamma cameras for imaging and spectroscopy applications. Such instruments can be used for a variety of tasks including gamma-ray astronomy, medical and industrial imaging, environmental cleanup, nuclear safeguards and security. In this work, we present the design and results from testing two configurations of arrays consisting of 6x6x20 and 5x7x25 mm^3 CZT detectors coupled to the recently developed front-end ASICs. The arrays design provides flexibility to extend its dimensions in conjunction with the opportunity to replace faulty individual detectors or higher-performing detectors with thicknesses potentially increased up to 4 cm. Each detector operates as a mini time projection chamber. For each gamma-ray event it provides 3D position information with high-spatial-resolution. This enhances imaging capability for the array and allows for correcting the detectors response non-uniformities due to the presence of crystal defects. This allows the developers to use relatively economical standard-grade (unselected) CZT crystals, while retaining good performance comparable to the large-volume pixelated detectors.

Room-Temperature Semiconductor Detectors - Wednesday 10:30 - 12:00 pm in Mendelssohn with Mac Black

Study of the impact of CZT detector characteristics on imaging performance

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LETI, CEA, Grenoble (1), NUVIAtech Instruments, Beaumont-Hague (2)

Our group has developed on a buttable CZT detection module combining standard 2.5 mm square anode pattern, low noise readout and FPGA based embedded processing. The benefit of such approach is to obtain simple design and high performance at the same time. No cathode readout is needed while anodes are large and easy to connect. Readout density is thus kept moderate and integration is easy. With large electrodes, charge sharing is limited and depth sensing is still feasible by an anode-only readout. Last but not least spatial resolution is improved by subpixel positioning while energy resolution is kept good. This device is thus well adapted to spectral imaging. This design architecture could address various low flux imaging techniques. For SPECT modality using classical parallel hole collimation, one can use high spatial resolution to deconvolve the collimator response accurately and help to improve sensitivity-resolution trade-off. In X-ray diffraction imaging, high energy and spatial resolution are useful to limit the blur on momentum transfer signature and also enable new system architectures. In the far field gamma imaging domain, we have recently integrated this module in a handheld device called NuVision that combines coded aperture and Compton imaging. However, one question that frequently arises is the precise quantification of imaging performance gain that is brought by a particular detector setup. The relative impact of detector area, thickness, spectral quality and imaging quality is not straightforward to evaluate. First, because imaging is often a complex multiparametric task. Second, because many aspects are intermixed: working condition, detector setup, data processing and statistical variability. The ground truth about imaging performance is obtained only by carefully controlling all these aspects and repeating the same experiment many times. We propose in this work to untangle those factors to understand better detector impact. We use using several tools. For controlling working conditions, radiation and detector physics, real acquisitions are compared with simulated data. That allows to take into account at least most meaningful physical phenomena. Statistical variability is quantified by using list-mode data and creating acquisition replicas. Data processing algorithm results are compared with theoretical figures of merit like Fisher information or optimal observer detectability performance. We finally apply this methodology to concrete cases to gain insight into observed results. We show how it can lead to guidelines for improving system and detector design.

Room-Temperature Semiconductor Detectors - Wednesday 10:30 - 12:00 pm in Mendelssohn with Mac Black

Development and Performance of the A400 RIID

Wahl, Christopher G. (1), Barron, David (1), Streicher, Michael (1), Kaye, Willy (1), Zhang, Feng (1), Yang, Hao (1), Jaworski, Jason (1), Slatina, Tj (1), Boucher, Y. Andy (1), Sowers, Jon (1), Moran, Kevin (1), He, Zhong (1)

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An improved-resolution replacement for NaI-based radioisotope-identification devices (RIIDs) has been developed using pixelated-CdZnTe (CZT) technology. Hardware and software design considerations and resulting features will be presented along with performance for security applications and current limitations and technical challenges. The resulting instrument uses four CZT crystals with a total volume of over 19 cm^3, has energy resolution better than 1.0% FWHM at 662 keV, a battery life of 8 hours, and weight of 2.25 kg. The system has been ruggedized with an injection-molded enclosure of a polycarbonate acrylonitrile butadiene styrene (PC/ABS) blend that maximizes impact strength in shock environments, vibration-dampening grommets on the detector head, and environmental sealing to withstand full submersion in 1 meter of water for 30 minutes (IP67). Besides reporting spectra and isotopic ID, the system reports directionaility to multiple sources on an isotope-by-isotope basis by using Compton imaging and clustering image-analysis algorithms. At lower energies, a centroid center-of-mass algorithm can localize single low-energy-emitting isotopes.

Room-Temperature Semiconductor Detectors - Wednesday 10:30 - 12:00 pm in Mendelssohn with Mac Black

Performance and longevity of pixelated TlBr arrays

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The design of portable radiation detection is placing increasing emphasis on radionuclide identification or classification, going beyond simpler measurements of intensity or exposure. Semiconductor detectors have potential advantages of better energy resolution versus the predominant use of scintillators in these instruments. The challenge for semiconductors is to combine the strength of resolution with sufficient sensitivity, and achieve practical cost points. Thallium bromide has considerable potential in meeting these needs due to its high intrinsic stopping efficiency and photofraction, and simple production. Amongst possible specific detector designs that have been demonstrated with TlBr, pixelated formats have shown the best energy resolutions (<3% without depth corrections). We will report on the fabrication and performance of pixelated TlBr arrays in thicknesses ranging from 5 to 10 mm, and with pitches of 1 and 1.7 mm. Discussion will also include the application of low temperature bump-bonding for high density readouts. Pulse height spectra are recorded over several months in order to assess projected work life and stability. Although methods such as cooling and and bias switching have been suggested as means to achieve longevity, methods here have focused on device construction and room temperature operation. This work has been supported by the US Department of Homeland Security, Domestic Nuclear Detection Office, under competitively awarded contract HSHQDC-16-C-00044 and HSHQDN-16-C-00024. This support does not constitute an express or implied endorsement on the part of the Government.

Room-Temperature Semiconductor Detectors - Wednesday 10:30 - 12:00 pm in Mendelssohn with Mac Black

Stable Thallium Bromide Detectors for PRD and SPRD Applications

Datta, Amlan (1), Becla, Piotr (1), Fiala, John (1), Becla, Kris (1), Motakef, Shariar (1)

CapeSym, Inc. (1)

Thallium bromide (TlBr) is a wide bandgap compound semiconductor which has a number of advantages relative to the incumbent CdZnTe. Until recently the suitability of this material for reliable gamma-ray detection was challenged by its short room temperature lifetime. Recently we have shown that periodic switching of bias on TlBr detectors can result in room temperature device lifetimes exceeding 10,000 hours of continuous operation. In this presentation we will report on the development and performance of a prototype Personal Radiation Detector (PRD) based on TlBr. The PRD electronics architecture and performance will be discussed. We will also report on performance of a number of TlBr single charge detectors for spectroscopy, where their uncorrected and corrected energy resolution competes with those of CZT detectors. As part of this development effort, large area spectroscopic detectors with Tl-metal contact have been fabricated and are undergoing long-term performance tests. Performance of these detectors will be also discussed. This work was supported in part by the U.S. Department of Homeland Security, Domestic Nuclear Detection office contract HSHQDN-16 -C-00025. This support does not constitute an express or implied endorsement on the part of the Government.

6.3.5 Algorithms and Modeling (Wednesday 10:30 - 12:00 pm in Hussey with Sara Pozzi)

Algorithms and Modeling - Wednesday 10:30 - 12:00 pm in Hussey with Sara Pozzi

Event-by-Event Fission Modeling with FREYA

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For many years, the state of the art for treatling fission in radiation transport codes has involved sampling from average distributions. However, such "average" fission models have limited interaction-by-interaction capabilities. Energy is not explicitly conserved and no correlations are available because all particles are emitted isotropically and independently. However, in a true fission event, the energies, momenta and multiplicities of emitted particles are correlated. Such correlations are interesting for many modern applications, including detecting small amounts of material and detector development. Recently, several Monte Carlo codes have become available that calculate complete fission events. Event-by-event techniques are particularly useful because it is possible to obtain the fission products as well as the prompt neutrons and photons emitted during the fission process, all with complete kinematic information. It is therefore possible to extract any desired correlation observables. Such codes, when included in broader Monte Carlo transport codes, such as MCNP, can be made broadly available to the community. The fast event-by-event fission code FREYA (Fission Reaction Event Yield Algorithm), one such code, generates large samples of complete fission events. We briefly describe the physics behind FREYA and compare our results with relevant available data on prompt neutron and photon emission. We discuss correlated measurements in particular for validation.

Algorithms and Modeling - Wednesday 10:30 - 12:00 pm in Hussey with Sara Pozzi

First Steps Toward Validating Computed Muon Tomography with the CRIPT Detector

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Cosmic-ray muons can be used to passively detect nuclear materials such as uranium and plutonium, as they interact preferentially with materials of high density and atomic number. Muon tomography imaging techniques can therefore be leveraged to address concerns of nuclear safety and non-proliferation. While most muon tomography systems reconstruct images based on measured muon scattering angles provided by coincident measurements, computed muon tomography is an alternative method based on attenuation. This method generalizes traditional computed tomography algorithms from medical imaging for use with measurements of cosmic-ray muons, and has applications in imaging large nuclear infrastructure such as spent fuel repositories. A computed muon tomography algorithm is currently under development at Canadian Nuclear Laboratories (CNL), where previous work has provided a proof-of-concept using a simplified model simulation of muon measurements taken around CNLs ZED-2 reactor. In the current work, a simulation study has been performed to assess the feasibility to experimentally validate the computed muon tomography algorithm using data from the Cosmic Ray Inspection and Passive Tomography (CRIPT) detector. Geant4 simulations have been used to model muon transport and detection using CRIPTs lower tracking module. Reconstructed images from the simulated data can identify the primary features of a lead brick target in a horizontal projection. However, the ability to reconstruct vertical projections is limited by both the natural angular distribution of cosmic-ray muons, as well as the restricted angular acceptance of the CRIPT detector. While the CRIPT detector is suitable for a first small scale experimental test of the computed muon tomography algorithm, further study and validation will be required to evaluate the vertical reconstruction capacity of the procedure.

Algorithms and Modeling - Wednesday 10:30 - 12:00 pm in Hussey with Sara Pozzi

Alpha and beta detection capabilities of an environmental continuous air monitoring system

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We assess the capabilities of the Canberra Alpha Beta Environmental Continuous Air Monitor (ECAM) to detect airborne contamination during a radiological emergency. We measured the response of the ECAM to standard calibration sources as well as custom filter sources, which were created by depositing actinide or radiostrontium solution onto clean filters. Source terms were scaled to quantities of interest and injected onto measured background, accounting for variations in the energy calibration. We then evaluated the minimum detectable integrated concentration for various alarm algorithms. In general, the analysis methods could detect the source terms at small fractions of the Derived Response Level (DRL) computed from early response Protective Action Guides (PAG), given reasonable probabilities of detection and false alarm rates.

Algorithms and Modeling - Wednesday 10:30 - 12:00 pm in Hussey with Sara Pozzi

Bayesian unfolding of elementary particle spectra in mixed beta-gamma fields

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Bruce Power, Tiverton, ON N0G 2T0, Canada (1)

Radiation exposure in nuclear facilities consists predominantly of beta- and gamma-emitting radionuclides that result in superficial and deep dose deposition to nuclear energy workers. Accurate determination of the elementary particle spectra that make up the mixed beta-gamma fields is desirable as it drives dose assessment models and provides insights into the dose deposition mechanisms throughout the facility. However, direct measurements of the constituent elementary particle spectra are challenging since detectors used to assess the fields often have comparable sensitivity to beta- and gamma-rays and the detector response matrices non-invertible and multi-modal. In this paper, a Bayesian inference method is developed that enables unfolding of beta- and gamma-ray spectra from simultaneous measurements made using two or more collocated detector systems. The outcomes of this method are posterior probability densities of all possible beta- and gamma-ray particle fluence spectra. To demonstrate its effectiveness, the method is applied to simulated data sets from a pair of passivated implanted planar silicon (PIPS) and LaBr_3(Ce) scintillator detectors and show it is able to recover the beta- and gamma-ray fluence spectra, with high purity, under different irradiation conditions.

Algorithms and Modeling - Wednesday 10:30 - 12:00 pm in Hussey with Sara Pozzi

Machine learning n/γ discrimination in CLYC scintillators*

Doucet, Emery (1), Brown, Tristan (1), Chowdhury, Partha (1), Lister, Christopher J. (1), Morse, Christopher (1), Bender, Peter C. (1), Rogers, Andrew M. (1)

University of Massachusetts Lowell, Lowell, MA, USA (1)

Many radiation detectors have multiple distinct responses, e.g. scintillation mechanisms. Often it is desirable to distinguish these waveform by waveform, e.g. n/γ discrimination in liquid scintillators. Cs_2LiYCl_6 (CLYC) is an emerging scintillator with excellent pulse shape discrimination (PSD) between gamma rays and neutrons. It detects gamma-rays, thermal neutrons via the ^{6}Li(n,α)^{3}H reaction, and fast neutrons via the ^{35}Cl(n,p)^{35}S reaction. Other channels such as ^{35}Cl(n,α)^{31}P open at higher energies [1]. PSD is a prime example of classification problems that are a common target of machine learning algorithms. Machine learning is a broad field that investigates techniques and algorithms to optimize over time a computer's performance in some task towards some definite outcome. We have applied two machine learning techniques to n/γ discrimination in ^{7}Li-enriched CLYC detectors, where the thermal neutron response is suppressed. We have previously optimized n/γ discrimination in CLYC by integrating charges in a prompt and a delayed time window, defining a PSD parameter as $Q_{prompt}/Q_{delayed}$. This achieves excellent n/γ separation, though the PSD worsens and disappears at neutron energies below a few hundred keV. Additionally, this method cannot distinguish the different neutron responses in CLYC. Here, we investigate and compare two machine learning algorithms, using diagnostic waveform data from a recent LANL experiment. Artificial neural networks (ANNs) are a modern and powerful tool for classification, and have already shown promise as a technique for n/γ PSD in liquid scintillators [2]. We use a simple ANN with one input per waveform sample, a single hidden layer of the same size, and a single sigmoid output classifying a waveform as a γ-ray or neutron. The network is implemented in Python using Keras [3] as a wrapper around Tensorflow [4]. ANN requires pre-classified training data generated from the charge-comparison method. Alternatively, by interpreting waveforms as points in a high-dimensional space, common algorithms for cluster analysis can be applied to PSD, which partition the space into K clusters of similar waveforms. Here, K is 2 (neutrons or γ-rays). We used a C++ implementation of the computationally straightforward and rapidly convergent kmeans++ algorithm [5], where the separation is produced entirely unaided, without a priori segregation of n-γ waveforms. We find that the kmeans++ algorithm can separate neutrons and gammas in CLYC, and that a very basic ANN can provide very good PSD in the energy range investigated. We plan to train an ANN on clean lower energy waveforms, to improve on charge-comparison methods. Additionally, we plan to construct an ANN training dataset to distinguish betweeen proton and alpha scintillations, and disentangle the different neutron responses of CLYC. *Supported by the NNSA Stewardship Science Academic Alliance Program under Grant DE-NA0002932 and the Office of Science under Grant DE-FG02-94ER40848. [1] N. D'Olympia et al., NIM A694, 140 (2012); ibid. A714, 121 (2013); ibid. A763, 433 (2014). [2] E. Ronchi et al., NIM A610, 534 (2009). [3] https://github.com/fchollet/keras [4] arXiv:1605.08695 [cs.DC] [5] D. Arthur and S. Vassilvitskii, Proc. 18th Ann. ACM-SIAM Symp. on Discrete Algorithms, 1027 (2007).

Algorithms and Modeling - Wednesday 10:30 - 12:00 pm in Hussey with Sara Pozzi

Quantifiaction of systematic uncertainties from experimental environments

Kelly, Keegan J. (1), Gomez, Jaime A. (1), Devlin, Matthew (1), O' Donnell, John M. (1), Taddeucci, Terry N. (1), Haight, Robert C. (1), White, Morgan C. (1), Neudecker, Denise (1)

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High-precision measurements carry with them a significant importance for data evaluations. Therefore, these measurements require a thorough investigation of systematic errors and uncertainties to ensure that the most accurate result possible is propagated to the evaluation. The Chi-Nu experiment at the Los Alamos Neutron Science Center is one such high-precision experiment designed to measure the prompt fission neutron spectrum from the fast-neutron-induced fission of major actinides ^{235}U and ^{239}Pu. While the Chi-Nu experimenters strive to understand many systematic effects from the experimental setup, a commonly overlooked source of systematic uncertainty is that induced by uncertainties in nuclear physics cross sections for materials in the experimental environment. For example, uncertainties in the ^{27}Al(n,el) cross section may induce a systematic uncertainty in the understanding of how neutrons interact with an experimental environment that contains a large amount of aluminum. A method for understanding how the cross sections for various materials in an experimental environment can be varied in order to assess the systematic uncertainty on the final result will be presented in the context of the Chi-Nu experiment.

6.3.6 Inorganic Scintillation Detectors (Wednesday 1:30 - 3:00 pm in Mendelssohn with Igor Jovanovic)

Inorganic Scintillation Detectors - Wednesday 1:30 - 3:00 pm in Mendelssohn with Igor Jovanovic

Zero-dimensional Cs4EuX6 (X=Br, I) All-Inorganic Perovskite Single Crystals for Gamma-ray Spectroscopy

Wu, Yuntao (1,2), Li, Qi (3,4), Rutstrom, Daniel J. (1,2), Greeley, Ian (1,2), Loyd, Matthew (1,2), Stand, Luis (1,5), Zhuravleva, Mariya (1,2), Koschan, Merry (1), Melcher, Charles L. (1,2,5,6)

Scintillation Materials Research Center, University of Tennessee, Knoxville, Tennessee 37996, USA (1), 2Department of Materials Science and Engineering, University of Tennessee, Knoxville, Tennessee 37996, USA (2), Physical Science Division, IBM Thomas J Watson Research Center, Yorktown Heights, NY 10598, USA (3), Department of Computer Science, University of Illinois at Urbana-Champaign, Urbana, IL 61801, USA (4), Bredesen Center for Interdisciplinary Research and Graduate Education, University of Tennessee, Knoxville, TN 37996, USA (5), Department of Nuclear Engineering, University of Tennessee, Knoxville, Tennessee 37996, USA (6)

Organic-inorganic and all-inorganic halide perovskites have become leading candidates toward high-performance optoelectronic devices and radiation detectors. In this work, we report novel zero-dimensional Cs4EuX6 (X=Br, I) perovskite single crystals as self-activated scintillators with superior performance for gamma-ray spectroscopy. Both Cs4EuBr6 and Cs4EuI6 single crystals grown by the Bridgman method were determined to have the trigonal crystal structure with the Rc space group, and have a melting point of approximately 540 degree celsius. Cs4EuBr6 and Cs4EuI6 exhibit blue emission under UV excitation and high light yields of 78,000 photons/MeV and 53,000 photons/MeV under 137Cs gamma-ray irradiation, respectively. In particular, the former represents the best result achieved for self-activated scintillators thus far. Thermally stimulated luminescence studies and density functional theory calculations elucidate the correlation between halogen vacancies and long-lived emission (afterglow) at room temperature in Cs4EuX6 (X=Br, I) single crystals. Our findings not only demonstrate the ultrahigh gamma-ray detection efficiency in Cs4EuX6 (X=Br, I), but will further promote the development of 0D metal halide-based novel luminescent and radiation detection materials.

Inorganic Scintillation Detectors - Wednesday 1:30 - 3:00 pm in Mendelssohn with Igor Jovanovic

High-performance composite scintillators for gamma/neutron detection

Lam, Stephanie (1), Guguschev, Christo (2), Hackett, Maria (1), Motakef, Shariar (1)

CapeSym, Inc., Natick, MA USA 01760 (1), Leibniz Institute of Crystal Growth, Berlin, Germany (2)

Composite scintillators hold the promise of high performance low-cost gamma-neutron detectors in sizes that would be otherwise prohibitively expensive or impossible to produce. For example, the excellent scintillation performance of SrI_2(Eu) and the dual mode detection capability of CLYC(Ce) make these halides crystals ideal candidates for nuclear radiation detection, but these detectors are expensive at large diameters (e.g. at 3-inches) due to decreased crystal growth yield. Fortunately, the cost of embedding small diameter crystals into a large plastic matrix such as polyvinyltoluene (PVT) is low, and the plastic matrix can even be shaped to improve light collection. This presentation will discuss the design, fabrication, and performance of CLYC(Ce)-PVT and SrI_2(Eu)-PVT composite scintillators. Fabrication of these composites were guided by Geant4 simulations to characterize the generation, transport, and collection of photons. Our first 2-inch diameter CLYC(Ce)-PVT achieved an energy resolution of 4.4% at 662 keV and a PSD of 3.2. More recently, we demonstrated the feasibility for 5-inch diameter composite fabrication. We will also present on SrI_2(Eu)-PVT composites, with which we have achieved 3.6% energy resolution at 662 keV. Other important considerations for composite fabrication will be discussed. This work has been supported by the U.S. Department of Homeland Security, Domestic Nuclear Detection Office, under competitively awarded contract HSHQDN-17-C-00008. This support does not constitute an express or implied endorsement on the part of the Government.

Inorganic Scintillation Detectors - Wednesday 1:30 - 3:00 pm in Mendelssohn with Igor Jovanovic

$KSr_{1.3}Ba_{0.7}I_5$(Eu): A New Ultra-high Light Yield Scintillator with 2.2% Energy Resolution

Stand, Luis (1,2), Zhuravleva, Mariya (2,3), Johnson, Jesse (2,3), Loyd, Matthew (2,3), Wu, Yuntao (2,3), Koschan, Merry (2,3), Goetz, Callie (4), Chen, Yanheng (4), Johnson, Nate (4), Lukosi, Eric (4), Melcher, Charles L. (1,2,3,4)

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In this work we focused our efforts on enhancing the light yield and energy resolution of KSr_2I_5:Eu by replacing some of the matrix strontium atoms with barium. As a result $KSr_{1.3}Ba_{0.7}I_5$:Eu, a new mixed metal halide scintillator, was discovered. $KSr_{1.3}Ba_{0.7}I_5$ has a monoclinic crystal structure with a density of 4.5 g/cm^3 and a melting point of 535 C. Excellent quality $KSr_{1.3}Ba_{0.7}I_5$ single crystals doped with 2, 4 and 6% Eu^{2+} were grown in evacuated quartz ampoules via the Bridgman technique, using a two-zone transparent furnace. Several characterization techniques were used to evaluate crystals that were up to 1 cm^3 in volume. Under UV and x-ray excitation, luminescence properties typical of the 5d-4f radiative transition in Eu^{2+} were observed. $KSr_{1.3}Ba_{0.7}I_5$:Eu 4% had a two-component scintillation decay time with time constants of 1.35 s (85%) and 4.1 s (15%). While KSr_2I_5:Eu has excellent scintillation properties, with light yield of 84,000 ph/MeV and a 3.0 % energy resolution, $KSr_{1.3}Ba_{0.7}I_5$:Eu 4% is even better at 120,000 ph/MeV and 2.3% energy resolution for 1 cm^3 crystals. Energy resolution as low as 2.2% at 662 keV was measured for 0.012 cm^3 $KSr_{1.3}Ba_{0.7}I_5$:Eu 4% crystals.

Inorganic Scintillation Detectors - Wednesday 1:30 - 3:00 pm in Mendelssohn with Igor Jovanovic

Identification of internal radioactive contaminants in elpasolites (CLYC, CLLB, CLLBC) and other inorganic scintillators

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We report the results from an experiment conducted to identify the isotopic contaminants known to produce measurable background emission in a family of inorganic scintillation crystals known as elpasolites, namely Cs_2LiYCl_6:Ce (CLYC), $Cs_2LiLaBr_6$:Ce (CLLB), and $Cs_2LiLa(Br,Cl)_6$:Ce (CLLBC), and in other inorganic scintillation crystals, such as Li co-doped NaI:Tl (NaIL). The intriguing properties of elpasolites are that they yield high light output in response to ionizing radiation, excellent energy resolution for γ-ray spectroscopy, and their ability to detect neutrons due to the presence of ^{6}Li and discriminate them from γ rays using pulse shape discrimination methods. There are, however, internal contaminants associated with certain constituents of these crystals that result in a measurable background signal. The signal from some of these contaminants is known and well-understood; for instance, lanthanum-containing crystals demonstrate a prominent 1436 keV γ-ray line and β-particle continuum in the internal background spectrum. However, the aforementioned crystals demonstrate an internal background spectrum that is commensurate with α-particle decay. Given that α-particle decay schemes are often complicated, determining the constituents of the crystals that are contributing to the contamination is a thorny problem. One method to understand the contaminants is to measure the γ-ray emission associated with -particle decay in coincidence with an external detector that can perform high-quality spectroscopic measurements. We performed such measurements using a high-purity germanium (HPGe) detector abutted to varying-sized crystals, seeking out coincident α-γ events in the pair. A scatter plot of the energy deposited by the γ-ray in the HPGe coincident with the energy deposited by the α-particle in the scintillation crystal allows one to identify the constituent isotope causing the contamination. This methodology was previously demonstrated by others [1]. We will show the results from measurements with elpasolites and other inorganic scintillators, as well as the $LaBr_3$:Ce (to corroborate previous studies), measured in coincidence with a HPGe detector, shown in terms of 2-d scatter of deposited energy in the HPGe and scintillator, and the methods that allowed for isotope identification for each of the inorganic scintillation crystals tested. [1] B.D. Milbrath, et al., Nuclear Instruments and Methods A 572 (2007) 774.

Inorganic Scintillation Detectors - Wednesday 1:30 - 3:00 pm in Mendelssohn with Igor Jovanovic

Radiation Hardness and Scintillation properties for Ce:GAGG and Ce:La-GPS Crystals

Kurosawa, Shunsuke (1,2), Murakami, Rikito (1), Yamaji, Akihiro (1), Horiai, Takahiko (1), Kodama, Shohei (1), Shoji, Yasuhiro (1), Yoshino, Masao (1), Ohashi, Yuji (1), Yokota, Yuui (1), Kamada, Kei (1), Yoshikawa, Akira (1)

Tohoku University (1), Yamagata University (2)

Ce-doped (Gd, La)$_2$Si$_2$O$_7$ and Ce-doped Gd$_3$(Ga, Al)$_5$O$_{12}$ scintillator has a high light outputs, fast decay times, these scintillators have been expected to applied to various fields. One of the application is to use in the space for astronomy, and the evaluation of the radiation hardness is required. We grew single crystals by the Czochralski technique, and evaluated its radiation hardness using 80-MeV proton rays in Tohoku University with a total dose of approximately 20,000 Gy. The results showed that light outputs and decay times were slightly degraded after the irradiation by few % than before for both Ce-doped (Gd, La)$_2$Si$_2$O$_7$ and Ce-doped Gd$_3$(Ga, Al)$_5$O$_{12}$ samples. Only the energy resolution was degraded dramatically in the range position with a thickness of less than 2-mm, and this degradation can be avoided with some shields. Thus, these scintillators were found to have strong radiation hardness.

Inorganic Scintillation Detectors - Wednesday 1:30 - 3:00 pm in Mendelssohn with Igor Jovanovic

Low-cost, Multi-mode Detector Solutions

Shirwadkar, Urmila (1), Van Loef, Edgar (1), Tower, Josh (1), Gueorguiev, Andrey (1), Markosyan, Gary (1), Soundara Pandian, Lakshmi (1), Mcclish, Mickel (1), Glodo, Jaroslaw (1), Shah, Kanai (1), Pozzi, Sara (2), Clarke, Shaun (2), Langeveld, William (3)

Radiation Monitoring Devices, Watertown, MA (1), University of Michigan, Ann Arbor, MI (2), Rapiscan Systems, Fremont, CA (3)

Low-cost detector solutions capable of providing efficient gamma-ray and neutron detection are essential in passive nuclear monitoring systems such as radiation portal monitors (RPM), large unattended sensors, or to detect Special Nuclear Materials (SNM) through Active Interrogation (AI). High sensitivity is critical for such applications, most often achieved through large detector volumes. Since large inorganic scintillators are expensive due to crystal growth yield issues, RMD is developing detectors based on organic scintillators. Three promising low-cost solutions are discussed in this paper - (1) Large-area polystyrene-based plastic scintillators for neutron detection, providing high fast neutron efficiency and excellent PSD (2) plastic scintillators doped with heavy-metals for imparting gamma-ray spectroscopy capabilities in addition to fast neutron detection and PSD, and (3) Composite detector technology based on inorganic scintillator submerged into the plastic scintillator, capable of thermal neutron detection, in addition to gamma spectroscopy, fast neutron detection, and PSD among all signatures. All these technologies are cost-effective, scalable, and the size is not limited by crystal growth yield issues. We have constructed composite detectors (up to 2 x 4) using PSD plastic scintillator as a host and CLYC as the inorganic component with up to 25% loading. Results from Geant4 calculations to support performance optimization of large composite systems will be presented. Along with these results, scintillation properties of sheet of PSD-capable plastic up to $\sim$ 12 x 12 x 3, and $\sim$ 3 diameter tin- and lead-loaded plastic scintillators with up to 90% tin- and 40% lead-compounds will be reported. Concentration studies performed to investigate effect of tin, lead, and PPO will be presented. Neutron and gamma efficiencies will be compared for samples with different metal and inorganic loading.

6.3.7 Gamma-Ray Imaging Systems (Wednesday 1:30 - 3:00 pm in Hussey with Kai Vetter)

Gamma-Ray Imaging Systems - Wednesday 1:30 - 3:00 pm in Hussey with Kai Vetter

3D Gamma-ray Mapping from the Ground to the Air

Haefner, Andrew (1), Pavlovsky, Ryan (1), Barnowski, Ross (1), Negut, Victor (1), Moran, Alex (1), Joshi, Tenzing (1), Suzuki, Erika (1), Vetter, Kai (1,2)

Lawrence Berkeley National Laboratory, Berkeley, CA (1), UC Berkely, Berkeley, CA (2)

At Lawrence Berkeley National Laboratory, we have developed the capability to map radioactive sources in 3D and in real-time. This enables fast and precise localization of sources and distributions in a variety of complex environments as well as providing immediate information for users. We have integrated this 3D mapping and visualization approach with remotely operated platforms, which can mitigate the need to send people into dangerous areas. Applications of this capability range from nuclear security and international safeguards to defense and nuclear decommissioning. Our mapping capability is performed in real-time onboard a compact, self-sufficient system called the Localization and Mapping Platform (LAMP). To create the 3D maps, LAMP has on onboard LiDAR that is fed into a Simultaneous Localization and Mapping algorithm that creates a model of the scene and tracks the device. This data is then fused with the gamma-ray data, which can be from Compton imaging or proximity self-shielded imaging. LAMP is designed to be detector and platform agnostic, which provides the ability to customize and optimize the use of this powerful 3-D mapping and visualization capability for different use cases and applications. We have integrated LAMP systems with both imaging and non-imaging gamma-ray sensors, as well as deployed it in a variety of configurations, including handheld, on an Unmanned Aerial Vehicle and on ground robots. We will present results from a variety of measurements, including from an RDD test measurement at Idaho National Laboratory, and from measurement campaigns in Fukushima Prefecture, Japan. Using these results, we will show the gains achieved compared to GPS-based heat mapping, which can be performed from UAVs. We will also discuss some of the challenges and optimizations to perform this real-time processing on a board computer built into the LAMP system. Note: This is for an invited talk.

Gamma-Ray Imaging Systems - Wednesday 1:30 - 3:00 pm in Hussey with Kai Vetter

Rotating Scatter Mask Optimization for Gamma Source Direction Identification

Holland, Darren E. (1), Bevins, James E. (2), Burggraf, Larry W. (2), Oday, Buckley E. (2)

Department of Mechanical Engineering, Cedarville University, Cedarville, OH (1), Department of Engineering Physics, Air Force Institute of Technology, WPAFB, OH (2)

Rotating scattering masks (RSMs) have shown promise as an inexpensive method for identifying a gamma sources direction. However, further examination of the current RSM design shows that changing the geometry may improve the identification by reducing or eliminating degenerate solutions and lowering the required count times. Three approaches are introduced to generate alternative mask geometries. The eigenvector method uses a spring-mass system to create a geometry basis. The binary approach uses ones and zeros to represent the geometry. Finally, a Hadamard matrix is modified to examine a decoupled geometric solution. Four criteria, the max and average modal assurance criteria, efficiency, and sensitivity, are proposed for evaluating the new RSM designs generated from each of these methodologies. An analysis of the resulting detector response matrices demonstrates that the binary and eigenvector methodologies produced masks with superior identification characteristics as compared to existing RSM designs.

Gamma-Ray Imaging Systems - Wednesday 1:30 - 3:00 pm in Hussey with Kai Vetter

Use of Pencil Beam Backscatter Radiography to Image Buried Root Structures

Baciak, James E. (1), Cui, Shuang (1), Gardiner, Hannah (1), Kovaleski, Scott (2), Zare, Alina (3)

Nuclear Engineering Program, University of Florida, Gainesville, FL (1), Electrical Engineering and Computer Science, University of Missouri, Columbia, MO (2), Electrical and Computer Engineering, University of Florida, Gainesville, FL (3)

There is a growing need for advanced tools and methods to accelerate the process of measuring root and soil characteristics and the creation of advanced algorithms for analyzing data can accelerate the development of field crops with deeper and more extensive root systems. Crops with these root systems could increase the amount of carbon stored in soils, leading to improved soil structure, fertilizer use efficiency, water productivity, and crop yield, as well as reduced topsoil erosion. Backscatter radiography by selective detection is a form of Compton backscatter radiography that collimates the dominant near-surface x-ray scatter signal to allow for sub-surface imaging of features of interest in applications in which traditional transmission radiography is impractical. Backscatter radiography by selective detection can utilize x-ray tubes up to 1 MV, although practical limitations of the backscatter signal normally limit use to below 600 kVp. In this paper, the principles or backscatter radiography with pencil beam x-ray geometry are reviewed. We present preliminary results using backscatter radiography showing the capability of such a technique to image sub-mm roots and plant structures with detectability of roots with less than 500 μm diameter achievable. We discuss current challenges and opportunities of a field-ready backscatter radiography system for use in buried root imaging and crop management.

Gamma-Ray Imaging Systems - Wednesday 1:30 - 3:00 pm in Hussey with Kai Vetter

Hard X-ray imaging using monolithic active pixel sensors (MAPS)

Li, Xuan (1), Wang, Zhehui (1), Uemura, Sho (1), Silva, Cesar Da (1), Liu, Ming (1), Brooks, Melynda (1), O'shaughnessy, Christopher M. (1), Morris, Chris (1), Demarteau, Marcel (2), Wagner, Robert (2), Xie, Junqi (2), Zhu, Ren-yuan (3), Zhang, Liyuan (3), Hu, Chen (3)

Los Alamos National Laboratory, Los Alamos, NM 87545 (1), Argonne National Laboratory, Lemont, IL 60439 (2), California Institute of Technology, Pasadena, CA 91125 (3)

Silicon detectors based on Monolithic Active Pixel Sensors (MAPS) have been widely used in high energy physics (HEP) experiments. MAPS detectors with outstanding properties such as radiation hardness, thin sensor and fine pixel resolution, high speed and low cost make them leading candidates for the next generation high luminosity colliders. We report initial results of using MAPS for hard X-ray absorption and Compton imaging. In addition to the unique hardware properties of the MAPS detectors, data methods are potentially powerful techniques to enhance image information extraction. The energy threshold of the MAPS is characterized using high-gain scintillator detectors. X-ray absorption images are obtained. Compton imaging is evaluated through GEANT4 simulation with one or more MAPS chips, a scintillator and an intensified camera. The work paves the way towards MAPS applications in synchrotrons and XFEL beamlines.

Gamma-Ray Imaging Systems - Wednesday 1:30 - 3:00 pm in Hussey with Kai Vetter

Development of assembly method of scintillator arrays consisting of Eu:SrI_2

Yoshino, Masao (1,3), Kamada, Kei (2,3), Shoji, Yasuhiro (1,3), Yokota, Yuui (2), Kurosawa, Shunsuke (2,4), Yamaji, Akihiro (1), Yoshikawa, Akira (1,2,3)

Institute for Materials Research, Tohoku University, Japan (1), New Industry Creation Hatchery Center, Tohoku University, Japan (2), C&A Corporation, Japan (3), Department of Physics, Yamagata University, Japan (4)

In the field of gamma-ray imaging, there are several ideas having been or being developed to obtain detailed radiation sources. Compton camera is one of the techniques for detection and imaging of radioactive sources. Applying kinematics of Compton scattering, Compton cameras could provide images of gamma-ray position without using any mechanical collimator; thus, Compton cameras achieved an intrinsic efficiency of 1% at 662 keV, which is drastically high compared to Pinhole-type gamma camera. However, in the low energy gamma-ray region from 100 keV to 300 keV, the angular resolution of Compton cameras makes worse in accordance with the deterioration of the energy resolution of detectors. The improvement of energy resolution of detectors is required. Scintillators have been applied to the detectors for Compton cameras. Focus on halide scintillator crystals has increased due to the high light yield and good energy resolution. Eu-doped strontium iodide (Eu:SrI_2) scintillator is one of the promising candidates for Compton cameras due to its high energy resolution even in low energy region. However, few previous studies on the Eu:SrI_2 arrays for Compton cameras have been reported because it is highly hygroscopic and, thus, difficult to dice crystals and assemble the scintillator pixels. In our previous study, the development of 8 * 8 matrix Eu:SrI_2 array has been reported. The pixel size of 3 * 3 * 3 mm^3 and energy resolution of 6.7 % were obtained. However, the accuracy of assembly and further improvement of energy resolution are required. In this study, the assembly method of arrays for halide scintillator materials was developed. Applying the method to Eu:SrI_2 scintillators, 8 * 8 matrix Eu:SrI_2 array with 3 * 3 * 3 mm^3 pixels was assembled. An energy resolution of 4.8 % FWHM at 662keV was obtained. In the conference, we will also talk about the further miniaturization of array pixels and improvement of energy resolution.

Gamma-Ray Imaging Systems - Wednesday 1:30 - 3:00 pm in Hussey with Kai Vetter

Activity quantification of caesium-137 sources in environmental media using the GRI Compton camera

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Nuclear Physics Group, University of Liverpool, Liverpool (UK) (1), Sheffield Hallam University (2)

In response to major radionuclide releases to the environment at Fukushima, Japan, remediation of agricultural land is underway and the scientific focus is now on understanding the dynamics of caesium-137 (^{137}Cs) in the extensive forest ecosystem [1]. This demands accurate quantification of activities for sources whose distributions vary spatially and temporally, such that rates and pathways of ^{137}Cs processing in plants and soils can be elucidated. A limitation of Compton-geometry gamma cameras [2] is the difficulty in quantifying source activities; efficiency is highly dependent on source position within the camera's field-of-view. New work to characterise the near-field response of the University of Liverpool-based GRI system to enable accurate estimation of ^{137}Cs source activity is presented. At present, activity can be reliably estimated from the event rate for point-like sources, and a method to derive activity for distributed sources from the reconstructed Compton images is in development. The ability to precisely determine activity and distribution at small scales (sub-cm resolution in a sub-metre phase space) is considered to have applications beyond studying the dynamics of radiocaesium in environmental media. The methods are underpinned by an extensive validation study of system performance. Experimental efficiency data were compared to simulations from the Geant4-based GAMOS package [3] for point ^{137}Cs sources ranged across the phase space under study. A spatially-dependent efficiency calibration function was then derived from the simulations, enabling point-source activity quantifications. Combined with corrections for well-known image distortion effects, it is hoped that quantitative information can be extracted from Compton images of extended sources in the near future. This will directly enable proof-of-concept experiments using dynamic, distributed sources in environmental media. The current results are specific to gamma-ray energy and detector assembly, but the method is generally applicable. References [1] T. J. Yasunari, et al., 'Cesium-137 deposition and contamination of Japanese soils due to the Fukushima nuclear accident,' Proceedings of the National Academy of Sciences 108 (2011) 530. [2] G. W. Phillips, 'Gamma-ray imaging with Compton cameras,' Nuclear Instruments and Methods in Physics Research B 99 (1995) 674-677. [3] http://fismed.ciemat.es/GAMOS/

6.3.8 Poster III - Medical and Environmental Applications (Wednesday 3:00 - 4:00 pm in Ballroom with Patricia Schuster)

Poster III - Medical and Environmental Applications - Wednesday 3:00 - 4:00 pm in Ballroom with Patricia Schuster

Radiation shielding analysis for the A-BNCT facility

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A proton accelerator based Boron Neutron Capture Therapy (A-BNCT) facility is under development in Korea. Neutron beams for the treatment are produced from beryllium (Be) target and 8mA, 10 MeV of the proton beam. Purpose of the research is performing a radiation shielding analysis for the facility design satisfying radiation safety requirements and obtaining an operating license for the radiation facility through the domestic nuclear commissioning procedure. The dose rate limit was set to 5Sv/hr for the workers area and the 0.25Sv/hr for the public area by applying 1/2 safety margin to the values recommended in ICRP-103. The facility modeling, radiation source terms evaluation, shielding analysis and dose rate evaluation were performed with MCNPX computational particle transport code. The minimum concrete thickness satisfying designated dose rate was estimated to 130 cm for accelerator room and 150 cm for treatment room through the bulk shield analysis. The facility was designed based on the bulk shield thickness. For the assessment of the radiation safety inside the facility, dose rates were calculated at several positions such as behind the shielding door, around the primary barriers near the radiation sources, and penetrations of ducts. The dose rate distribution was mapped for the verification of the radiation safety for the entire facility. As a result, it was proved that the dose rate inside the facility satisfied the dose limit.

Poster III - Medical and Environmental Applications - Wednesday 3:00 - 4:00 pm in Ballroom with Patricia Schuster

TBI Commissioning Using Radiocromic Film And Ionization Chamber

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Introduction: Total Body Irradiation (TBI) is a special technique of radiotherapy that is part of the bone marrow transplantation conditioning in which it is necessary to treat patients diagnosed with leukemia, lymphoma, autoimmune diseases, multiple myeloma, among others. The function of this procedure is immunosuppression, bone marrow ablation and destruction of malignant cells in order to avoid rejection to the marrow of the patient who received it. The doses required for this treatment are equal to or greater than the tolerance of the risk organs, so a high accuracy and reliability in this treatment is required. This precision, in which we can obtain with the dosimetry, procedure by which we can check the dose being delivered on the surface or internal organs Objective: Based on the previous data, the aim of this study is to present a methodology for the commissioning and evaluation of dose distribution at certain depths of the primary beam (PB) and off-axis of TBI, verifying the commissioning parameters for this treatment. Materials and methods: In this work, the irradiations were performed in a Clinac 2100SC linear accelerator (Varian Medical Systems, Palo Alto, USA). In order to determine the PDP (Percentage Depth Dose, at the PB) at 20 cm depth, radiocromic films and an ionization chamber, both detectors positioned at this depth, were used inside a cubic phantom with water. Positioning the radiochromic film, inside a solid water plates phantom, at depths of 1.5, 5, 10 and 15 cm for 6 MV (400 cGy in 15 cm depth) and at depths of 2.5, 5, 10 and 15 cm for 15 MV (also totaling 400 cGy in 15 cm depth), it was posible to calculate the Off-Axis fator (dose outside the central ray divided by the dose in the central ray, measured in the air). Results: The ionization chamber and the radiochromic films showed similarity in the reading of the PDDs (differences of up to 5%) and the radiochromic films allowed to raise off-axis data in four different depths. Although the dosimetry with films is more complicated, since there is a time required for the preparation of the films and obtaining the data (scanning of the films), it was verified that the film is a good dosimeter to obtain a beam dose profile of photons, reaching a precision similar to that of the ionization chamber, used in automatic scanning systems. Conclusions: The aim of this study is to present a methodology for the commissioning and evaluation of dose distribution at certain depths of the primary beam (PB) and off-axis of TBI. The data obtained showed a suitable methodology to implement the application of the TBI dosimetry, with ionization chambers and radiochromic films. Keys-works: Total body irradiation; dosimetry; radiochromic films.

Poster III - Medical and Environmental Applications - Wednesday 3:00 - 4:00 pm in Ballroom with Patricia Schuster

Optimization of Gamma-ray Detectors in Neutron-Induced Gamma-ray Spectroscopy for Geophysical Applications

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Neutron-induced gamma-ray spectroscopy for borehole logging utilizes two gamma-ray detectors to identify lithology and measure oil/water saturation of the formation. The former can be obtained from analyzing capture gamma-ray spectroscopy with a detector far from the source ('far detector') while the latter from counting inelastic gamma-ray emitted from carbon and oxygen with 'near detector.' The severe environment in borehole requires the measurement time less than 1 s per point and the optimization of detectors inevitable. Due to its complexity of laboratory experiment, Monte Carlo simulations can efficiently provide grounds for designing a well logging sonde. This study is aimed at locating and selecting the gamma-ray detectors to effectively retrieve those two radiological attributes mentioned above. First, spectra of incident gamma-rays at various locations within a sonde was simulated using f4 tally of MCNP6 code. Total 19 'void' detectors were set 15 - 195 cm away (10 cm interval) from neutron source inserted in five types of geological medium - basalt, granite, limestone, shale and sandstone. Interaction of emitted neutrons from the source and creation of induced gamma-rays were simulated for 10^6 - 10^7 neutron source particles with weight windows for variance reduction. Aside from oxygen which has low neutron capture cross section, silicon is the second most abundant element for four out of those five media and calcium for limestone. In order to maximize the collection of characteristic gamma rays at 3.5395 MeV and 4.9368 MeV from silicon and at 4.4189 MeV from calcium, the location of 'far detector' was desired to be 65 - 75 cm away from the source. The results suggested that the location of 'near detector' would be optimal at 15 cm away from the source for the detection of 6.1313 MeV and 4.4189 MeV inelastic gamma-rays, each related to interactions with carbon and oxygen, respectively. Additionally, analysis on the simulated gamma-ray spectra implied that there possibly exist considerable effects from the borehole fluid (hydrogen at 2.2237 MeV), the boron layer for shielding direct neutron from the source (at 0.47874 MeV), and the sonde housing (iron at 0.84733 MeV). The spectral response from the gamma-ray detectors located at the optimized locations was then simulated using f8 tally of MCNP, for four types of gamma-ray detector materials - NaI, BGO, GSO, and CLYC (Cs_2LiYCl_6) - with the sonde located in the previous five geological medium. The BGO far detector showed the highest counts at the silicon capture gamma-ray energies (3.5395 MeV and 4.9368 MeV) while the BGO and GSO near detectors respectively exhibited the highest counts at oxygen (6.1313 MeV) and carbon (4.4189 MeV) inelastic gamma-ray energies. From the analysis of spectral response from these four detectors in sandstone, which recorded the highest total pulse counts among five formations, BGO and GSO were identified to show similar spectra to that of gamma-ray energy distribution simulated for a void detector. Additional peaks shown in NaI (0.058822 MeV) and CLYC (0.079817 MeV) spectra were attributed from the inherent capture gamma-rays by iodine and yttrium, respectively.

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The development and optimization design for X-ray laser

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Purpose: This study is to develop nano-focused X-ray light source - X-ray laser, and to study its optimal design. To explore the preparation of materials, the optimal neutron beam irradiation time, dose, resonant cavity length, width and height, and optimize the irradiation parameters. Finally explore the possible direction of applications. Materials and Methods: Complete preparation of different irradiation time Nb material, a total of 6 groups to complete the neutron beam irradiation and annealing. Experiments was designed to complete the measurement of different Nb (including raw materials, a total of 6 groups), the X-ray refraction differences using high-purity germanium detector instrument. Results: The experimental result of the relative wavelength versus the X-ray direction conversion, the experimental study on the relative adjustment of the lattice parameters in the X-ray conversion direction, the design and calculation of the resonant cavity length, width and height dimensions were completed, and the optimization parameters were designed. Conclusion: This nanofocus X-ray laser sources to be completed can be served as light sources for phase contrast imaging and as a radiotherapy tool for treatment of superficial tumors. Keywords: X-ray Laser, Nb, Neutron Beam, HP Ge detector

Poster III - Medical and Environmental Applications - Wednesday 3:00 - 4:00 pm in Ballroom with Patricia Schuster

Radiation Hardened Charge-Sensitive Amplifier Survived up to 2 Mrad by proposed Layout techniques and Size Optimization

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This paper presents various integrated circuit designs for a radiation hardening Operational Amplifier (OP-Amp) by using advanced layout techniques and size optimizations based on 180 nm standard CMOS fabrication. Thanks to the continuous development in metal-oxide semiconductor (MOS) fabrication technology, transistors have become more radiation tolerant through steadily decreasing gate-oxide thickness, increasing a tunneling probability between gate-oxide and channel. Unfortunately, even though this radiation hardened property of the developed transistor, the field of nuclear power plants (NPP) requires more high radiation hardness levels, such as the total ionizing dose (TID) of approximately 100 Mrad gamma-ray around the reactor in-core. In the harsh radiating environment like NPP, sensors, for instance, a micro-pocket-fission detector (MPFD) would be a promising technology to be operated for detecting neutrons in reactor core. In addition, readout circuits should be fundamentally placed close to sensors for minimizing signal interferences and white noise. Therefore, radiation hardening ability is necessarily required for the circuits. For the reason, we describe several designs of radiation hardening preamplifiers with preliminarily results of irradiation tests that show the DC gain of 40 dB, phase margin of 60 degree and unity-gain frequency of 100 MHz with the supply voltage in the range of 0.9V.

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Measurement of the Spatio-Spectral Distribution of Secondary Neutrons with ^{4}He Gas Scintillation Detectors at a Proton Therapy Facility

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This work assesses the performance of ^{4}He-PMT gas scintillation neutron detectors for measuring the spatio-spectral distribution of secondary neutrons in the treatment room at a proton therapy facility where the proton beam itself generates secondary neutrons in various locations within the patient anatomy and the beam collimator. The capability of the ^{4}He detectors to measure the incident neutron energy is vital for measuring the neutron dose, and thereby understanding and mitigating the secondary cancer risks and dose impacts due to neutrons for the patients undergoing proton therapy. Neutron spectral distributions were measured at different angular locations relative to a water equivalent phantom that was irradiated by a 10cm x 10cm beam of protons with an average energy of 176 MeV. The results of the measurements show the suitability of these detectors for neutron dose verification.

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Instrumentation for a High-Altitude Dosimeter using PSD Plastic Scintillator

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This paper reports on the design and testing of a cosmic radiation sensor devised to characterize the radiation fields at high altitudes (such as those encountered in airplanes, balloons, etc.). The device is based on a plastic scintillator that performs pulse-shape discrimination (PSD) and uses custom electronics that is capable of measuring energy spectra for various types of radiation, with energies up to 25 MeVee, discriminated by their linear energy transfer (LET). Although this approach is normally used to discriminate gamma and neutron radiation in terrestrial environments, other types of radiation, including protons and high-energy nuclei, will be present in a high-altitude environment. Our goal is to design a compact, cost-effective, and mechanically robust system that can be installed into commercial aircraft without impacting their operation. This paper discusses the rationale for choosing the various components of the system, including a 2" x 2" cylinder of Eljen EJ-276 (formerly EJ-299-33A) PSD plastic scintillator. A review of PSD methodology will be presented alongside a discussion of how these radiation sensors would operate in an aircraft flying at 50,000 feet, with the goal of achieving a PSD figure of merit greater than 2 for neutrons with energies up to 40 MeV.

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Impact of channel configurations on bandwidth of a cross-strip electrode with multiple ASICs

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The bandwidth of readout electronics has a great influence on the sensitivity of a detector system. When the number of readout channels of a detector outnumbers that of the application-specific integrated circuit (ASIC), multiple ASICs are required. It is important to balance the load of each ASIC to obtain a higher sensitivity for the detector read out by multiple ASICs. The load balancing of ASICs can be achieved by a well-designed configuration of anodes and cathodes. In this study, a Monte Carlo simulation was performed to investigate the influence of different anode configurations on the bandwidth of the cadmium zinc telluride (CZT) detector with a cross-strip electrode pattern. A Na-22 point source was placed 40 mm from the center of the edge face of the detector. It is found that, with an optimal cathode configuration, the successive anode configuration provides about 3% higher bandwidth than the alternate anode configuration.

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Niowave Uranium Target Assembly

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In fiscal year 2013, the Congress passed the American Medical Isotope Production Act, which is a legislation that supports the domestic production of Mo-99 and phasing out the use of highly enriched uranium in the production of medical isotopes. To meet this growing commercial market, Niowave has embarked on a major expansion. As a result, Niowaves Radioisotope Program had established both the infrastructure and the NRC license to operate a subcritical uranium target assembly (UTA), distribute radioisotopes and reprocess nuclear fuel. Niowave has fully executed its license by completing the following steps: -Irradiating UTA with a superconducting electron linac, -Extracting Mo-99 from irradiated uranium using the low enriched uranium modified Cintichem (LMC) process, -Radiochemical recycling and purifying of irradiated fuel using the uranium redox extraction (UREX) process, -Fabricating purified uranium targets, -Reloading UTA for further irradiation, and -Packaging and shipping of the medical isotopes to complete the overall process. In addition to the production of diagnostic radioisotopes such as Mo-99, we are developing production schemes for therapeutic beta-emitters and other industrial and strategic radioisotopes. Niowaves radioisotopes production facility has also gained interest from other application areas due to its versatility, ease of access, and capability to provide demonstrations and experimental data. These areas include neutron or X-ray based active interrogation, reprocessing of uranium and transuranic elements for sustainable nuclear fuel cycle and waste minimization, development of intense fast neutron source for material irradiation damage, and other advanced nuclear technologies to support the nations nuclear energy and security needs. This presentation will focus on production of medical radioisotopes using Niowaves UTA. Niowaves UTA is a pool-type subcritical uranium assembly, which consists of both LEU and NU fuel rods submerged in light water with an effective multiplication factor of k_{eff} =0.43. Recent irradiation of the core yielded microcurie levels of Mo-99, Xe-133, and other medical fission products at the end of bombardment. A single uranium pellet was extracted post irradiation and went through the entirety of the radiochemical processes to yield a solution of sodium molybdate with 20 nCi of Mo-99. In addition, a gas extraction module (GEM) was developed to extract volatile fission fragments from the fuel rod via cryo-pumping on a condenser cup. With our capability to perform radiochemistry and fuel fabrication, we succeeded in turning natural uranium metal into a fine grain oxide powder then into a pellet with $\sim$ 60% of theoretical density (higher porosity) to allow volatiles to escape the pellet. The quantities of radioxenon produced and extracted into the condenser cup was in the sub-microcurie level. In summary, Niowaves Radioisotope Program with its established facilities and NRC license puts a vast range of radioisotopes at our fingertips to provide affordable life-saving radioisotopes to our healthcare system and guarantees U.S. independence from foreign radiopharmaceuticals.

Poster III - Medical and Environmental Applications - Wednesday 3:00 - 4:00 pm in Ballroom with Patricia Schuster

Nondestructive Assessment of Transportation Fuel Cask using Time-Tagged Neutron Interrogations

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For the nuclear reactors operating in the U.S., although the used fuel pools remain to be the major choice for the storage of spent nuclear fuels, there has been an increasing tendency of employing the dry cask storage as an alternative. In the last several decades, for the purpose of reprocessing, the demand for spent fuel transportation from an at-reactor (AR) pool to an away-from-reactor (AFR) storage at a reprocessing plant has increased dramatically, which makes the application of cask in the dry storage and transport service more important. During the transportation of spent fuel casks, theres probability of various risks, such as mis-loading of spent fuel, the missing or dislocation of fuel rods inside the cask, and large mechanical defects. Thus, the monitoring of the condition of the interior of the sealed cask is a challenging task. In this study, we focus on a Monte Carlo study on several approaches for nondestructive evaluation (NDE) of transportation fuel casks that based on an associate-particle neutron generator (APNG) and time-tagged neutron interrogation techniques. We studied the use of neutron transmission and back scattering measurements, the characteristic prompt gamma rays analysis to assess the potential damage to fuel rod assemblies in transportation of spent fuel casks. In this work, we used Geant4 simulation to model neutron beam configurations created by a D-T neutron generator, a realistic transportation fuel cask, and various detector systems for detecting the neutron and gamma rays emerging from the surface of the fuel cask. The timing and energy information of the signals will be studied in order to obtain an indication of the potential defects inside the fuel cask. In the future study, we will simulate various abnormalities scenarios that could potential happened during the transportation of the spent fuel casks, and the feasibility of using the time-tagged neutron interrogations for nondestructive assessment of spent fuel casks.

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A new positron-gamma phoswich detector based on wavelength discrimination

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In detectors such as the beta probe for use in nuclear medicine, there is a need to discriminate beta particles from background gamma radiation. In this paper, we propose a new method to discriminate radiation types in a mixed radiation field of beta (+, positron) and gamma () radiation. The method exploits scintillators peak emission wavelength property, instead of the conventional pulse shape discrimination (PSD) approach. Scintillators often have distinguishable emission wavelengths i.e. that of calcium fluoride (CaF_2(Eu)) and cerium-doped Gadolinium Aluminium Gallium Garnet (Ce:GAGG) are approximately 380 nm $\sim$ 450 nm and 470 nm$\sim$ 700 nm respectively. We use a two-layer phoswhich detector which consists of CaF_2(Eu) and Ce:GAGG, having dimensions of 3 mm x 3 mm x 0.5 mm and 3 mm x 3 mm x 5 mm respectively. The phoswhich detector was placed at the center of two adjacent two optical filters (short pass and long pass), each coupled to a silicon photomultiplier (SiPM). Optical filters were used in order to direct a specific scintillator photon wavelength to its corresponding SiPM. Finally, a Na-22 positron source and Cs-137 gamma source were used to validate the proposed approach. Results confirm that we can discriminate positron and gamma radiation real time and a gamma rejection ratio of 99.965% was achieved.

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Characterization of Thin TlBr Detectors for Intense Radiation Fields

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In order to obtain gamma-ray spectra in intense radiation fields such as in nuclear power plants, nuclear spent fuel reprocessing plants, and Fukushima Daiichi nuclear power plant, small volume detectors with good peak efficiencies are ideal. Detector materials with high atomic numbers are requisite for constructing small-volume gamma-ray spectrometers capable of obtaining gamma-ray spectra in intense radiation fields. Thallium bromide (TlBr) is an attractive semiconductor material for fabrication of gamma-ray spectrometers with good peak efficiency because it has high atomic numbers (81 and 35) and high density (7.56 g/cm^3). TlBr crystals exhibit high resistivity at room temperature because of the wide-bandgap energy of 2.68 eV. Good charge transport properties for both electrons and holes are obtained from zone-purified TlBr crystals. In this study, thin TlBr detectors were fabricated for constructing gamma-ray spectrometers for intense radiation fields. Commercially available TlBr materials were purified by the zone-purification methods. The single crystals were obtained by the traveling molten-zone method. The as-grown crystals were cut into wafers with a diamond wire saw. The wafers were polished mechanically to obtain very thin TlBr wafers. Electrodes of the detectors were constructed by vacuum evaporation of Tl on the wafer surfaces. Small single pixel devices with the active volume of approximately 1.5 mm 1.5 mm 0.66 mm were fabricated in this study. The device was tested with a ^{137}Cs gamma-ray source at room temperature. Despite the very small active volume, clear full-energy peak of 662 keV was obtained from the device. With rise-time discrimination, the device exhibited an energy resolution of 1.8% FWHM for 662-keV gamma-rays. The small volume TlBr devices are promising for isotope identification in intense radiation fields such as in Fukushima Daiichi nuclear power plant.

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Ruggedized HPGe detectors for in-situ gamma spectroscopy

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This paper presents the design and performance of turnkey and compact HPGe solutions, developed by Mirion Technologies (CANBERRA Lingolsheim) for radionuclide identification outdoor and under harsh environmental conditions. Surveys can be undertaken under various weather conditions, in contaminated areas, underground or immersed under water (sea, rivers, pools), with fast on-site deployment and without compromising the performances and reliability experienced with laboratory-grade HPGe instruments.

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Development and image quality of indirect X-ray CMOS flat panel detector with novel readout method for medical applications

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Indirect flat-panel detectors typically uses thin film transistor layer (TFT) or CMOS (complementary metal oxide semiconductor) coupled with scintillation layer for a large X-ray medical imaging. Typically, the visible light is emitted isotropically and photodiode array converts it in electric signal for X-ray imaging display. A light spread and attenuation of emitted light in scintillator grains leads to a degradation of image quality due to light scattering. The conventional flat-panel detector has the scintillator in the front and the photodiodes in the back to the incident direction of x-rays. In this study, the photodiode array is placed to the front of the scintillator as novel readout method (back-side irradiation) in order to prevent of a degradation of spatial resolution using a thick scintillator. We proposed the prototype of a new indirect CMOS FP detector and will show the experimental results on this new technology. A CMOS image sensor (CIS) with a large area for the high resolution X-ray imaging was used. The sensor has an active area of 125 x 125mm2 comprised with 2304 x 2304 pixels and a pixel size of 55 x 55um2. X-ray imaging characterization in terms of the light output and the MTF will be presented by using the use of various X-ray tube voltage, GOS scintillator with different thickness, silicon wafer thickness. As preliminary results, X-ray detector using a thin scintillator and novel readout method have almost same results but the back-side irradiation method shows slightly better performance as increasing the X-ray tube voltage. We expect that this technology will open potential for further dose reductions and image quality improvement in clinical imaging.

Poster III - Medical and Environmental Applications - Wednesday 3:00 - 4:00 pm in Ballroom with Patricia Schuster

Imaging of plutonium particles using an EMCCD-camera-based alpha-particle imaging system

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Imaging distribution of PuO_2 particles is extremely important for internal exposure of a worker to these particles. An Imaging Plate (IP) system has been used to acquire the image of PuO_2 particles. However, the IP system could not acquire accurate activities of PuO_2 particles and its spatial resolution was required to improve for precise measurement of PuO_2 particles. In this study, PuO_2 particles were measured using an electron multiplying (EM)CCD-camera-based alpha-particle imaging system and it compared with the IP system and a Silicon Photomultiplier(SiPM)-based alpha-particle imaging system. A plutonium(Pu) sample was used to acquire a 2-dimensional distribution image of alpha particles. A ZnS(Ag) scintillator was used as a scintillator and scintillation light was detected by the EMCCD camera. The EMCCD-camera-based alpha-particle imaging system can be used to accurately measure the number of alpha particles one-by-one emitted from the PuO_2 particles, so that their activities can be accurately evaluated. Moreover, the spatial resolution of this system was superior to those of the IP system and the SiPM-based alpha particle imaging system.

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Image denoising with conditional generative adversarial networks (cGAN) in low dose chest radiography

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Purpose Low dose technologies in medical field has been a hot topic as the recognition that radiation has an adverse effect on the human body. Unfortunately, the radiation dose and image quality are highly dependent, and a reduction in the radiation dose results in a poor image quality. To address the image quality degradation caused by minimizing the radiation dose, image processing is generally used.Howeverit is not easy to restore the image quality to a level that can be utilized in clinical practice with conventional denoising algorithm. Therefore, the purpose of this study is to recover deteriorated image quality due to minimizing radiation dose by using conditional generative adversarial network (cGAN). Materials & Methods We obtained radiograph of chest phantom by using proto type digital radiography system. Images were acquired using various X-ray tube angles and acquisition conditions. Tensorflow framework was used for developing cGAN model. Corrupted images with three kinds of Gaussian noise (standard deviation of 0.2, 0.3, and 0.4) were used as the input and non-corrupted images were used as the output of cGAN model. To evaluate the performance of the developed model, we investigated the similarity between the prediction image and the output image using the mean structure similarity index measure (MSSIM). To evaluate the image quality locally, we evaluated MSSIM with various window size including 3232, 6464, and 128128. Results Denoised image obtained with conventional algorithm including total variation minimization (TV) and non-local mean (NLM) algorithm showed relatively good noise reduction performance in corrupted images with low Gaussian noise level. However, noise level became increased performance of conventional algorithm significantly dropped. As the noise level increased, MSSIM of the result images obtained TV and NLM algorithms decreased by an average of 0.9 %. However, the developed cGAN based denoising algorithm showed the highest value of MSSIM in spite of the increase of noise level. In addition, the cGAN based denoising algorithm dose not lower the spatial resolution after image processing. Conclusion In this study, we have developed a deep learning based noise reduction algorithms. The developed algorithm achieved superior performance to conventional denoising algorithm. The results of this study suggested the possibility of further reducing the radiation dose in medical fields.

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The research of bi-modal imaging method with a photoneutron source

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Fusion of the X-ray imaging and neutron imaging can provide both the mass thickness information and elemental information simultaneously, which may contribute significantly to the research of fuel cell and the turbine blades quality control in the industrial applications. In this research, an e-LINAC based bi-modal imaging system is proposed to meet this requirement. A 10 MeV e-LINAC, accompanied by a heavy water photon-to-neutron converter, is used to provide both the X-ray imaging beam and the energy-selective neutron imaging beam. By combining the two penetrating images of X-rays and photoneutrons, the varied background caused by the various mass thicknesses of the inspected object are removed from the raw images, and a factor is formed to identify the elemental concentration information or isotopic abundance information of the inspected object. The light-Z materials, which are placed behind a metal wedge of inhomogeneous thickness, can be found and quantitatively analyzed. This research presents a feasible and cost-effective method to integrate two different imaging technologies into one e-LINAC driven system. The bi-modal imaging method can significantly improve the capability of nondestructive inspection when compared with the imaging methods of only using X-rays technology or neutrons technology.

Poster III - Medical and Environmental Applications - Wednesday 3:00 - 4:00 pm in Ballroom with Patricia Schuster

Performance Estimation of Gamma Electron Vertex Imaging (GEVI) System for Proton Therapy Monitoring

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In proton therapy, the prescribe dose can be concentrated on the tumor volume while minimizing the unnecessary dose to adjacent normal tissues as compared with the conventional radiation therapy using x-ray or electron beam. However, the proton dose distribution in the patient can be easily distorted from the planned one due to uncertainties in the treatment. To overcome this limitation and fully utilize advantages of proton therapy, therefore, the real-time monitoring technique should be developed. For this purpose, a prompt gamma (PG) imaging, which measures proton-induced PGs having a close correlation with the dose distribution, was suggested. To measure the two-dimensional PG distribution with the high detection efficiency, we proposed a new imaging method, gamma electron vertex imaging (GEVI), and demonstrated the possibility of the imaging method. Based on the previous results, in the present study, we developed a GEVI imaging system for clinical applications, and tested its performance for therapeutic proton beams. To image the PG distribution, the system converts PGs to electrons by Compton scattering using the beryllium plate, and then measures the trajectories and energies of converted electrons using a double-sided silicon strip detector (DSSD) array and a plastic scintillation detector. With measured trajectories, the PG distribution is reconstructed by applying the line back-projection algorithm. To estimate the performance of the imaging system, a therapeutic proton pencil beam extracted from 230-MeV cyclotron at Samsung Medical Center in Korea was delivered to the solid water phantom, and the emitted PGs were imaged using the imaging system. The developed imaging system can measure the PG distribution using GEVI method, and the beam position and range can be verified with the measured PG distribution. We expect that the imaging system can be used to proton therapy monitoring by measuring the PG distribution.

Poster III - Medical and Environmental Applications - Wednesday 3:00 - 4:00 pm in Ballroom with Patricia Schuster

Sparse-view virtual monochromatic CT imaging using a dictionary-learning based reconstruction algorithm

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In dual-energy computed tomography (CT), besides obtaining material-specific information, it is necessary to generate a single set of images for routine diagnostics, similar to conventional polychromatic single-energy CT images. In this study, we investigated a low-dose method to generating such a single set of images that synthesizes virtual monochromatic CT images using sparse-view dual-energy projection data. This approach involves a basis material decomposition in the projection domain, a synthesization of monochromatic projections, and a sparse-view CT reconstruction using a dictionary-learning (DL) based algorithm. We implemented the proposed imaging algorithm and performed a systematic simulation with a three-dimensional numerical phantom (256 x 256 x 40) containing several biological materials to demonstrate its viability. We synthesized virtual monochromatic CT images with 60 projections far less than what is required by the Nyquist sampling theory at three different energies of 50, 90, and 130 keV from dual-source dual-energy CT of 80 and 140 kVp. We quantitatively evaluated their image quality in comparison with conventional polychromatic single-energy CT. The results indicated that the proposed method provided quantitative information on the imaged anatomy at reduced radiation dosage and effectively reduced beam-hardening artifacts in the reconstructed CT images.

Poster III - Medical and Environmental Applications - Wednesday 3:00 - 4:00 pm in Ballroom with Patricia Schuster

X-ray imaging quality of the CMOS X-ray flat panel detector in different modes of dental CT system

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In this study, we have investigated the experimental demonstration of image quality in dental CT application with a high-resolution CMOS X-ray detector. To acquisition 2D projection image from a dental CT system, we applied the X-ray tube (SXR-130, Rayence inc.) having 0.5 mm focal spot and flat panel X-ray CMOS detector (Xmaru1215, Rayence inc.) having a 116 x 145 mm active area with 49.5 m pixel pitch and 2352 x 2944 pixels in full mode. The CMOS detector has with 99 m pixel pitch and 1176 1472 pixels for the 2 2 binning mode. The X-ray imaging performance such as X-ray linearity, signal to noise ratio, dynamic range, spatial resolution and DQE (Detective Quantum Efficiency) were measured and investigated. X-ray CT image qualities of CMOS X-ray flat panel detector were evaluated in terms of full and binning modes, projection number and exposure dose. And quantitative image evaluation with CT QA phantom was studied in practical dental CT conditions. The X-ray signal of CMOS flat panel detectors with full resolution and binning mode linearly increased as the incident X-ray dose increases. From the measurement results of X-ray imaging performance in terms of MTF and DQE, X-ray CMOS detector with full mode compared to binning mode showed improved image quality. And also, the quantitative analysis of image quality was investigated by using the cone-beam CT phantom. The filtered-backprojection (FBP) and compressed sensing (CS) reconstruction methods were used to generate 3D images and the comparisons were made between different modes of acquisition. In the skull phantom testing, there constructed 3D images in full mode have better overall image quality than others; however, full mode required a longer data acquisition time, resulting in the highest radiation exposure to the patient. Our experimental results show that similar image quality with the possible use of the CT system in a non-diagnostic environment can be obtained in the binning mode, which requires a significantly reduced projection time.

Poster III - Medical and Environmental Applications - Wednesday 3:00 - 4:00 pm in Ballroom with Patricia Schuster

Performance evaluation of a prototype mobile C-arm CT system with high-resolution X-ray flat panel detector

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The introduction of digital flat panel detector (FPD)-based C-arm CBCT (cone-beam computed tomography) system provides an attractive technology for real-time 2D image in standard fluoroscopy and three-dimensional or cross-sectional visualization with higher spatial resolution. A modern CBCT system with C-arm gantry incorporating a large-area flat-panel detector is widely used as an important imaging tool for anatomical diagnosis and image-guidance in spine surgery, orthopedic and interventional suite and image guide radiation therapy. Recently, the large-area CMOS flat panel imagers have been widely used in X-ray medical imaging applications including dental CBCT, mammography as well as NDT (nondestructive testing). The CMOS based X-ray detector has many advantages such as the higher readout speed, low noise, high spatial resolution and high system integration compared to amorphous silicon TFT-based flat panel detector. Based upon these attractive merits, we have developed a prototype mobile C-arm CT system with flat-panel detector and successfully operated our system in an efficient way by controlling our C-arm gantry, X-ray pulse generator and CMOS-based flat-panel detector with high spatial resolution. The 8lp/cm pattern in spatial resolution is clearly visible. And low contrast resolution with 16mm diameter and 30HU(Hounsfield unit) is also detectable. The results indicated that the system was capable of providing better contrast and improved spatial resolution and more clearly visualized arteries filled with iodine agent. This paper demonstrate the significant potential of X-ray CMOS flat panel imager for imaging-guided equipment with high-resolution and high-frame rate in low-dose fluoroscopy and angiography applications.

Poster III - Medical and Environmental Applications - Wednesday 3:00 - 4:00 pm in Ballroom with Patricia Schuster

Study of 3D Fast Compton Camera Image Reconstruction Method by Algebraic Spatial Sampling

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Compton camera has been proposed as an imaging tool of high potential in astronomy, industry, homeland security, and medical imaging. Since it allows radiation density images to be reconstructed at different depths from a single shot without tomography or moving the patient, Compton camera is expected to be used in heavy ion treatment inline monitoring. Improving its resolution and reducing the reconstruction time are the key to facilitate the progress of the use in clinic therapy. In this paper, we present an algebraic method using dimension-reduction and canonical form to acquire the point on the event conical surface, which can not only be used in direct image reconstruction or pre-calculation of maximum likelihood expectation maximization(MLEM) algorithm as a kind of fast back-projection method, but also be used in stochastic origin ensemble(SOE) algorithm as an approach of spatial symmetrically sampling with resolution recovery. The 3D image reconstruction based on the dimension-reduction and canonical form sampling method is not affected by the choice of imaging space such as the size of voxels and orientation. Instead, it can achieve nearly real-time imaging for changeable imaging space because of its fewer computations. Preliminary experiments show that this method has high resolution and quick speed for multi-point sources and extended sources image reconstruction. The reconstruction using dimension-reduction and canonical form sampling method has nearly 4mm resolution for three point-like sources and nearly 8mm resolution for extended source. The sampling efficiency is 1,446,514(iterations/second). The method is promising to enhance the spatial resolution and speed up the reconstruction in Compton camera imaging, optimize the reconstruction of SOE algorithm, as well as weaken or even eliminate the effect of spatial orientation of imaging space, which is distortion in the direction perpendicular to the imaging plane.

Poster III - Medical and Environmental Applications - Wednesday 3:00 - 4:00 pm in Ballroom with Patricia Schuster

Triple-interaction events selection for prompt gamma emission reconstruction during proton therapy

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Purpose: A prototype Compton camera (CC) was built to image prompt gamma (PG) emissions from nucleus excited by protons during proton radiotherapy. PG interactions in the CC are recorded and used to reconstruct images of the PG emission for beam range verification. PG interactions captured by the CC are labeled as single-, double-, triple-interaction or more depending on the number of times the PG interacts in the camera. But due to the finite time resolution of the CC, two or three gammas could arrive at the camera simultaneously, and their interactions could be registered as a false triple-interaction event. This study focuses on the determination of true and false triple-interactions so that false events can be removed from the data prior to image reconstruction. Methods: For triple-interactions, the initial energy of the PGs can be calculated from the information of each interaction. In Compton imaging, if the initial energy is known, a cone can be created for the gamma interacted at least twice. Usually in proton therapy, the beam axis is known from the machine specifics and treatment plan, and PG emissions are most likely to originate along the beam axis. The distance from the cone surface to the beam axis is calculated and a threshold can then be set to reject those cones who do not come within a specified distance to the beam axis. Since the time resolution of CC is not fine enough to tell the order of the interactions, each of the six possible permutations of the interaction ordering is tested, by computing the cone-to-beam-axial distance and the likelihood of that particular order happening; the order sequence with the smallest distance and the largest likelihood is kept. Then, only events whose determined initial energy is within an emission lines of interest are used for image reconstruction. To test this triple-interaction sorting method, a data set was collected by placing a ^{232}Th source positioned 1.45 cm vertically and 6.8 cm horizontally from the camera center and 20 cm away from the camera. A background measurement (with no source) was also acquired. Results: The CC count rate was 321 counts/second from the ^{232}Th source versus 182 counts/second for the background measurement. In the test data set, 30.8 million interactions are detected with 25.3 million single-interactions, 4.7 million double-interactions and 0.8 million triple-interactions. Due to the large amount of concrete used for shielding at the proton center, the background spectrum shows strong traces of ^{232}Th, along with ^{40}K, which complicates the task of finding events due to the ^{232}Th source. The process identified 50,600 gammas as valid triple-interactions. In the spectrum of the calculated initial energy, the 2.6, 0.97, 0.91 and 0.58 MeV emission lines of ^{232}Th are clearly shown, along with the single escape peak of ^{232}Th and the emission line of ^{40}K at 2.1 and 1.46 MeV, respectively. There are 6,400 gammas under the peaks at 2.6, 0.97 and 0.91 MeV and 4,100 of them are full absorptions. Using these events, the source can be correctly reconstructed.

Poster III - Medical and Environmental Applications - Wednesday 3:00 - 4:00 pm in Ballroom with Patricia Schuster

Image Reconstruction for Rotational Modulation Collimator (RMC) Using Non Local Means (NLM) Denoising Filter

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A rotational modulation collimator (RMC) is an indirect imaging device for locating remote radiation sources. An RMC consists of a detector and a pair of identical masks. The system records the number of photons detected as the masks rotate together. The modulated profile is used to visualize the source directions. A recent development has proposed a universal-field imaging model and proven the feasibility of the RMC for detecting mid-range sources, which is often desirable in the applications of homeland security and environmental monitoring. However, the baseline method sometimes introduces artifacts in the reconstructed image when the number of detected photons is insufficient. It is undesirable since sources are often blocked or insulated in practice. In addition, the reconstructed images exhibit 180 symmetricity in the source estimates due to the conventional symmetric mask design. To solve these problems, we propose a new image reconstruction method using a variance stabilization (VS) transform and a non-local means (NLM) filter. We also propose to employ asymmetric masks to remove the 180 ambiguity. We implemented the proposed algorithm and simulated using Matlab and Monte-Carlo N-Particle (MCNP6) code. The results show that the proposed method successfully reduces noise from the modulation profiles and improves the quality of the reconstructed images. The proposed method successfully suppresses the artifacts even when the number of detected photons are low. Experiments over a wide range of source activities verifies that our algorithm outperforms the baseline method. Furthermore, the 180 ambiguity is no longer present.

Poster III - Medical and Environmental Applications - Wednesday 3:00 - 4:00 pm in Ballroom with Patricia Schuster

Performance of the Gamma Ray Industrial Process Tomography used for Characterization of the Vesicular Igneous Rock

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The gamma ray tomography techniques for industrial processes evaluation have been designated as the most promising in order to visualize the structure and the distribution of solids, liquids and gases inside multiphase systems, such as industrial columns or pipes, obtaining measurements in real conditions without interrupting the operation in pharmaceutical, biochemical, petrochemical and chemical industries. However, no studies related to gamma tomography for analysis of oil reservoir rocks, which have multiphase mixtures in their inner, have been found in the literature. In this work, a study is proposed to establish the procedure for the acquisition and processing of three-dimensional images of reservoir rock samples obtained by gamma ray industrial process tomography. The 3D nature of the achieved data provides new perspectives for the characterization of the rock inner. A high spatial resolution was obtained in the reconstructed image. It can be clearly seen the pore spaces where the liquid (oil and water) and gas reside, as well as the dimension and interconnectivity of the vesicles. A primary application of porosity aims to quantify the storage capacity of the rock and, subsequently, define the volume of hydrocarbons available to be produced.

Poster III - Medical and Environmental Applications - Wednesday 3:00 - 4:00 pm in Ballroom with Patricia Schuster

DIGITAL ROCK ANALYSIS USING MICROCT AND FLUID FLOW SIMULATIONS IN COQUINA SAMPLE

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A better and comprehensive insight into internal structure of rocks and quantitative methods for it characterization still is a great challenge. MicroCT can be applied for visualization of the inner structure of a material and this paper shows how it can be used for the 3D visualization and quantitative analysis of complex pore network in a non-destructive manner. Lacustrine carbonate rocks form important hydrocarbon accumulations, some of which are contained in oil fields and coquinas are one of the main reservoir. The complexity and heterogeneity turn a difficult characterization of internal complex structures of these deposits make them a challenge in terms of reservoir description and the use of this digital data on fluid flow simulation studies its essential. To perform digital rock analysis we use Navier-Stokes equations in computational fluid flow simulation and applied this methodology in different regions along the sample in order to compare the results obtained for the absolute permeability as a function of the porosity estimated by MicroCT.

Poster III - Medical and Environmental Applications - Wednesday 3:00 - 4:00 pm in Ballroom with Patricia Schuster

Fruit PET: 3-D imaging of carbon distribution in fruit using OpenPET

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To achieve increase of food production and promotion of greening, it is important to research the physiological functions of plants. Thus, various molecular imaging techniques which image the behavior of molecules in living plants using radio isotopes have been developed. Most of the higher plants studied in laboratory experiments are thin and small; therefore, these 2-D planar images are sufficient for studying them. However, it is difficult to acquire images of photoassimilate translocation and distribution in fruit, which is the representative sink organs to be harvested, using planar imaging, because fruit has 3-D living structures. Therefore, positron emission tomography (PET), which offers high sensitive and quantitative 3-D images, must be used to study fruit. In this paper, we applied the OpenPET, which can visualize a physically opened space between two detector rings. For plant experiments, it is important to adjust the system to the plant growth environment, including factors such as light, temperature, and humidity because the physiological function of plants is strongly influenced by the environmental conditions. Thus, it is necessary to control those conditions strictly. The OpenPET which has the space between the detector rings can easily provide a growth environment suitable for a target plant in the imaging field of view (FOV). In addition, it is easily to inject radio tracers into the plant. In order to validate the usefulness of OpenPET for the research of the physiological functions of plants with fruits, a PET experiment was conducted. A strawberry was prepared as the target plant and about 125 MBq $^{11}CO_2$ gas which was produced with a compact cyclotron was fed to a leaf. After the injection of $^{11}CO_2$, one fruit was set in the center of the FOV and ^{11}C-labeled photoassimilate in the fruit was imaged. The PET scanning was carried out simultaneously in the list mode for 3 h. The PET data were reconstructed by the ordered subsets EM (OS-EM). The reconstructed images showed that photoassimilate was accumulated in a part of the fruit. This result suggests that OpenPET is promising for researching the physiological functions of plants.

Poster III - Medical and Environmental Applications - Wednesday 3:00 - 4:00 pm in Ballroom with Patricia Schuster

Increasing the Efficiency of Lens Coupled MeV Radiography

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Increasing the Efficiency of Lens Coupled MeV Radiography (LA-UR-18-21779) J. A. Mendez[1], S. J. Balzer[1], G.P. Salazar[1], B. Tobias[1], J.L. Schei[1], L.E. Antonuk[2], Y. El-Mohri[2], Q. Zhao[2] [1]Los Alamos National Laboratory Los Alamos, NM, USA [2]The University of Michigan Ann Arbor, MI, USA For nearly three decades, lens coupled radiographic detectors have been used to record MeV radiographic data. While lens coupling by definition is a relatively inefficient means to couple secondary quanta from a scintillator screen to a light sensitive detector, recent engineering advances have led to significant performance improvements. To record MeV primary quanta with sufficient quality, a lens coupled, scintillator-based detector exhibiting high detective quantum efficiency (DQE) is required[1]. The quantum efficiency of primary photon conversion to secondary photons is dominated by the scintillator. Efficient collection of secondary quanta emitted at the scintillator face is dominated by coupling optics to the imager. Recently, gamma ray camera design improvements were made which include the use of a, 9.25cm x 9.25cm, 9Kx9K format back-thinned charge coupled device (CCD) and a new lens having a 16% larger numerical aperture. These upgrades have led to an improvement of 40% in zero-frequency DQE. Furthermore, as shown in Figure 1, the slope of the noise power spectrum (NPS) has improved, yielding even larger improvements in DQE at higher frequencies. Noise power spectra were obtained by characterizing the segmented LSO scintillator and lens-coupled CCD with a calibrated ^{60}Co radiation source and agree with predictions made by a comprehensive quantum noise model developed for analysis of radiographic data from hydro-tests. This model applies a cascaded systems analysis with both stochastic and deterministic elements so as to accurately model both white and pink noise components[2],[3], and accurately reflects the coloring of quantum noise and associated improvement in finite-frequency DQE due to optically coupling. Finally, Monte Carlo modeling of the scintillator array has been performed using the EGSnrc

code[4]. This analysis places an upper bound on GRC performance by evaluating the radiation Swank factor5 and quantum efficiency (QE) of the scintillator, which consists of segmented lutetium oxyorthosilicate in a stainless steel septal structure. The current design is estimated to achieve a zero-frequency DQE of 53% for 1.25 MeV radiation sources such as ^{60}Co. This modeling and data obtained during characterization of the gamma ray camera upgrade are invaluable for the design and optimization of next- generation, high-performance detectors for MeV radiography[6]. [1]JA Mendez, Los Alamos National Laboratory Report LA-UR-06-7571 [2]P Monnin, et al., Physics in Medicine and Biology 61, 2083 (2016) [3]S Watson, DARHT Technical Note LA-UR-17-27948 [4]I Kawrakow, et al., Technical Report PIRS-701, National Research Council Canada (2017) [5]RK Swank, Journal of Applied Physics 44, 4199 (1973) [6]J Mendez, et al., Los Alamos National Laboratory Classified Report LA-CP-17-20487

Poster III - Medical and Environmental Applications - Wednesday 3:00 - 4:00 pm in Ballroom with Patricia Schuster

Determination of oil and water in drilled bore cores via fast-neutron resonance transmission radiography

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Fast Neutron Resonance Transmission Radiography is proposed for non-destructive, quantitative determination of the weight percentages of oil and water in cores taken from subterranean or underwater geological formations. The ability of the method to distinguish water from oil stems from the unambiguously-specific energy dependence of the neutron cross-sections for the principal elemental constituents. Monte-Carlo simulations and results of experimental investigations indicate that the technique can provide a rapid, accurate and non-destructive method for quantitative evaluation of core fluids in thick intact cores, including those of tight shales for which the use of conventional core analytical approaches appears to be questionable

Poster III - Medical and Environmental Applications - Wednesday 3:00 - 4:00 pm in Ballroom with Patricia Schuster

A novel estimation method of water-equivalent thicknesses of secondary particle tracks using secondary electron bremsstrahlung emitted from therapeutic ion beams for attenuation correction

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Monitoring methods of therapeutic beams based on measurement of secondary particles were proposed and studied worldwide. Since the secondary particles suffer from substances in the human bodies before reach detectors, estimation methods of the water-equivalent thicknesses of the tracks of the secondary particles are required for attenuation correction. In this work, we studied a novel estimation method of the water-equivalent thicknesses based on observation of energy distribution of secondary electron bremsstrahlung (SEB) emitted from the trajectories of the therapeutic beams. A Monte Carlo simulation was performed using PHITS version 2.82. Geometrical setup of the simulation had an axially symmetric arrangement to reduce the calculation time of the simulation. The setup consisted of an irradiation target (water), a collimator having multi-slits (silver) and a one-dimensional position sensitive detector (cadmium telluride (CdTe)). A 12C beam having the energy of 290 MeV/u was injected to the water target. The beam axis corresponded with the symmetric axis of the setup. The target had a cylindrical shape with the length and radius of 50 and 100 mm, respectively. The beam passed through the target because the range of the beam was approximately 16 cm and longer than the target length. The target was surrounded by the collimator which had a tubular shape having the length, inner radius and outer radius of 80, 58 and 83 mm, respectively. The collimator had 39 slits with a width of 1 mm along the beam axis. The septal thickness of the collimator was 1 mm. The collimator was surrounded by the CdTe detector which had a tubular shape having the length, inner radius and outer radius of 80, 88 and 88.5 mm, respectively. The detector was divided into 39 detection elements along the beam axis. The position of the center of each slit along the beam axis was made to coincide with the position of the center of the corresponding detection element. In each detection element, a distribution of energy deposition owing to SEB emission was recorded during the beam injection. The simulation was iterated with varying the radius of the target to 40, 30, 20, 10 and 0.1 mm. The simulation results were plotted on a R_1-vs.-R_2 scatter plot where R_1 was defined as the ratio of the yield having the deposition energy between 30 and 40 keV to that between 20 and 30 keV, and R_2 was defined as the ratio of the yield having the deposition energy between 60 and 70 keV to that between 20 and 30 keV. We found that clusters are formed at different positions on the plot by different radii of the phantom, and that the water-equivalent thicknesses were able to be estimated by using the R_1 vs. R_2 plot.

Poster III - Medical and Environmental Applications - Wednesday 3:00 - 4:00 pm in Ballroom with Patricia Schuster

Lead Rubber as an Effective Substitute of Electron Beam Bolus in Electron Beam Therapy

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Purpose To treat the superficial diseases, the low surface dose usually results in underdose for the surface tumor. Many researchers have used various methods to enhance the surface dose of the electron beam. However, the lead rubber that may substitute the electron beam bolus not found in recent researches. Therefore , the purpose of this study works to evaluate the effectiveness of lead rubber on electron bolus in electron beam therapy. Materials and Methods The surface dose enhancement effect of lead sheet, 1 mm thickness 0.5 mmPb-eq lead rubber sheet and relative thickness of solid water flat were measured and compared. The surface dose of various thick of lead sheet (1mm thickness/sheet), 0.5 mm Pb-eq lead rubber sheet (1mm thickness/sheet), and the same thick bolus of high energy electron beams were measured and compared the effective substitute of electron beam bolus. 6-, 9-, 12-, 15-MeV electron beams of Elekta Synergy linear accelerator was used as the electron beam source. Measurements were carried out with a PTW thin-window parallel plate ionization chamber and a PTW Unidose electrometer. The chamber was positioned at the surface of 100 cm SSD in 30 x 30 x 30 cm3 solid water phantom and irradiated with 10 x10 cm2applicator. Results All data were normalized to its own open field surface dose. For 6-MeV, the enhance effect varied from 104% to 108% for 1 to 4 mm thickness bolus. For 9-MeV, it varied from 104% to 105%. For 12-MeV, it varied from 104% to 103%. For 15-MeV, it varied from 101% to 103%. For 6-MeV, the enhance effect varied from 102% down to 34% for 1 to 2 mm thickness Pb lead sheet. For 9-MeV, it varied from 122% down to 75%. For 12-MeV, it varied from 124% down to 100%. For 15-MeV, it varied from 123% to 103%. For 6-MeV, the enhance effect varied from 129% down to 24% for 1 to 4 mm thickness 0.5 mm Pb-eq lead rubber sheet. For 9-MeV, it varied from 125% down to 68%. For 12-MeV, it varied from 117% down to 97%. For 15-MeV, it varied from 114% down to 97%. Discussions and Conclusion The enhance effect of traditional bolus was just to shift the PDD curve toward the source. The 1 mm thick and 0.5 mm Pb-eq lead rubber sheet seems to has the significant enhance effect on the electron beam surface dose. The 1 mm lead sheet is useful for higher energy electron beams, 9-, 12- and 15-MeV but not suggested for the 6-MeV beam due to the attenuation. We concluded that 1 mm thick and 0.5 mm Pb-eq lead rubber sheet act as a good substitute bolus material for all energy electron beams clinically. Keywords: Dosimetry, Surface dose, Lead rubber, Electron beams

Poster III - Medical and Environmental Applications - Wednesday 3:00 - 4:00 pm in Ballroom with Patricia Schuster

A Consideration for Interpretation of between scatter degradation factor and image quality according to beam-hardening in medical radiography

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Recently, due to increased demand for safety worldwide, a number of studies on additional X-ray filters used to reduce patient X-ray exposure have been carried out. However, the scattered dose increases with the addition of filters. This in turn may adversely affect medical images. This effect of additional filtering has not received much attention. Thus, we quantitatively verified that thicker additional filters lead to larger changes in the scattered dose due to X-ray beam-hardening and have greater effects on medical images. As an evaluation index, the relative standard deviation as well as the scatter degradation factor, which can quantitatively express the decrease in the degree of contrast in imaging, was analyzed. The results of this study are consistent with the Klein-Nishina equation, which describes the probability of Compton scattering, which predominantly affects the generation of scattered radiation in the diagnostic radiation energy range. The Klein-Nishina equation indicates that incident light beams with higher energies lead to higher forward scattering rates. When we used a 2.5 mm Al filter, which is recommended for use with tube voltages of 70 kVp or higher by the NCRP, we observed a 0.69% change in FSR and a change of 0.146 in RSD when compared to the condition wherein the filter was not used. In addition, there was a difference of 0.005 in SDF. Thus we verified that the scattered dose generated by an increase in the beam-hardening effect causes degradation of the quality of medical radiography. Considering that medical imaging relies on the degree of X-ray absorption as a contrast for a given subject configuration, the result of a decrease in SDF is highly significant, because this indicates that imaging contrast is diminished by the scattered dose. It is expected that these results are used as a basis for future filter research in order to improve image quality.

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Sterilization and Advanced Manufacturing Using Superconducting Electron Linacs

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Whether for single use medical devices which must be terminally sterilized in final packaging, or biologically contaminated waste that is too hazardous to dispose of by other methods, sterilization is essential to many industries. This is often done by means of irradiation with high-activity Co-60 sources. For this purpose, an estimated 400 million curies (MCi) of Co-60 are currently in use worldwide; however, high-activity radioactive sources pose a risk to homeland security. Individual sterilization facilities may possess between 1 to 5 MCi of Co-60 which could be repurposed into a radiological dispersion device, or dirty bomb. In an effort to reduce dependence on Co-60, Niowave is working on an alternative technology, x-ray based sterilization. Niowaves superconducting electron linear accelerators produce high-power electron beams that in turn make high fluxes of bremsstrahlung x-rays. Feasibility studies have shown that high-power accelerator facilities can compete economically with Co-60 gamma ray facilities. Accelerators have numerous advantages compared to isotope sources due to the nature of machine-produced radiation. Systems are tunable on demand for energy, intensity, and profile of the radiant field based upon the requirements of use. It can be possible to decrease processing time by selecting an appropriate scan area and dose rate as desired. Furthermore, the electron or x-ray source is only present while irradiating product, and can be easily turned on or off. Additionally, applications of Niowaves superconducting accelerators are not limited to x-ray sterilization. The same system without a bremsstrahlung converter can provide a high intensity, tunable source of electrons for a variety of other applications. In this talk, Niowaves proposed commercial sterilization facility will be presented including the high-power electron accelerator, facility layout, dosimetry methods, and MCNP modeling. Results from successful sterilization runs and alternative uses of the system for advanced manufacturing will be discussed.

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Mechanical x-ray (MEXRAY) generator for MeV radiography

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Radiography is an important tool for determining the internal structure of objects of interest to the emergency response community. The inherent density of these objects requires high-energy radiation (in the form of x-ray or gamma-rays) to be used which limits the range of available radiation sources/generators. Field personnel, for example nuclear-counter-terrorism teams, require compact megavolt radiography, the needs of which are not adequately addressed with the currently available x-ray generators. The need for man-portable, low-power alternatives currently remains unfulfilled. High-energy (>500 keV) x-ray generators are large and expensive capital items which severely limits both their availability and their applicability. Because they are normally insulated with oil, they are also extremely heavy and have large waste streams. Alternatively, high-energy radioisotope sources, for example Cobalt-60 have regulatory headaches making them undesirable. We have developed a megavolt x-ray system which uses mechanical charge separation to create high-energy electrons which can then be used to create x-ray radiation. This approach relies on established physical principles e.g. charge separation, bremsstrahlung radiation, parallel-plate capacitors, and the photoelectric effect, combined in a unique manner to produce a highly-efficient, low-cost, compact, high-energy x-ray generator. This type of source is also extremely versatile because it can be used in either a pulsed- or steady-state- manner making it suitable for multiple-pulse hydrotesting, JTOT radiography, or simply as a compact, low-impedance, high-energy electron injector. The main advantages of MEXRAY over other megavolt x-ray systems are: compact, light-weight, man-portable, rugged, easily repairable, and low-power. Results on the operation of the MEXRAY system and some of the challenges will be presented.

Poster III - Medical and Environmental Applications - Wednesday 3:00 - 4:00 pm in Ballroom with Patricia Schuster

Elemental distribution of benign prostatic hyperplasia cell line using synchrotron X-ray microfluorescence

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Benign prostatic hyperplasia (BPH) is characterized by an increased number of epithelial cells and stromal cells within the periurethral area of the prostate and also by an increase in the volume of prostatic smooth muscle resulting in an increase in prostatic urethral resistance. Several large population studies have shown that progressive enlargement of the prostate gland is extremely common; BPH is one of the most common diseases in aged men which can lead to lower urinary tract symptoms (LUTS). Trace elements are an essential critical for various biological functions in the human body and may be regarded as possible biomarkers of hyperplastic transformation of prostate gland. The X-ray microfluorescence technique (μXRF) is a rapid and non-destructive method of elemental analysis that provides useful elemental information about samples. In this study was investigated elemental distribution of spheroids of human prostate cells obtained through the following cell lines: BPH and normal cell line (RWPE-1) using synchrotron X-ray microfluorescence (μSRXRF). The measurements were performed with a standard geometry of 45 of incidence, excited by a white beam using a pixel size of 25 μm and a time of 300 ms/pixel at the XRF beamline at the Synchrotron Light National Laboratory (Campinas, Brazil). The results by μSRXRF showed non-uniform elemental distribution in all the spheroids analyzed and a great disturbance in the intensity of some trace elements in BPH cells.

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The Classification and Identification of Tumor and Normal Breast Tissues Using a Comparison of Two X-ray Fluorescence and X-ray Diffraction Techniques

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Over the past several decades, efforts have been devoted to developing techniques that can investigate the role of trace elements in biological systems and their structural composition, in order to understand their correlation to morbid conditions. The present study was implemented using two different X-ray detection systems; a conventional monochromatic X-ray system for X-ray Fluorescence (XRF) and Angular Dispersive X-ray Diffraction (ADXRD) techniques, and a combined Polarized Energy Dispersive X-ray Fluorescence (PEDXRF) and Energy Dispersive X-ray Diffraction (EDXRD) system. As both of these systems encompass different XRF techniques, the primary objective of this study was to evaluate the performance and accuracy of each system using results achieved from XRF measurements. The assessment of the two systems was carried out using invasive ductal carcinoma (IDC) of breast and normal surrounding breast tissues. Both of these systems are capable of measuring trace elements in biological samples through XRF techniques yet they have differences in terms of measurement acquisition time and scatter rejection. This study concentrates on exploring these features by utilizing the two XRF spectrometers to analyze the following trace elements: Cl, K, Ca, Fe, Cu, Zn, Br and Rb in 19 matched pairs of tumour and normal breast tissue specimens. The results established from the two XRF systems are in a very good agreement with each other. The statistical analysis reveals a significant and measurable increase at $P < 0.01$ in the concentration of K, Ca, Fe, Zn and Rb in the tumor tissue when compared to the healthy tissue. The preceding results agree with the findings reported by Farquharson [1]; however, the levels of Cl, Cu and Br attained by both systems have demonstrated a statistically insignificant difference between the normal and cancerous tissues. The second objective of this study was to highlight the features and discrepancies between each X-ray Diffraction (XRD) spectrometer incorporated in both systems by investigating the structural components (i.e. Adipose, fibrous and water) of the same breast tissues. Analyzing the diffraction spectra of the tissue from both XRD systems have indicated a statistically significant difference in the composition of normal and malignant samples. Furthermore, the results have shown a remarkable increase in the fibrous and water contents of the tumour tissue at $P < 0.01$, and a significant increase in the adipose content of the normal tissue at $P < 0.01$. [1] M. J. Farquharson, A. Al-Ebraheem, S. Cornacchi, G. Gohla, and P. Lovrics, "The use of X-ray interaction data to differentiate malignant from normal breast tissue at surgical margins and biopsy analysis," X-Ray Spectrom., vol. 42, no. 5, pp. 349-358, 2013.

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Using an On-board Cone-beam Computed Tomography Scanner as a Reading Modality for Gel Dosimetry: a feasibility study

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olymer-gel dosimeters can be used to measure three-dimensional (3D) dose distribution for radiotherapy and have gradually become a useful tool for application in 3D dose verification. If the on-board cone beam image guiding system in a medical linear accelerator can be used as the dose readout of polymer gels, dose delivery validation might benefit from having more accessible 3D dosimetry validation using gel dosimeters. In this study, the cone-beam computed tomography (CBCT) scanner mounted in the linac was used to read the N-isopropylacrylamide gel dosimeters. The linearity of dose response from 1 Gy to 12 Gy was determined to be 0.985. The average percent standard error for various doses was 12.8%. After irradiation, a 12- to 24-h post delay time was required to achieve stable CBCT readings. For dose verification, both the dose profile and depth dose were in accordance with the treatment planning results. The dose difference at the isocenter between the gel measurement and the treatment planning system was 3.8%. The gamma pass rate was 92.6% under the condition of 5%/5 mm. By enhancing the quality of CBCT images and reducing the influence of image artifacts on gel images, CBCT has the potential to be a primary tool for reading gel dosimeters. The applicability of polymer gels for 3D dose verification could be improved in clinical practice.

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Application of compressible breast phantoms on the estimation of average glandular dose in mammography

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Purpose The determination of accurate compressed breast thickness (CBT) can help assess the average glandular dose (AGD) during mammography. Imaging using compressible breast phantoms can better simulate the actual CBT in mammography and obtain more similar mammographic conditions. This study developed a thickness measurement device (TMD) to generate a thickness correction (TC) model and assess the AGD for the compressible breast phantom under different compression conditions in mammography. Materials and Method This study used a digital X-ray mammography system (Mammomat NovationDR, Siemens) equipped with a flexible compression paddle (FP) (Model-nr. 10048517) and a rigid compression paddle (RP) (Model-nr. 10048515). First, several polymethylmethacrylate (PMMA) slabs and rods were used to develop the TMD. Further, the RP and the FP were used to apply different compression forces on the 4-cm-thick bolus phantom (Model: MT-CB-410S, CIVCO Medical Solutions). Thereafter, the compression thickness at different locations of the phantom was measured using the TMD, based on which a TC model of the maximum thickness measurement was established. In addition, the Stereotactic Needle Biopsy Training Phantom (Model: 013, Computerized Imaging Reference Systems) was imaged after 80-200 N compression forces were applied by the RP and FP. The compression thickness was estimated using the TC model and measured using the TMD to assess AGD changes under different compression conditions in mammography. The method of AGD assessment reported by Dance et al. (2000) was used in this study. Results The TC model was derived on the basis of the compression force, system indicated thickness (SIT), and phantom length. When RP and FP were used on the Stereotactic Needle Biopsy Training Phantom, the root-mean-square error (RMSE) values between the SIT value and the measured compression thickness by the TMD were 9.8 and 15.7 mm, respectively. Using these thicknesses to calculate AGD, the RMSE values of AGD calculated by SIT were 0.26 and 0.42 mGy, respectively. After correcting thickness with the TC model, the RMSE values between the estimated compression thickness and the measured compression thickness by TMD were 1.4 and 1.0 mm, respectively. When using these thicknesses to calculate AGD, the RMSE values of calculated AGD were 0.02 and 0.02 mGy, respectively. Conclusion Combining the measurements of the TMD and bolus phantom, the TC model proposed in this study can rapidly and accurately evaluate the maximum compression thickness according to the compression conditions on compressible phantoms. For AGD evaluation, the Stereotactic Needle Biopsy Training Phantom was imaged under different compression conditions, and the calculated AGD based on the maximum compression thickness determined by the TC model was highly accurate.

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Three-Dimensional Dose Evaluation of the Blood Irradiator using Monte Carlo Simulation and MAGAT gel dosimeter

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Blood irradiators are frequently used to irradiate blood products to decrease the occurrence of the graft versus host disease and inhibit the proliferation of lymphocytes. The dose distribution within the irradiation volume is affected by the source and sample geometry. Understanding the three-dimensional dose distribution is therefore necessary. In this study, MCNPX was used to construct the geometry of the blood irradiator, and simulate the Cs-137 exposure to the sample. Absorbed doses were tallied in different distances from the central axis, and compared with the results obtained by the MAGAT gel. In addition, the mesh tally was used to evaluate the three-dimensional dose distribution. Simulated results showed that the dose at the distances of 0.0, 0.8, 1.8, and 2.8 cm from the axis was 29.7, 25.8, 22.4, and 21.3 Gy, respectively. The percent differences between Monte Carlo simulation and MAGAT gel measurement were 8.7%, 3.0%, -0.5%, and -5.1%. The dose was a function of distance from axis in the XY plane with a fitting formula of $y = 29.233e^{-0.128x}$ (R^2=0.99). Cold spots can be observed in the top and bottom of the axis. Through this study, the uniformity of the dose distribution in the irradiation volume can be evaluated to ensure that blood products can achieve the accurate dose delivery.

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Noise reduction filtering in CT polymer gel dosimetry: comparison MDCT and CBCT

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Background: X-ray cone-beam computed tomography (CBCT) is the most commonly used as a method of guidance of inter-fractional corrections before treatment in radiotherapy. Multi-detector CT (MDCT) combined with adaptive mean filtering has successfully contributed dose information from irradiated polymer gel dosimeters; however, CBCT has not yet be investigated. Purpose: Therefore, this study aims to evaluate whether CBCT with different noise reduction filters is potential to achieve adequate dose resolutions in polymer gel dosimeters. Methods: Each vial was filled with normoxic polymer gel and irradiated with uniform doses of 0-16Gy to generate dose response curves. After irradiation, CBCT was used to perform the dose measurement. In addition, image postprocessing using noise reduction filtering techniques have been examined. Results: Results indicated that dose response of slope was 0.75 and 2.94 for MDCT and CBCT in irradiated dose of 6-16Gy, respectively. Moreover, normalized least-mean fourth (NLMF) filter was performed the lowest dose variance of 0-1 HU, demonstrating a highly effective tool for noise reduction in CBCT gel dosimetry. Conclusion: Normoxic polymer gel dosimetry combined with CBCT and NLMF filtering provides a useful method for dose measurement in radiotherapy, especially in case of stereotactic body radiation therapy.

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CBCT polymer gel dosimetry for pretreatment verification in adaptive radiation therapy

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Background: Adaptive radiation therapy (ART) based on cone-beam computed tomography (CBCT) has emerged as a domain of dedicated cancer radiotherapy system. Polymer gel dosimeter have been widely studied for use in the pre-treatment verification of clinical radiation therapy. CBCT is one of methods for extracting 3D dose information in gel dosimetry. Purpose: This study aims to evaluate the 3D dose accuracy using CBCT gel dosimeters in ART treatment, as comparing to 2D ionization chamber array. Methods: A CIRS thorax phantom was used for the measurement of simulated treatment plans using both traditional sim CT and CBCT. A gel vial was simulated as left-side lung cancer and four vials was inserted into heart, spine cord, and right-side lung, respectively, as organ-at-risk (OAR). After irradiation, CBCT scan was performed for dose readouts. The measured dose volumes were compared with the planned dose volume. Results: For the 3%/3mm and 2%/2mm criteria, the pass rates of the dose volumes were higher than 95%. No significant difference was revealed on dose measurement between CBCT gel dosimeter and 2D ionization chamber array. Conclusion: This study concluded that the CBCT gel dosimeter could be used for clinical verifications in adaptive radiation therapy.

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Study of radon exhalation as a function of soil water content

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The main objective of this work is to study how the water content in the soil affects on radon exhalation. For this purpose, a radon-impermeable deposit has been designed. Inside it, a pitchblende stone has been introduced. This container has been filled with dry soil and a certain amount of water has been added. This addition has allowed to increase the humidity of the system. In order to know the amount of exhaled radon, an electret system connected to a chamber H has been used. The chamber has been inserted into the floor allowing the accumulation of the gas inside it. From the results obtained it is observed that a greater amount of water in the soil allows the exhalation of radon towards the surface.

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Estimation for Radiation Dose and Risk of exposure induced cancer death based on EOS imaging system

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Background:Radiography has been one of the standardized methods for diagnosis and long-term monitoring of the spine deformity. The EOS imaging system consists of two orthogonal x ray fan beams which simultaneously acquire frontal and lateral projection images of a standing patient and allows 3D reconstructions of the trunk in standing position. The EOS system is available in routine clinical use in adolescent idiopathic scoliosis (AIS) to determine the prognosis and follow up in recent years. Correlations of breast and endometrial cancer with radiation exposure have recently been reported in a cohort of AIS patients who had been previously undergone radiographic scoliosis examinations during their routine follow up period. Also, some studies have reported that conventional radiographs with ionizing radiation have been associated with 1 to 2 % increased lifetime risk of developing cancer in children. Purpose: To estimate radiation dose for whole spine imaging using EOS imaging system and risk of exposure induced cancer death calculated from adolescent by using phantom. Methods: We analyzed the average dose of EOS imaging system by using phantom. Optically Stimulated Luminescent Dosimeters (OSLD) were placed in a tissue-equivalent phantom at difference sites of interest. Dose measurements were obtained after frontal and lateral projection exposures.Lifetime risks were expressed in terms of risk of exposure-induced death (REID) assessed by the data including age, gender and mortality statistics (Asian) of the patient in the personal computer-based Monte Carlo (PCXMC) software. The REID was calculated in three different ages of 10, 15 and 18 years old as a function of gender. Results: Effective doses for EOS (combined frontal and lateral projections) were 521.4 Sv in thyroid gland, 169.89Sv in lung, and 422.44Sv in breast by OSLD. The REID values were estimated from PCXMC as 0.00506 % for female and 0.00354 % for male, 0.00416 % for female and 0.00291 % for male, and 0.00371 % for female and 0.00261 % for male in 10, 15, and 18 years old respectively. The REID values were considerably higher in females than males, and the radiation risk decreased with increasing age in both genders. Conclusions: Although individual cancer risk estimates as a function of gender and age are small, the concern about the risks from EOS is related to the rapid increase in its use for in adolescent idiopathic scoliosis (AIS).

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Radiation dosimetry using thermoluminescence of Nd doped $LiYF_4$ single crystals

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Thermoluminescence (TL) materials for radiation dosimetry can store the incident radiation energy as the trapped electrons. The trapped electrons are released with luminescence by thermally or optically stimulation, that are called TL or optically stimulated luminescence (OSL), respectively. TL and OSL properties of various oxide, chloride, bromide, iodide, and fluoride materials had been reported. Fluorides are air-stable as similar as oxides, but TL and OSL properties of fluoride materials have been less intensively studied than those of oxide materials due to the difficulty of the synthesis. The synthesis of high-quality fluoride materials requires preventing the impurities originated from oxygen and water. Among fluoride materials, rare-earth ions doped CaF_2 are well known commercial TL materials. The $LiCaAlF_6$-based materials are also promising materials for radiation dosimetry applications. The Ce-doped, Eu-doped, and Mn-doped $LiCaAlF_6$ have been studied for the dosimetry applications. Rare-earth ions doped $LiYF_4$ phosphors (for example, Nd-doped $LiYF_4$) had been studied for solid-state laser applications; however, they had not been studied for the TL dosimetry applications. In the present study, we have investigated the TL dosimetric properties of the Nd-doped $LiYF_4$ single crystals. From the X-ray induced luminescence spectra of the Nd-doped $LiYF_4$ single crystals, several emission peaks were observed. These peaks can be attributed to the 4f-4f transitions of Nd3+ ions. From the TL glow curves of the Nd-doped $LiYF_4$ single crystals after irradiation with 1 Gy of X-ray, glow peaks of the Nd-doped $LiYF_4$ single crystals were observed at the temperatures of approximately 100, 180, 250 and 350 degrees C. From the TL glow curves of the 3% Nd-doped $LiYF_4$ single crystal after irradiation with 0.01-10,000 mGy of X-ray, the TL intensity tends to increase with the increasing of X-ray dose. The TL glow curves after irradiation with 0.01-100 mGy of X-ray show the relatively strong glow peak at 180 C. The intensities of the glow peaks at 100, 250, and 350 degrees C after the irradiation with 1,000 and 10,000 mGy of X-ray are relatively high comparing to those after the irradiation with 0.01-100 mGy of X-ray. From the dose response curves of the 3% Nd-doped $LiYF_4$ single crystal, the total TL intensity in the ranges from 140 to 250 degrees C shows a good linearity against X-ray dose. These results indicate that the glow peak at 180 degrees C is suitable for the TL dosimetry.

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Radiation damage evaluation of the optical fiber type OSL small size dosimeter using for the radiotherapy dosimetry

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Radiotherapies are one of the low invasive treatments for cancers. In order to accurately estimate the irradiation dose, it is better to insert a dosimeter into an affected region in a patient body. We, therefore, are developing a small size dosimeter consisting of an optical fiber and optically stimulated luminescence (OSL) elements. We have investigated various properties of the OSL small size dosimeter under irradiation of the therapeutic radiation. In order to practically use our dosimeters in therapeutic situation, the effect of radiation damage have to be confirmed. In this paper, we evaluate the radiation damage of the OSL small size dosimeter. We fabricated an OSL small size dosimeters using Eu:BaFBr as an OSL element. In this dosimeter, powdered Eu:BaFBr adhered on a tip of a quartz optical fiber. In order to evaluate radiation damage, we irradiated the fabricated dosimeter with intense ^{60}Co gamma-rays. The dosimeter signal intensity decreased about 7% after 200 Gy irradiation. In order to evaluate effect of deterioration of the optical fiber, we irradiated only the optical fiber with intense ^{60}Co gamma rays. The transmittance at 300 nm decreased with intense gamma-ray irradiation. However, no remarkable changes were observed at 400 nm and 630 nm wavelength. The Eu:BaFBr emits OSL photons at 420 nm under irradiation of stimulation light of 620 nm. Because the stimulation light and the OSL emission were not interfered in the optical fiber, the dosimeter deterioration might be caused by decrease in yield of the Eu:BaFBr OSL. Since the decrease of the dosimeter response was 0.035% for 1 Gy irradiation, the radiation damage of our OSL dosimeter can be ignored for practical irradiation in radiotherapy, which is generally a few tens of Gy.

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A Radiation Distribution Modeling for Development of Mobile Diagnostic Radiography with Low Dose Exposure

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In development of a mobile radiographic imaging apparatus, it is needed to pre-calculate the ambient scattered doses as interest in low dose exposure is increasing. This is because strongly related with additional radiation damage of the patients, caregivers and radiologists around X-ray emission area. Monte Carlo Simulation with well applied system characteristics, especially, X-ray tube and collimator, is a powerful method to estimate the radiation distribution of the X-ray. The purpose of this study is to verify an MC simulation model with leakage radiation and stray radiation distribution for accurate scattered dose distribution validation and to predict various scattered dose distributions with low dose exposure condition. The 3D CAD models of X-ray tube and collimator were imported into Geant4 toolkit with a method which allows that the models to be directly loaded. To reduce simulation time, simulation tasks run in parallel modes like multi-thread and openMPI and X-ray photons were emitted on the anode instead of electron beam flows from the filament. To validate the X-ray generation methods with heel effect of X-ray tube, we designed simple comparison models. In the leakage and stray radiation distribution, we compared between experimental and simulation dose results at 11 points and as a function of height and distance, respectively. From the results, the profiles of X-ray distribution at 300 mm apart from focal spot were similar between X-ray generation methods. This result shows that it is reliable to generate an anode target X-ray spectrum on the surface without the process of electrons hitting the anode. The leakage radiation dose values at 11 points were similar between experimental and simulation results with under the 10%. The stray radiation dose values were similar between experimental and simulation results as a function of height and distance. Based on our preliminary results, the possibility of MC simulation tool with well applied X-ray tube and collimator for validation of scatter radiation was proved. Further study is being performed to acquire the scattered radiation distribution according to the shape, thickness and structure of lead shield for development of the mobile radiographic system with low dose exposure condition.

Poster III - Medical and Environmental Applications - Wednesday 3:00 - 4:00 pm in Ballroom with Patricia Schuster

Radon Distribution Modelling in the Typical Vietnamese Building Based on CFD Code

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Radon gas is an important source of ionizing radiation of natural origin and a major contributor to the ionizing radiation dose received by the general population. It comes mainly from exposure to radon and its airborne decay products in the homes of the general population. The concentration of radon inside the complex building was simulated based on the Computational Fluid Dynamics (CFD) programs as ANSYS FLUENT and OpenFOAM. The model of the building in this study is a typical Korean house with two-floor structure. Using the CFD programs to solve the governing equations incorporation with the radon sources, the impact of radon ventilation on indoor air quality was studied in this paper. Keywords: Radon, CFD, Simulation, Vietnamese Building.

6.3.9 Nonproliferation, Safeguards, and Homeland Security (Wednesday 4:00 - 5:30 pm in Mendelssohn with Sara Pozzi)

Nonproliferation, Safeguards, and Homeland Security - Wednesday 4:00 - 5:30 pm in Mendelssohn with Sara Pozzi

Associated Particle Imaging: History, Recent Advances, and Research Needs

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Interrogating neutrons from a Cf-252 source or a neutron generator may be tagged in time and position using the fission fragments or alpha particles associated with spontaneous fission or fusion, respectively. These neutrons may stimulate prompt emissions in an interrogated object. The interrogating neutrons or prompt emissions may be recorded in detectors adjacent to the object in such a way that the following types of images may be reconstructed: transmission, induced fission imaging, elastic scatter, and inelastic scatter. Further material information is available from induced gammas. This paper gives a short history of the associated particle method, reviews some recent advances resulting from our work, and discusses remaining research needs.

Nonproliferation, Safeguards, and Homeland Security - Wednesday 4:00 - 5:30 pm in Mendelssohn with Sara Pozzi

Nontraditional detectors in nonproliferation and security

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Nonproliferation and homeland security often require capabilities to measure radiation in environments exceeding the typical laboratory conditions. In particular, the detectors are expected to be scalable and cheap, yet spectroscopic, robust and fast. Two application can particularly benefit from these properties: (1) active interrogation for cargo scanning where the detectors are subjected to intense radiation fields and require to cover large areas in a form of dense radiography arrays, and (2) mobile detectors coupled with unmanned aerial/ground vehicles (UAV/UGV) for source-search and area characterization. Active interrogation methods have conflicting requirements of high resolution radiographic images with low dose and fast scan times. Emerging active interrogation technologies producing monoenergetic photon beams are currently based on Inverse Compton Scattering or low-energy nuclear reactions, for example ^{11}B(d,n-γ)^{12}C with prominent gamma peaks at 4.4 and 15.1 MeV. These photon sources, coupled with high-resolution arrays of Cherenkov detectors, could lead to decreased dose and scan time as well as improved image quality and material determination. Cherenkov detectors allow for low cross talk in tightly coupled arrays of small detector units while providing fast response (nanoseconds) and reasonable spectroscopy for well-resolved gamma rays. The presentation will cover a utility of custom-designed Cherenkov detectors in application to the ^{11}B(d,n-γ)^{12}C source-based radiography to measure the differential attenuation of the most prominent photons and relate the relative transmission of the two main energies to an approximate Zeff. In contrast to active interrogation arrays, the UAV/UAG detectors are required to be light yet robust and disposable. To counter these challenges, we developed silicon-based scintillators that are quickly prepared (few hours), robust, inexpensive, and geometrically flexible via molds. We focus on gamma and neutron detection, based on pulse shape discrimination (PSD), with solid light-weight scintillators not requiring complex growth techniques or significant environmental proofing. As part of the presentation, we will compare the performance of the custom scintillators against traditionally-employed PSD-capable scintillators.

Nonproliferation, Safeguards, and Homeland Security - Wednesday 4:00 - 5:30 pm in Mendelssohn with Sara Pozzi

Use of Active Neutron Interrogation Post-Irradiation Decay Kinetics to Assess Fissionable Assemblies

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Active neutron interrogation was used to study the post-irradiation decay kinetics of fissionable assemblies with the goal of developing methods for characterizing heterogeneous arrangements of highly-enriched uranium (HEU) and depleted uranium (DU). Irradiations were performed using a deuterium-tritium electronic neutron generator; measurements were performed using an array of filtered, polyethylene-moderated ^{3}He proportional counters surrounding the items of interest under test, to detect neutrons leaking from the assemblies after six-minute irradiation periods. Nuclear material included a 100-kg DU annulus encased in nylon and aluminum sleeves, and three metal disks of HEU weighing 5.5 kg, 5.9 kg, and 8.9 kg. The decay-profile of the measured neutron signals from each experiment was fit as a linear sum of the six-group β-delayed neutron signals from ^{235}U and ^{238}U fission, and reported as a fission split showing the percent of total observed signal due to fission in ^{235}U. Significant asymmetry in the observed fission split was observed in most cases, owing to the orientation of the detectors to the assemblies, the orientation of the DT-ENG with respect to the assemblies, and the presence of local moderators (polyethylene) and neutron absorbers (cadmium). In general it is shown that for 'realistic' item geometries and measurement layouts a simple fit of the decay kinetics cannot be used to estimate uranium enrichment but can be used to make bounding-estimates of enrichment and material composition and geometry. A comprehensive modeling campaign was performed to study these effects in greater detail and has revealed interesting relationships between the measured signatures and the phenomena that occur within heterogeneous fissionable assemblies subjected to active neutron interrogation.

Nonproliferation, Safeguards, and Homeland Security - Wednesday 4:00 - 5:30 pm in Mendelssohn with Sara Pozzi

High-order angular correlation of californium-252 fission neutrons and the effect of detector crosstalk

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One technique for the quantification of nuclear materials depends on the analysis of the temporal correlation between neutrons emitted due to the induced or spontaneous fission of heavy isotopes, often using helium-3 proportional counters. However, since 95% of prompt fission neutrons originate from the fission fragments, after the fragments have been fully accelerated and when travelling typically in opposing directions, the kinematics of the fission reaction has a strong influence on the angular distribution of correlated neutrons. Since organic scintillators are sensitive to fast neutrons, it is possible to measure this angular correlation to higher orders of multiplicity with the prospect of new techniques which may complement and corroborate existing methods. Previously, a field-programmable gate array (FPGA) system was introduced utilizing organic scintillators to determine such temporal and angular correlations using a novel event-triggered algorithm. In this paper, an analysis of high-order angular correlation from experimental measurements using californium-252 is presented along with comprehensive Geant4 simulations using both an uncorrelated fission model, i.e., an average fission model, and the FREYA fission model to quantify the impact of detector crosstalk on such distributions. The results from these approaches demonstrate that, although a bimodal trend for the neutron angular distributions is observed for californium-252, the peak at 0^{o} of detector separation is greater than that at 180^{o}, which is contrary to intuition. This contrasting trend is thought to arise due to neutron crosstalk between detectors, as asserted by the results of simulations presented in this paper. Further, it was determined that 20% of all events in the first-order angular correlation, i.e. the distribution of a second event detected within a coincidence window with a first, triggering event, are in fact because of detector crosstalk in our experimental configuration; while up to 45% of the events recorded by the detectors adjacent to the 0^{o} position are due to crosstalk. Higher-order angular correlations have also been investigated and were found to have a higher proportion of crosstalk events compared to the first-order correlation. These higher-order distributions also exhibit anisotropic angular correlations, although the significance of the anisotropy is observed to fall with increasing order. In presenting these results the understanding for practical measurements of prompt, fission neutron emission is expanded. This is of relevance to the development and correction of event-by-event techniques with the potential to benefit the non-proliferation and homeland security applications.

Nonproliferation, Safeguards, and Homeland Security - Wednesday 4:00 - 5:30 pm in Mendelssohn with Sara Pozzi

Multiple Monoenergetic Gamma Radiography for Nuclear Smuggling Detection in Commercial Cargo

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The 9/11 Commission Act of 2007 mandates that all maritime cargo containers bound for the United States undergo both passive radiation inspection and nonintrusive imaging to combat the possible smuggling of special nuclear materials (SNM) or assembled weapons through commercial cargo. Implementation of this "100% scanning" mandate, however, has been delayed significantly due to the logistical and technical challenges associated with deploying systems in ports capable of detecting nuclear threats and distinguishing them from benign cargo. A nonintrusive imaging system capable of precisely identifying materials, while minimizing the physical footprint of the system and the radiation dose to inspected cargo, could provide a key tool for achieving the goals of the 100% scanning mandate. This talk will present results from a prototype radiography system that uses monoenergetic gamma rays from nuclear reactions to quantitatively image cargo in both its areal density and effective atomic number. The system utilizes 3 MeV deuterons accelerated by a radio-frequency quadrupole (RFQ) accelerator incident on a boron target to produce 4.4 and 15.1 MeV gamma rays via the ^{11}B(d,n)^{12}C reaction. Transmitted gamma rays were detected using a large array of high-efficiency NaI (Tl) detectors, providing cm-scale spatial resolution for the imaging. The transmitted spectra were compared against a large simulation library of materials covering the complete range of atomic numbers and relevant areal densities to provide precise and accurate material identification, including the separation of benign high-Z materials (e.g., Pb, W) from SNM (e.g., U, Pu). Recently released results from the prototype system will be presented along with a discussion of possible future applications of this technique for cargo security.

6.3.10 Detector Electronics and Signal Processing (Wednesday 4:00 - 5:30 pm in Hussey with Gianluigi De Geronimo)

Detector Electronics and Signal Processing - Wednesday 4:00 - 5:30 pm in Hussey with Gianluigi De Geronimo

Digital Pulse Deconvolution With Adaptive Shaping For Real-Time High-Resolution High-Throughput Gamma Spectroscopy

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The recent developments in digital signal processing and field programmable gate arrays (FPGAs) make it possible to achieve improved signal to noise ratio, high throughput, reliability and flexibility as compared to traditional analog systems. The objective of pulse processing techniques is to achieve an optimum signal to noise ratio, permitting operation at high-count rates with high throughput and minimal degradation of energy resolution. At high count rate conditions, the effect of pile-up and baseline shift is more severe. The high resolution and the high throughput are conflicting issues, as the shorter filter provides high throughput but poor energy resolution whereas longer filters ensure good energy resolution with very low throughput. In this work, a high-resolution high-throughput real-time adaptive digital pulse processing system including pulse deconvolution is developed for high count rate applications. The detection system consists of a semiconductor detector followed by a charge sensitive preamplifier whose output is a long-tailed exponential pulse. A digital pulse deconvolution technique is developed to reconstruct the original detector signal from the preamplifier output signal, which reduces the resolution deterioration due to pulse pile-up. The digital trapezoid shaping algorithm is applied, and it performs adaptive shaping according to the time interval of separation between incoming preamplifier pulses. It selects the optimum shaping parameters (i.e., the rise time and flattop time of the trapezoid shaping filter) for each incoming pulse, thus minimizing the throughput losses. The high purity germanium (HPGe) detectors preamplifier pulses are sampled at a high frequency by a digitizer and digitally processed through a series of algorithms that include a digital pulse deconvolver, adaptive shaping filter, timing filter, baseline restorer, and pile-up rejecter. The digital pulse processing algorithms are implemented on a reconfigurable FPGA and tested experimentally with a ^{137}Cs source for varying count-rate and pulse shaping conditions. Experimental testing of the developed pulse deconvolution technique with the adaptive approach demonstrated that nearly four times to twice the throughput is achievable as compared to traditional analog and digital techniques with 25% improvement in energy resolution relative to traditional digital shaping (e.g. as performed by commercial systems).

Detector Electronics and Signal Processing - Wednesday 4:00 - 5:30 pm in Hussey with Gianluigi De Geronimo

Development and applications of miniature TDCR acquisition system for in-situ radionuclide metrology

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This work presents the design and the basic features of a newly developed front-end digital pulse processing device for the application of the triple-to-double coincidence ratio (TDCR) method in liquid scintillation (LS) counting. The device (hereafter called nanoTDCR) allows coincidence counting of the signals from LS counters equipped with three photomultiplier tubes (PMT) and is designed for the primary standardization of radionuclides by the TDCR method. In contrast with other front-end TDCR acquisition systems developed by metrology institutes, it uses extendable dead-time systems in each PMT channel. The system allows simultaneous counting within two different base dead-time durations and two different coincidence windows. The important characteristics and the operation of the device are presented. The specific metrological features of the system are discussed, including the graphical adjustment of the channels thresholds, the traceability to time and frequency units and the observed linearity of the system, tested up to 90 ks^{-1}with more than 95% dead-time. Several applications of TDCR measurements with the nanoTDCR device are presented: absolute standardization of pure beta radionuclides (^{3}H, ^{14}C, ^{90}Sr/Y), standardization of radionuclides decaying through electron-capture followed by gamma de-excitation (^{103}Pd, ^{103m}Rh), absolute activity measurements of ^{222}Rn and activity measurement of ^{220}Rn progeny with LS. The use of this system for the measurement of the decay of radionuclides is illustrated by the determination of the half-lives of ^{103m}Rh, and ^{212}Pb, and the assessment of the concentration of a pure-beta impurity - ^{33}P in ^{32}P. Some other potential applications to the measurement of short-lived radionuclides used in nuclear medicine are finally discussed.

Detector Electronics and Signal Processing - Wednesday 4:00 - 5:30 pm in Hussey with Gianluigi De Geronimo

Front-End ASIC for Germanium Strip Detectors

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The characteristics of a recently developed front-end application specific integrated circuit (ASIC) designed for high-purity germanium (HPGe) strip detectors are detailed. The ASIC derives from the silicon strip NCIASCIC2 [1], but adds a time-to-analog circuit to allow the depth of interaction in a detector to be determined. The ASIC contains 32 channels and the ASIC can instrument either cathode or anode signals from the HPGe detector. The ASIC has a small noise slope allowing it to maintain germanium energy resolution at the large, 30 pF, input capacitance of a germanium strip detector connected through the cryostat by a kapton flex cable. The channels provide low- noise charge amplification, four shaping times, four gain ranges, trimmable discrimination for each channel, time to analog output, and peak detectors with analog memory. The channels process events in parallel and the ASIC emits a logical-OR of the internal discriminators for external control. The ASIC sparsifies the triggered channels for low deadtime readout. Each channel dissipates 6.2 mW and covers an energy range up to 4 MeV in HPGe. Initial measurements demonstrate an equivalent noise charge (ENC) of 133 electrons, at an input capacitance of 1 pF. [1] G. De Geronimo et al., IEEE Trans. Nuc. Sci. 55, 2008, 2323.

Detector Electronics and Signal Processing - Wednesday 4:00 - 5:30 pm in Hussey with Gianluigi De Geronimo

A PET detector performance evaluation platform with FPGA-based 1-bit sigma-delta modulation readout electronics

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To evaluate a high performance and compact PET detector, we designed and implemented a 32-channel detector performance evaluation platform for dual-scintillator-end readout PET detectors. With only a simple front-end charge-sensitive preamplifier on each channel, it applied latest FPGA-based 1-bit - modulation to trigger, digitize, and process the output signals from silicon photomultiplier (MPPC from Hamamatsu Photonics K.K.) arrays. Since all conventional ADC and TDC were implemented inside FPGA, the entire circuit is compact, low-cost, and flexible for different signal and readout requirement through programming. By implementing a novel row and column output wiring method, the number of readout electronics channels from one MPPC array was reduced from 64 to 16, enabling signal readout by using a low-cost and off-the-shelf FPGA evaluation board, with less than 6% of the on-chip resource to be used. With a master & slave board-to-board communication architecture, a digital coincidence logic was also implemented to select a gamma interaction event with its scintillation lights being simultaneously detected from two MPPC arrays. The evaluation platform can read and process both positive and negative polarity signals from MPPC anodes and cathodes. To validate the platform design and performance, a prototype detector that consisted of two latest 88 arrays of 22 mm^2 MPPCs (Model S13361-2050-08) coupled to both ends of a 15x15 array of 1120 mm^3 LYSO scintillator crystals for depth-of-interaction measurement was tested with a ^{22}Na radioisotope source. The flood source image of crystal identification and energy spectrum were measured with very good results, demonstrating that the performance evaluation platform can provide required performance in signal digitization, event coincidence and other glue logic for the signal measurement. This implemented prototype detector evaluation platform will also provide the technical basis for the development of full readout and processing electronics for the PET system.

Detector Electronics and Signal Processing - Wednesday 4:00 - 5:30 pm in Hussey with Gianluigi De Geronimo

Microstructural Engineering of the Near-UV Quantum Efficiency in VO_2 Thin Film Based Neutron Detectors

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The need for fast, sensitive detection of UV and near-UV radiation emitted from neutron activated scintillators is of critical importance for the next generation of compact, sensitive, low power neutron detectors. Vanadium Dioxide (VO_2) thin films have potential for highly sensitive measurements of photons in lieu of photomultipliers thus making VO_2 thin films a promising detector component. By optimizing photon carrier transfer mechanisms in VO_2 deposited on TiO_2/TiO_2:Nb as well as growth parameters enables a broad range of UV and near-UV detection devices without the need of photomultipliers. Our project goal is to optimize the photosensitivity of VO_2 thin films in the near-UV and UV regions following recent demonstrations that VO_2 grown on niobium doped TiO_2 (TiO_2:Nb) substrates can extend its photoconductive response into the visible spectrum. By controlling the microstructure of the films via deposition parameters and substrate doping, we optimize the VO_2 growth on TiO_2 and TiO_2:Nb substrates. The choice of substrate enables strain engineering in the monoclinic structure (i.e. the insulating VO_2 phase) toward the tetragonal structure in the metallic phase. By using X-ray diffraction, we determine that films grown on TiO_2:Nb structurally exhibit a $\sim .25^o$ shift in peak location compared to the undoped films demonstrating additional strain effects that reduce the band gap energy necessary for carrier displacement. The films exhibit a photocurrent, upon 405 nm illumination, for both the doped and undoped films with a greater quantum efficiency associated with the optimized doped films, suggesting that optimized doping enhances the near-UV quantum efficiency of the film via VO_2 band-gap energy reduction thus favoring photocarrier transfer from the substrate to the film. Thus by using optimized thin film properties we demonstrate VO_2 on TiO_2:Nbs potential as a UV detector for scintillator-based neutron detection applications.

Detector Electronics and Signal Processing - Wednesday 4:00 - 5:30 pm in Hussey with Gianluigi De Geronimo

Improvement of MRPC time reconstruction based on neural network algorithm

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Particle identification(PID) is very important in the study of hadronic physics and it is usually accomplished with the Time-of-Flight(ToF) system in large detectors. The Solenoidal Large Intensity Device(SoLID) at Jefferson Lab(JLab) plans to use the multi-gap resistive plate chamber(MRPC) in its ToF system to separate π/k up to 7GeV/c, which requires the time resolution of MRPC to be better than 20ps. For present MRPC, the signal is read out using the Time-Over-Threshold(ToT) method and the uncertainty of the TDC can even reach 20 to 30ps, which is large enough to overwhelm the intrinsic precision of MRPC. Therefore a fast amplifier and the pulse digital sampling system is under consideration. In the mean time, a new analysis method using the information of the detailed signal waveform is also necessary. We propose an algorithm based on the artificial neural network(NN) which learns the signal pattern with the training data of the entire leading edge. Compared to the ToT method which only uses the threshold crossing time and the total time over threshold, our method can achieve a higher precision. The output of the NN restores the true time when particles arrive at MRPC, rather than the time when the read out signal is above some threshold. Hence, an accurate arriving time can be obtained. Furthermore, NN is an end-to-end solution and once a good model is trained, it can be very easy and fast to calculate the MRPC time without the complicated calibration. We simulate the waveform of a 5-gap, 0.25mm-thick MRPC with Geant4 and feed the leading edge of the simulation signal to a fully-connected NN. The test on simulation data shows that the NN algorithm improves the time resolution by about 20ps. A preliminary result of the test on the experiment data will also be presented in this paper. With the development of the high energy physics experiments, MRPC detector will find more applications and this algorithm will improve the time resolution and thus the ability to identify particles, as well as simplifying the calibration.

6.4 Thursday

6.4.1 Nonproliferation, National and Homeland Security Applications (Thursday 8:00 - 9:30 am in Mendelssohn with Zhong He)

Nonproliferation, National and Homeland Security Applications - Thursday 8:00 - 9:30 am in Mendelssohn with Zhong He

Current and Future Radiation Detection Development and Procurement Programs at the Joint Product Leader for Radiological and Nuclear Defense

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A short overview of the Joint Product Leader for Radiological and Nuclear Defense (JPdL-RND) will precede a summary of the current and future radiation detection development and procurement programs at JPdL-RND. Current and future programs for JPdL-RND include RADIAC survey equipment, dosimetry, and radioisotope identification across the full spectrum of platforms used by the DoD. Additionally, opportunities for proposal submission using several new contract vehicles for the various programs will be summarized. Finally, the linkages between technology developers such as DTRA and other Government agencies such as DNDO and NNSA will be described as well as examples of procurement coordination between various relevant governmental entities.

Nonproliferation, National and Homeland Security Applications - Thursday 8:00 - 9:30 am in Mendelssohn with Zhong He

End user experience with the SCoTSS Compton imager and directional survey spectrometer

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Canadian Hazards Information Service, Natural Resources Canada, Canada (1), Department of Physics, Carleton University, Canada (2), Measurement Science and Standards, National Research Council Canada, Canada (3), Defense Research and Development Canada, Department of National Defence, Canada (4), Canada Border Services Agency, Canada (5), Royal Canadian Mounted Police, Canada (6), Radiation Solutions Inc., Canada (7)

The Silicon photomultiplier-based Compton Telescope for Safety and Security (SCoTSS) has been developed incorporating end-user requirements into the design process. The end-user group includes those responsible for mobile survey in the event of a radiological or nuclear accident, those responsible for radiation survey support to security operations at major events and at Canadian borders, as well as some of those responsible for Canadian defense applications. The result is a high sensitivity rugged mobile survey and mapping instrument, capable of direction reconstruction in motion, as well as imaging of a field of view. The SCoTSS development program has reached a technology readiness level of eight, and we are proceeding with field trials of the instrument in high fidelity operational environments. Prospective end users have been involved in trial set up and execution, assuring applicability in their mission spaces. SCoTSS has been subject to trials involving hidden sources, heavily shielded sources, open sources distributed over a large area, source moving with respect to imager, and congested built environments. We present here the results of those end-user experiences including a critical examination of required performance features for a fieldable device both in real time and post-acquisition. We present quantitative performance measures under service conditions.

Nonproliferation, National and Homeland Security Applications - Thursday 8:00 - 9:30 am in Mendelssohn with Zhong He

Adaptive, Multi-Energy Computed Tomography (AMECT) for Security Inspection System

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X-ray Computed Tomography (CT) is a widely used tool for security inspection, where scanned objects typically contain multiple materials with different atomic numbers. In these cases, Dual Energy CT (DECT) has numerous advantages over conventional single-energy CT, including improved image quality, reduction of effect of scatter and other artifacts, and better material decomposition. Therefore, DECT has become the standard for inspection of objects containing multiple materials. In this paper, we present a new CT technology: Adaptive, Multi-Energy Computed Tomography, AMECT. AMECT is based on adaptive modulated-energy cargo radiography techniques that have been developed over the last few years. To perform CT imaging, we propose to utilize the exact and fast Katsevich image reconstruction algorithm. Key enabling AMECT techniques include: X-ray source with deep intra-pulse control generating energy- and intensity-modulated pulses. Two-dimensional arrays of fast X-ray detectors, where the detectors temporal resolution is substantially less than X-ray pulse width. Real-time algorithm for X-ray pulse-by-pulse selection of dual and multi-energy windows for dual/multi-energy material decomposition. Filtered Backprojection (FBP) helical image reconstruction based on the theoretically exact Katsevich algorithm. The AMECT approach for dual- (or, multi-) energy CT mitigates the main disadvantages of the conventional interlaced approach: Ambiguity and artifacts in reconstructions caused by inability to select optimal energy windows and by displacement of object between pulses in the conventional interlaced dual-energy method. Distortion of CT image of the boundaries between regions with large difference in Z. Small range of object thicknesses where material decomposition is valid.

Nonproliferation, National and Homeland Security Applications - Thursday 8:00 - 9:30 am in Mendelssohn with Zhong He

PIPS-CZT: A Compact, Low-Cost Atmospheric Radioxenon Detection System

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The Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO) is able to identify clandestine nuclear weapon tests that occur anywhere on the globe by monitoring the atmosphere for the presence of several radioxenon isotopes (^{131m}Xe, ^{133}Xe, ^{133m}Xe, ^{135}Xe) that are characteristic byproducts of nuclear explosions. Identifying the beta-gamma coincidence decays signature to these isotopes is an effective tool to discriminate them from background and thereby detect the radioxenon at extremely low concentrations (<1 mBq/m^3), and is a technique utilized by many detectors employed by the CTBTO in the International Monitoring System (IMS). The PIPS-CZT is the most recent prototype radioxenon detector designed at Oregon State University that aims to provide a compact and low-cost system that is competitive with the detectors used in the IMS. The PIPS-CZT uses a PIPSBox as a gas cell and electron detector, while a pair of coplanar CZT crystals are used for photon detection. The PIPSBox is comprised of two independent thin silicon plates surrounding the gas, which provide high-resolution electron measurement with negligible memory effect when compared to plastic scintillators typically used in beta-gamma coincidence systems. Coplanar CZT provides high-resolution photon detection at room temperature. A custom eight-channel digital pulse processor (DPP8) routes the four independent signals into a high-performance FPGA, wherein coincident pulses occurring in the detectors are identified in hardware in real-time. Measurements made with the PIPS-CZT system using radioxenon gas samples created in the OSU TRIGA reactor are presented.

Nonproliferation, National and Homeland Security Applications - Thursday 8:00 - 9:30 am in Mendelssohn with Zhong He

Characterization of a Low Background Proportional Counter for a High Throughput Argon-37 Collection and Measurement System

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The measurement of ^{37}Ar has been proposed as a method of detecting underground nuclear testing. The isotope ^{37}Ar is generated by neutron activation of calcium by the reaction, ^{40}Ca(n, α)^{37}Ar, and, as a noble gas, is able to migrate more freely underground. Pacific Northwest National Laboratory has developed a high throughput ^{37}Ar collection and measurement system using modified Ultra-Low Background Proportional Counters (ULBPCs). This system is capable of collecting and measuring argon from either atmospheric or soil gas samples. The system mixes purified argon samples into P10 count gas and performs an automated measurement with minimal operator intervention. This paper describes quantification of ^{37}Ar and how we account for varying background conditions. An example is provided in which ^{39}Ar has been shown to be a significant background in some sample sets, created by process ^{39}K(n,p)^{39}Ar during the same underground nuclear explosion. To account for the large background of ^{39}Ar, we fit the background with an exponential plus a Gaussian and use that information in calculating small ^{37}Ar activities. We discuss the efforts put forth to purify and count samples, as well as discuss quantifying ^{39}Ar backgrounds.

Nonproliferation, National and Homeland Security Applications - Thursday 8:00 - 9:30 am in Mendelssohn with Zhong He

Comparison of Pulse Shape Discrimination Performance of Stilbene and Liquid Scintillator under High Count-Rate Conditions

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The detection of fast neutrons in high-count-rate scenarios, such as can be expected during Active Interrogation of objects using an electric neutron generator for detecting the presence of Special Nuclear Materials and contraband is of growing interest to the security community. Liquid scintillators have long been the standard option for investigations involving fast neutron detection in the presence of gamma radiation. However, the recent commercial availability of solution grown single crystal stilbene, a material with excellent neutron-gamma pulse shape discrimination (PSD) capability, may provide an attractive option for applications where reduced handing issues and increased PSD performance provide significant advantages. We compare the pulse-shape-discrimination performance of a large stilbene detector, manufactured at the Lawrence Livermore National Laboratory, containing a 10 cm long x 10 cm diameter crystal produced by Inrad Optics, to a similarly sized liquid scintillator, made by Eljen Technologies, Inc. (type EJ-309). Tests were conducted under various high-count-rate scenarios produced using a D-T neutron generator in concert with materials including low enriched uranium, iron, high density polyethylene, and cadmium. Signals were sampled at 250MS/s, using a SIS3316 digitizer, and 256 samples were recorded for each trigger. Pulse shape discrimination was performed during post processing with an extension of previously described wavelet and event fitting algorithms, which were also used to reject pulse pile-up events and to correct the energy calibration for event signals clipped during digitization. Results from these measurements showed that the stilbene detector may have several advantages beneficial for SNM detection. The intrinsically better pulse-shape discrimination performance of stilbene facilitates higher event use efficiency by about a factor of two, despite the fact that the liquid scintillator events have slightly narrower pulse widths. The stilbene detector also demonstrated a better gamma rejection ratio. We observed that even with the significant efficiency loss for the liquid scintillator, pulse pileup still resulted in an observable background from gamma misidentification, which was not evident in stilbene data, during the earliest times of the beam off period. Details of the measurements and results will be presented. This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344, DHS/DNDO IAA HSHQDC-15-X-B0006, with financial support by the Domestic Nuclear Detection Office in the Department of Homeland Security. This support does not constitute an express or implied endorsement on the part of the government.

6.4.2 Unconventional Radiation Detectors and Techniques (Thursday 8:00 - 9:30 am in Hussey with Igor Jovanovic)

Unconventional Radiation Detectors and Techniques - Thursday 8:00 - 9:30 am in Hussey with Igor Jovanovic

Liquid Xenon Detectors: New Developments and Applications in Dark Matter Detection, Neutrino Physics, and Homeland Security

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Liquid xenon has a number of desirable qualities that make it well-suited for a wide range of applications in particle physics, nuclear physics, and homeland security. It is a bright scintillator, with fast response time, large charge yield and high electron mobility, and is readily available with a material cost similar to that of sodium iodide. The high density and high atomic number of liquid xenon make it ideal for detecting and imaging gamma rays with high efficiency, with 3% FWHM energy resolution and mm-scale position reconstruction. Large, homogeneous detectors may be built, with liquid xenon active masses of 1-10 kg in many labs around the world, 100-1000 kg in several running experiments, and up to 10,000 kg in experiments currently under construction. Liquid xenon detector physics will be described, with latest results on energy resolution, gamma/neutron discrimination, and position reconstruction. These studies use calibrations with a variety of external gamma-ray and neutron sources, as well as gaseous sources dissolved in the liquid xenon.

Unconventional Radiation Detectors and Techniques - Thursday 8:00 - 9:30 am in Hussey with Igor Jovanovic

A large-scale demonstration of scalable TES microcalorimeter readout: The SLEDGEHAMMER gamma-ray spectrometer

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(This abstract is for an invited talk) Microcalorimeters based on transition-edge sensors (TESs) have been successfully deployed in numerous spectroscopic instruments that operate over a large range of incident photon energies. Increasing the count rates of these instruments has required a new approach to detector readout. To this end, over the past few years our group has developed a new readout technology: the microwave superconducting quantum interference device (SQUID) multiplexer. Using microwave based readout increases the available readout bandwidth from a few MHz to several GHz, allowing many more devices to be read out as well as supporting readout of much faster individual devices. An important application that requires this additional readout bandwidth is the use of TES microcalorimeters to perform non-destructive isotopic analysis with gamma-ray spectroscopy of the complex mixtures of actinide isotopes found in the nuclear fuel cycle. The precision of existing gamma spectroscopy methods is insufficient to safeguard large facilities. Higher-precision methods are slow, labor-intensive, and destructive to the sample. Steady progress has been made over the last 10 years developing TES microcalorimeter instruments with this capability, leading to the development of arrays demonstrating significantly better energy resolution than state-of-the-art High-Purity Germanium (HPGe) detectors. Previous gamma-ray measurements with TES arrays have demonstrated lower uncertainty than HPGe and shown the potential to reduce reliance on destructive analysis. However, TES arrays with much higher count rate capability are needed to (1) match the measurement speed of HPGe, and (2) assess and minimize the systematic errors in deduced material composition. The microwave SQUID multiplexer has now matured to the point where it has been deployed with the SLEDGEHAMMER gamma-ray spectrometer. This pathfinder instrument currently consists of 256 TES microcalorimeters read out using the microwave SQUID multiplexer, and will be increased to 512 TES microcalorimeters later in the program. This instrument has already been taken to Los Alamos National Laboratory and used to measure the isotopic content of a wide variety of samples relevant to actinide accounting during the nuclear fuel cycle, including plutonium isotopic standards and a sample containing fission products taken from spent fuel from the Three Mile Island power reactor. We describe the development of the instrument, present spectra of measured samples, and discuss prospects for further improvements in system performance. We also describe planned applications of the microwave SQUID multiplexer to spectrometers operating at other energy ranges, where both the total bandwidth and per-detector bandwidth are crucial for successful deployment of instruments. We gratefully acknowledge the support of the U.S. Department of Energy through the NEUP program.

Unconventional Radiation Detectors and Techniques - Thursday 8:00 - 9:30 am in Hussey with Igor Jovanovic

Determination of individual L-X-ray line emission intensities in the decay of Cm-244 with a high energy resolution metallic magnetic calorimeter

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Management of trans-uranium elements, as Cm-244, is essential for different applications such as nuclear fuel cycle facilities, waste management, fundamental parameter quantification etc. Emissions of L-X-rays by actinides are quite intense due to the large internal conversion coefficients of the gamma transitions. These emissions can be beneficial for the quantitative analysis of actinides by photon spectrometry, however the L X-rays emitted by radionuclides are generally not well known. Several studies explored the L-X-ray regions of actinides and measured total intensities of L-X-ray groups, partially with large uncertainties up to 10 %. However, they cannot resolve the L-X-ray lines due to the limited energy resolution (FWHM 200 eV at 25 keV) of the semi-conductor detectors. The present work shows and discusses the measurement of L-X-ray individual line emission intensities using an ultra-high-resolution spectrometer. CEA-LNHB developed a cryogenic detector called SMX3 based on a Metallic Magnetic Calorimeter (MMC) conceived for photon spectrometry below 25 keV. SMX3 is a four pixels cryogenic detector with a constant intrinsic efficiency close to unity below 25 keV and an energy resolution of 30 eV at 25 keV . An electroplated source of Cm-244 has been prepared at LNHB with an activity of 72 kBq, thin enough to avoid self-absorption. The detector was operated at 10 mK using a dilution refrigerator. In order to reach sufficient counting statistics in the spectrum (5 million counts in the L-X-ray region in each pixel) the source was measured during 15 days. A quantitative analysis in metrological experiments requires accurate and precise estimation of photon counting rate and photon energy. An extendable dead time treatment was applied, which has a dead time window depending on the duration of the detected pulse . A high-resolution spectrum is obtained showing that the individual lines in the region of L-X-rays are successfully separated despite the narrow energy spacing. In addition, this spectrum shows the region of M-X-ray lines, which is completely unknown for Cm-244. Using the peak fitting program Colegram, the complex L X-ray region was fitted to determine the peak areas and hence the relative intensities for L X-ray lines.

Unconventional Radiation Detectors and Techniques - Thursday 8:00 - 9:30 am in Hussey with Igor Jovanovic

A frequency coded source using transmission nuclear resonance fluorescence for isotope identification and assay

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We propose a new method of isotopic imaging based on transmission nuclear resonance fluorescence (NRF). In our approach, we pass a bremsstrahlung beam through a beam chopper made of two filters with the same non-resonant cross section but different NRF cross sections. The beam then travels through a test object and is measured using a calorimeter. The time-varying component of the calorimeter output consists of a weak NRF signal ($\sim$ 1e-6 of the total) and the stochastic noise of the entire output. The stochastic noise has a white noise frequency spectrum, so is spread evenly across all frequencies, while the small NRF signal is concentrated at the beam chopper frequency. We boost the signal to noise ratio of the NRF signal by taking the Fourier transform of the time-varying component of the calorimeter output and only retaining the frequency which matches the beam chopper rotation frequency. We call this a frequency coded source (FCS). In a simplified Python model, our system can infer isotopic compositions to within 10% using a modest photon flux and measurement times on the order of minutes. Because our method can use a calorimeter and either a continuous-wave or pulsed photon source, it could be used as a low cost, man-portable device for isotopic identification and assay. Although we have shown this using photons, the FCS method is equally applicable to neutron transmission measurements.

Unconventional Radiation Detectors and Techniques - Thursday 8:00 - 9:30 am in Hussey with Igor Jovanovic

Measurement of Muon-induced Fast Neutrons from Surrounding Rock in the WATCHBOY detector

Sutanto, Felicia (1)

for the AIT Collaboration (1)

We investigate the rate of muon-induced fast neutron production in rock at a depth of $\sim$ 400 m.w.e. Two complimentary experiments (MARS and WATCHBOY) were used. The MARS detector was a mobile neutron detector system for measuring the neutron spectrum between 50 and 400 MeV at multiple depths. WATCHBOY was a 2 ton gadolinium-doped water Cherenkov detector shielded by a 40 ton pure water outer muon veto. Both detectors were situated at the same depth at the Kimballton Underground Research Facility. WATCHBOY was deployed over a $\sim$ 13 month period between July 2013 and August 2014. The main purpose of WATCHBOY was to measure the rate of muogenic radionuclide (such as ^{9}Li) production in water. Both fast neutrons and muogenic radionuclides are an important background in antineutrino experiments because they mimic the inverse beta reaction (IBD) by producing correlated event pairs. While WATCHBOY seeks to measure radionuclides created by muons, its primary background was correlated pairs of events caused by fast neutrons entering the detector due to muon spallation in the surrounding rock. Using the fast neutron energy spectrum obtained by MARS, we used a Geant4-based simulation to predict the rates of correlated neutron-like events in WATCHBOY. We found that the predicted rates were broadly consistent with the observed rates in WATCHBOY. Part of this work was performed under the auspices of the US Department of Energy by Lawrence Livermore National Laboratory under contract DE-AC52-07NA27344, release number LLNL-ABS-747161. The research of F. Sutanto was performed under appointment to the Nuclear Energy University Programs Fellowship.

6.4.3 Poster IV - Physics, Security Applications, and Signal Processing (Thursday 9:30 - 10:30 am in Ballroom with Angela Di Fulvio)

Poster IV - Physics, Security Applications, and Signal Processing - Thursday 9:30 - 10:30 am in Ballroom with Angela Di Fulvio

Radiological Isotopic Categorization using Modern Machine Learning

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Remote Sensing Laboratory - Andrews (1)

Radioactive isotope identification and categorization via gamma-ray spectroscopy is a mature field with a rich history of fruitful applications. Similarly, machine learning and data scientific techniques, boosted by ubiquitous high-speed computing, have been shown capable of solving once intractable problems. We present applications of machine (deep) learning to the categorization of radioactive isotopes as observed in commonly fielded detection suites. We compare and contrast these novel approaches with classical (non-adaptive) techniques, such as template matching, and illustrate where the largest gains in sensitivity, precision, and efficiency are likely to be found. We furthermore illustrate methods by which observational modes other than gamma-rays can be naturally integrated using non-adaptive techniques.

Poster IV - Physics, Security Applications, and Signal Processing - Thursday 9:30 - 10:30 am in Ballroom with Angela Di Fulvio

Pulse shape discrimination with a low-cost digitizer using commercial off-the-shelf components

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Abstract— Pulse shape discrimination of neutrons and gammas is demonstrated using a FemtoDAQ, a low-cost digitizer that uses commercial off-the-shelf components. This digitizer is paired with a CLYC scintillator coupled to a photomultiplier tube to concurrently detect neutrons and gammas. Python code was written to analyze the detector waveforms to determine the energy deposited and distinguish neutron and gamma events within the CLYC crystal. The energy of each waveform is determined by the summation of the discrete amplitudes recorded by the digitizer for each pulse. This method is compared to a traditional multichannel analyzer operating with commercial software for validation and shown to produce the same energy spectrum. Pulse shape discrimination is accomplished by measuring and summing the amplitudes of the prompt portion of each waveform (first 80 ns) and the delayed portion (following 500 ns) and then calculating a ratio of the delayed region to the total. This technique was able to clearly distinguish thermal neutron events from gamma events with a figure of merit of 1.42.

Poster IV - Physics, Security Applications, and Signal Processing - Thursday 9:30 - 10:30 am in Ballroom with Angela Di Fulvio

Investigating the Non-ideal Behavior of Amptek A111 Charge Sensitive Preamplifier & Discriminator Boards Used in Common Safeguards Neutron Coincidence Counters

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Neutron coincidence counting is a well-established technique used for the nondestructive quantification of special nuclear material during international safeguards inspections. These counters are commonly designed with an annular body, centered about an inner well for sample assay, and populated with ^{3}He tubes connected to a varying number of preamplifiers. The Canberra Industries JAB-01 preamplifier/amplifier/discriminator board is employed within their own neutron coincidence counters, built for use by the International Atomic Energy Agency. Non-ideal behavior of these boards was first revealed in a detector characterization, using list mode data acquisition, of a Canberra Industries JCC-71 Neutron Coincidence Collar implementing four JAB-01 boards. List mode data acquisition and analysis reveals features that have commonly been overlooked by historic timing gate selection while using shift register data acquisition methods. It is known that double pulsing effects are not fully captured within the predelay setting, and therefore, they influence the response of the system within the standard operating regime. We set out to identify and correct for double pulsing in our post analysis of neutron pulse trains, while isolating this behavior and adjusting the respective electronics to reduce this effect. The responses of two different JAB-01 board systems: the JCC-71 Neutron Coincidence Collar and the JCC-51 Active Well Neutron Coincidence Counter, are compared with the responses of an AnTech Inc. 2071-17 Neutron Coincidence Collar, with independent electronics, and a JCC-71 employing novel preamplifiers designed at Oak Ridge National Laboratory, to address these concerns.

Poster IV - Physics, Security Applications, and Signal Processing - Thursday 9:30 - 10:30 am in Ballroom with Angela Di Fulvio

Low Cost Current Mode Data Acquisition Board

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A low-cost data acquisition control board for current mode operation was developed and tested. The board provides 4 independent data measuring channels running on current mode. Each channel can be configured with 500 integration selections and 2500 gain selections manually and digitally. The data from all 4 channels are sampled by a 32-bit micro-controller with onboard 16-bit high-speed ADCs with sample rates up to 1200 kpps/channel. The board also provides 22 general I/Os, which can be used to control mechanical components such as raster scanning tables, linear motion stages and rotating collimators. The micro-controller can be programed and controlled and powered with USB. Collected data can be stored in SD-card or real-time transfer with USB. With 3D printed shielded casing, the board costs less than $150 to make. The board can work with most scintillation detector. With an open system design, other modules can be added to this board to increase functionality. The board has been tested on several projects and different computers running Windows, Linux and MacOS. SDKs are available for custom data acquisition software developments.

Poster IV - Physics, Security Applications, and Signal Processing - Thursday 9:30 - 10:30 am in Ballroom with Angela Di Fulvio

A Channel Number Reduction Technique for SiPM Sensor Arrays by Using a Unity-Gain Amplifier

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This work presents a channel number reduction circuit for array-type SiPM-based radiation detectors while maintaining high quality pulse information including energy resolution. The major component of the proposed configuration called the bootstrap technique, a unity-gain amplifier exploiting the Miller effect, keep the same AC voltages of two sides of a detector, resulting in no effective detector capacitance between the nodes. This technique ideally allows combining channels without any performance degradation in terms of rise time and amplitude of signals that can be caused due to the accumulated capacitance when SiPM cells are shorted in parallel in a signal multiplexing scheme. In order to verify the configuration, we designed and built a test board inserting a unity-gain amplifier between a 16-pixel SiPM array and a conventional charge-sensitive amplifier as a preamplifier. The measured pulses at the output of the front-end system show that the bootstrap technique can successfully mitigate performance degradation of rise time and amplitude. This technique can be adopted in many applications that require a multiplexed readout of a large area of photodetectors, for instance, in cargo scanning technologies, radiation monitoring in nuclear plant facilities and advanced medical imaging instruments such as PET and SPECT.

Poster IV - Physics, Security Applications, and Signal Processing - Thursday 9:30 - 10:30 am in Ballroom with Angela Di Fulvio

RHBD Techniques to Minimize TID Effects from High Radiation Dose in Digital Integrated Circuits

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Seoul National University (1), Korea Atomic Energy Research Institute (2)

This work presents RHBD techniques of digital circuits such as inverters and flip flops mainly aimed for TID effect compensation. The proposed designs are expected to reduce influence of TID on currents of CMOS devices. Prior works reported that leakage current increase of NMOS devices is significantly larger than that of PMOS. From this observation, this work suggests following RHBD design topologies: a. stacked NMOS inverter which stacks NMOS devices in a pull down network, b. pseudo PMOS inverter which uses weak and always-on NMOS device as a pull down network, c. PMOS-only inverter which uses only PMOS devices in the inverter, and d. dummy transistor inverter which introduces dummy gates to surround the NMOS. By applying these topologies, we expect increase in inverter and flip flops lifetime under TID effects while minimizing additional design effort and complexity. The designed circuits are under fabrication in 180 nm CMOS process. In order to verify the radiation robustness, the chips including inverters and flip-flops based on the proposed topologies with various P-N ratios will be measured in an irradiation test facility. Since inverter and flip-flop are essential building blocks of digital systems, the proposed techniques can be widely exploited in various circuits that require reliable operation under radiation-emitting circumstances such as nuclear power plant and space environment. Keywords: RHBD, TID, flip-flop, stacking, pseudo-PMOS, dummy transistor, PMOS-only inverter.

Poster IV - Physics, Security Applications, and Signal Processing - Thursday 9:30 - 10:30 am in Ballroom with Angela Di Fulvio

Development of an Efficient Multiplexing Scheme for Multichannel Detection Systems Based on Organic Scintillators and Silicon Photomultipliers

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Many radiation detection applications require a large number of detectors, which frequently leads to complex and expensive hardware/software solutions. Therefore, it is beneficial to efficiently multiplex (as many as possible) detectors into a single data-readout channel to dramatically decrease the equipment cost while only marginally decreasing the system performance. This work demonstrates a multiplexing method based on mixing silicon photomultiplier pulses with sinusoids of varying and well-defined frequency. A prototype with several detector channels has been developed to clearly demonstrate the effectiveness of this multiplexing approach. Further, the effects of varying the frequency and amplitude of the mixed sinusoid on the frequency tagging efficiency, as well as other pulse characteristics, have been characterized. Specifically, the ability of silicon photomultipliers to provide effective pulse shape discrimination (PSD) when coupled to certain organic scintillators, despite significant altering of the pulse shape, has been demonstrated. In addition, PSD in the frequency domain using frequency gradient analysis has been investigated and the benefits of performing the pulse analysis in the frequency domain instead are shown to greatly benefit the aforementioned multiplexing approach. In the full paper, we will show that several PSD-capable organic scintillators can be multiplexed into a single digitizer channel without affecting the PSD performance for individual detectors. Also, it will be shown that each detector signal after multiplexing still carries the information on the signal origin; e.g., the position information is preserved, as well as the timing and PSD performance. This relatively simple multiplexing approach will dramatically decrease the number of readout channels for various multi-channel radiation detection systems, which will lead to major hardware-cost improvements at the expense of only minor PSD performance loss. This work has a potential to affect many existing and novel multi-channel detection systems that could benefit from the readout channel reduction and not just those based on organic scintillators.

Poster IV - Physics, Security Applications, and Signal Processing - Thursday 9:30 - 10:30 am in Ballroom with Angela Di Fulvio

Bayesian unmixing algorithms for identification of gamma sources using radiation portal monitors

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One major challenge with nuclear security measurements involves the installation of radiation portal monitors (RPMs) at border crossings. RPMs typically contain 3He proportional counters embedded in polyethylene for neutron detection, and slabs of polyvinyl-toluene (PVT) for gamma-ray detection. In the presence of natural background radiation, customs and border protection agents screen inbound vehicles and cargo container for suspicious levels of radiation relative to background and flag these for a more thorough secondary inspection in which the radiation source is located and identified. Although organic scintillators exhibit worse energy resolution compared to inorganic scintillators, they are relatively inexpensive and easy to operate. They thus appear as sensible candidates to enhance the deployment and democratize the use of radiation portal monitors for detection of gamma sources, provided that efficient and robust computational methods can be used to palliate their limited sensitivity/specificity. In this context of identification of a large variety of sources, including natural and medical sources, sensitive sources of particular interest, but also potentially new/unknown sources for which no reference measurement is available, statistical methods are particularly appealing for their ability to capture the random nature of the measurements. Among them, Bayesian methods form a generic framework allowing for uncertainty quantification and propagation, which is of prime interest for detection (of known and unknown sources), classification, and quantification of smuggled nuclear and radiological materials. In a previous work, we have demonstrated the potential benefits of Bayesian models and associated estimation algorithms with organic scintillators for the detection of single and mixed gamma sources with short measurement times. In this work, a library of pulse height distributions (PHDs) associated with single gamma sources including sources of potential interest and medical sources representative of nuisance sources is constructed from measurements using two different materials: liquid EJ-309 and stilbene crystal. We propose to compare the estimation performance of these two materials using previously developed algorithms. We will also introduce a new, faster, Bayesian algorithm and compare its estimation performance to the performance of the previous methods.

Poster IV - Physics, Security Applications, and Signal Processing - Thursday 9:30 - 10:30 am in Ballroom with Angela Di Fulvio

Application of Convolutional Neural Networks to Radiation Detection: An Empirical Study

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A Convolutional Neural Network is introduced as a solution to detect man-made radiation sources in a simulated urban environment with dynamic background. The dataset used describes a 2"x4"x16" Thallium-doped Sodium Iodide scintillator traversing an urban environment at a fixed velocity. Without temporal dependence between energy spectra and information of the environment, the implemented approach obtains a sensitivity of 80

Poster IV - Physics, Security Applications, and Signal Processing - Thursday 9:30 - 10:30 am in Ballroom with Angela Di Fulvio

Evaluation of Covariant Behavior of Experimental Quantities through Statistical Analysis of Matched Pairs of Pulse Height Data

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Understanding and proper treatment of correlated information is very important in measurement science because it is a common problem. Covariance, if unrecognized or ignored without justification, can lead to errors. Correlations can be introduced in many ways. Measurement procedures, assumptions, algorithms, operators, nuclear data, model mis-match and many other factors including physical variables such as environmental conditions can introduce co-dependences. In the current work, the correlation between a pair of measured data, namely the full energy or photo-peak (FEP) and the background continuum under the peak will be evaluated. Pulse height spectra were acquired using a High Purity Germanium spectrometer and multiple uranium enrichment standards supplied by New Brunswick Laboratories. The Uranium enrichment standards that were measured were the Certified Reference Materials (CRM) with ^{235}U fractional abundances ranging from 0.32 at% to 93.23 at%. The measurements were performed under near ideal conditions, taking precautions to minimize sources of systematic uncertainties. Under fixed geometrical measurement conditions the uranium enrichment, in atom fraction, of an optically thick chemical compound is directly proportional to the intensity of a -ray of a given energy (e.g. 185.7 keV) emitted directly following decay of ^{235}U and emerging out of the sample. The objectives of the measurement were to acquire high quality spectra that can be used to construct an enrichment meter calibration, and to utilize the full energy peak ratios to evaluate the limitations in the in the knowledge of the branching ratios of gamma lines emitted by uranium isotopes. Propagation of uncertainties and evaluation of covariances were of utmost concern in this work. Using a three Region of Interest (ROI) peak analysis method,

full energy peak areas (FEP) and continuum counts under the FEP were estimated from the gamma ray spectra. The FEP and continuum under the FEP are an associated pair of random variables because they are measured simultaneously and further are derived from the same pulse height spectrum. For a given measurement, the two random variables can be expected to be correlated because of various factors. Further, under well shielded conditions and for pure compounds a large part of the continuum under the FEP under the relatively lower energy gamma ray peaks from ^{235}U can be expected to be due to down-scattered higher energy gamma rays emitted by ^{238}U daughters. The ^{238}U abundance goes down (up) as enrichment goes up (down). So it is natural to ask the question as to what degree the FEP and the continuum under FEP are correlated. This work examines this question experimentally, for a given measurement item measured during a given measurement campaign, by acquiring a series of spectra close in time so that the sample linear correlation coefficient can be computed. For the eight uranium standards, covariant behavior of FEP and continuum from prominent gamma lines emitted by ^{235}U (143.76, 163.356, 185.715, 205.315 keV) were evaluated directly through statistical analysis of the matched data pairs.

Poster IV - Physics, Security Applications, and Signal Processing - Thursday 9:30 - 10:30 am in Ballroom with Angela Di Fulvio

On the Fabrication and Characterization of Heterogeneous Composite Neutron Detector with Triple-Pulse-Shape-Discrimination Capability

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This study describes the fabrication and characterization of a novel-triple-pulse-shape-discrimination (PSD)-capable composite neutron detector that utilizes fast neutron sensitive scintillating polyvinyl toluene (PVT) and ^{6}Li-glass rods. The objectives of the study are two-fold: 1) Assess the effect of PPO (primary dopant) loading on the mechanical properties of the PVT, and 2) fabricate a triple PSD-capable composite detector using PPO-doped PVT and ^{6}Li-glass rods. Thermal and mechanical characterization revealed that as the weight content of the PPO in PVT increased from 0% to 30%, the glass transition temperature (Tg) of the PVT decreased. The PVT with the highest weight content (30% PPO) exhibited PSD capabilities but also experienced a decrease in Tg to around 20C, making it mechanically soft and difficult to machine, both undesirable attributes in a composite detector. Therefore, a crosslinking agent (divinylbenzene, DVB) was introduced to control the mechanical properties while still exploiting the PSD capabilities of the high PPO content-doped PVT. The composite was then fabricated using the crosslinked PVT as the fast neutron and gamma sensitive material and ^{6}Li-glass rods as the thermal neutron sensitive material. The final composite had a glass weight content of 6% and dimensions of 2 x 2. UV/Vis spectroscopy and spectrofluorophotometry were used to characterize the optical properties of the composite. A ^{252}Cf source was used to test the PSD capabilities and intrinsic efficiency of the composite. The figure of merit was also calculated and defined as the ratio of separation between the full-width half-max of two peaks of interest. The figure of merit for the fast neutron and gamma peaks was measured at 0.58. The thermal neutrons and gammas peaks had a figure of merit of 2.17. The figure of merit for the fast and thermal neutron peaks was 1.56. ^{60}Co source was used to test the gamma rejection of the composite. Future work will continue to focus on effect of crosslinking on detector performance and fabrication of a shards-based triple PSD composite detector.

Poster IV - Physics, Security Applications, and Signal Processing - Thursday 9:30 - 10:30 am in Ballroom with Angela Di Fulvio

Development of a Sub-Miniature Gamma Camera for Multimodal Imaging System

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The main feature of multipurpose sub-millimeter gamma-ray (MSG) imaging module are the expandability of the gamma-ray detection part and field programmable gate array (FPGA)-based data acquisition (DAQ) system with an ethernet environment. However, there are three remaining elements to develop a sub-miniature gamma camera, which can be employed for various application, such as an intraoperative imaging, nondestructive imaging, and wearable personal monitoring. For this reasons, we developed a sub-miniature gamma camera for multipurpose imaging system with a function-based electronics module, temperature-compensation logic, and registered diverging collimator. First, the electronics were reorganized according to the function into MPPC base, signal processing, integrated power generator, and compact FPGA base board. Second, we developed the temperature-compensation logic, which consisted of a temperature sensor, DAC, and onboard programmable high-voltage generator. Third, we designed a registered diverging collimator, in order to widen the imaging area and improve the efficiency of the gamma camera. Initially, we verified the performance of the reorganized sub-miniature gamma-ray imaging module, flood images and energy spectrum were acquired using Tc-99m. The image exhibited 729 (2727) dots in the 841 (2929) scintillator pixels, and the peak-to-valley ratios were improved by 128% and 144%, compared with MSG. The energy resolution of the integrated spectrum of the 140-keV peak was 18.0%. For a larger stability, we aim to apply the temperature compensation logic into the imaging module. Moreover, we will design the registered diverging collimator for wide-area imaging.

Poster IV - Physics, Security Applications, and Signal Processing - Thursday 9:30 - 10:30 am in Ballroom with Angela Di Fulvio

Real-time performance analysis and parameter optimization for spectral anomaly detection

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Spectral anomaly detection algorithms determine whether a measured gamma-ray spectrum is consistent with prior measured background and "nuisance" sources such as granite or ice melt. In prior work, we developed a computationally efficient algorithm known as N-SCRAD to analyze data from mobile and unattended sensors. Here we improve the statistical framework underlying N-SCRAD so that parameters such as the foreground integration time can be optimized on the fly. We also develop a method to analyze the performance of the algorithm in real time via estimation of the minimum detectable activity.

Poster IV - Physics, Security Applications, and Signal Processing - Thursday 9:30 - 10:30 am in Ballroom with Angela Di Fulvio

Comparison of gamma ray localization using system matrixes obtained by either MCNP Simulations or Ray-driven Calculations for Coded-aperture imaging systems

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A coded-aperture system based on a large-area silicon photo-multiplier (SiPM) coupled with inorganic scintillator was developed for the gamma ray localization in the field of nuclear safety and security. Monte Carlo simulations of the performance were conducted to verify its performance. For the coded-aperture imaging (CAI) system, the mask was designed with an 11 rank modified uniformly redundant array (MURA), and the SiPM readout consisted of 12 x 12 pixels. A two-centimeter-thick tungsten mask was used to encode the gamma-ray field. The 144 pixels are read-out with a resistor-based charge-division circuit that reduces the readout outputs from 144 to four signals per module, from which the deposited energy and interaction position can be extracted. For image localization, maximum-likelihood expectation maximization (MLEM) and compress-sensing (CS) methods are used with either: (1) a system matrix generated both the Monte-Carlo N-Particle (MCNP) code, or (2) a mathematical system-matrix model utilizing a ray-driven method. In this paper, reconstructed images of gamma ray sources with various positions and activities were simulated and measured with the simulation tools and the physical system in order to compare and evaluate the relative strengths of the two different system matrix formulations. Both system matrixes generated by MCNP and ray-driven methods are effective in localizing isolated point sources; however, there are critical differences when several gamma sources with different strengths are in the field of view. Although the MCNP-based system matrix requires more processing time to generate, its more accurate incorporation of the competing gamma-ray interaction processes results in effective localization of multiple point sources. In contrast, the rapidly produced ray-driven reconstruction matrix demonstrates reduced accuracy in localizing extending distributions due to its simplified treatment of the particle transport, the magnitude of which is quantified in the paper.

Poster IV - Physics, Security Applications, and Signal Processing - Thursday 9:30 - 10:30 am in Ballroom with Angela Di Fulvio

Applications of Principal Component Analysis for Energy Reconstruction in Position-Sensitive Semiconductor Detectors

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Position-sensitive semiconductor detectors provide a combination of high energy and spatial resolution for characterizing gamma radiation sources. The accuracy of characterizations depends on the ability to estimate the energy deposition and position of distinct gamma-ray interactions that occur within the detector. In detectors with pixelated electrodes, observed signal amplitude depends on the position of interaction. Failure to completely compensate for this spatially non-uniform response contributes to systematic error and inhibits energy reconstruction. Digitization of electrode signals provides a wealth of information about a gamma-ray detection event time sequence. Sources of energy reconstruction systematic error manifest themselves in perturbations in the digitized signals, but human intuition often fails to translate these changes in the signal to optimal energy corrections. In order to extract information about underlying causes of systematic error for position-sensitive semiconductor detectors, principal component analysis is applied to digitized signals. The analysis provides a quantitative measure of the way in which electrode signals vary using sets of orthogonal bases. Correlations between these bases and energy deposition provide additional corrections for phenomena that were previously neglected. These methods are demonstrated with large-volume, pixelated CdZnTe detectors. Compared to conventional energy reconstruction techniques, corrections based on principal components improve 662 keV photopeak FWHM and FWTM by 8 and 15%, respectively, for single-pixel events.

Poster IV - Physics, Security Applications, and Signal Processing - Thursday 9:30 - 10:30 am in Ballroom with Angela Di Fulvio

Improving spatial reconstruction algorithms for near-field imaging

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A commercial portable germanium detector, the GeGI, has been developed by PHDS Co. for the use of wide-field and pinhole imaging. Initial experiments have tested the GeGIs imaging capabilities for near-field measurements and shown that the algorithms developed for wide-field imaging do not apply to near-field imaging. The end result is that images of sources in the near-field modality are not correctly calculated. One of the reasons why far-field algorithms do not apply to near-field imaging is that efficiency is a function of both photon energy and location of photon interaction. Work previously shown at the INMM Nuclear Materials Science, Processing and Signature Discovery Workshop has quantified the spatial variations of efficiency within an orthogonal strip detector. Presented at that workshop was an overall map, based on interaction location and energy deposition, of efficiency. This map allows improved confidence in the quantification of radiation sources measured in the near-field domain. Analysis of the previously collected dataset has been expanded to create new algorithms that determine the interaction position. The previous data set was collected through the use of a collimated radiation source that was rastered across the face of the detector. Thus, the detector response is measured based on a known photon interaction location. From this dataset, the inverse problem can be solved that then determines the photon interaction location based on the detector response. The algorithm is tested with a radiation beam sampled at an unknown location as well as an uncollimated point source. These algorithms are based on the Shockley-Ramo method of induced currents on the neighboring strips of the orthogonal strips of germanium. The algorithms developed are supported by electric field simulations of the germanium as well as Monte-Carlo simulations of the radiation transport. This work, coupled with the understanding of the spatially-dependent efficiency, will result in a significant improvement in the ability to preserve the isotopic heterogeneity when quantifying a heterogeneous or small source via gamma spectroscopy. Near-field imaging is important as it could be a fast, non-destructive method for determining the isotopic distribution within a heterogeneous sample. Understanding the heterogeneity of a sample can provide valuable information that would be lost if measured with traditional gamma-ray spectrometers. This work is a contribution to a PhD dissertation seeking to improve the triage of nuclear forensic samples by way of a portable germanium gamma-ray imager. In-field measurements that could quantify a heterogeneous isotopic distribution would help provide more timely information to the nuclear forensic analyst, and thus be an improvement over the current gamma-ray spectroscopy.

Poster IV - Physics, Security Applications, and Signal Processing - Thursday 9:30 - 10:30 am in Ballroom with Angela Di Fulvio

Near-field 3D Spherical Active Coded Aperture Gamma-ray Imaging

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The Portable Radiation Imaging Spectroscopy and Mapping (PRISM) system is a CdZnTe-based, hand-portable, dual-mode, omnidirectional spherical active coded aperture, designed to overcome field-of-view anisotropy in active two-plane systems. Equipped with a visual camera, light detection and ranging (LiDAR) unit, and inertial measurement unit (IMU), the system is capable of real-time contextual sensing, mapping, and tracking - facilitating free-moving 3D coded aperture and Compton imaging with scene data fusion in near real-time. Hand-held free-moving imagers are efficient search tools as they can overcome the inverse square law by moving much closer to potential sources than traditional static imagers. However, as the system is brought close to the source, near-field effects can begin to dominate and, if not accounted for in the reconstruction, can produce artifacts and additional blurring. By properly characterizing and utilizing the near-field effects, the artifacts can be removed and spatial resolution can be increased. In this work we describe the methods used to characterize the near-field effects and the subsequent improvements in imaging, specifically in the coded aperture domain. Results gathered from simulations and measurements with the prototype system will be shown.

Poster IV - Physics, Security Applications, and Signal Processing - Thursday 9:30 - 10:30 am in Ballroom with Angela Di Fulvio

Design and Construction of MATADOR: An Adaptive Time Encoded Imaging System

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Localization of radiological sources, and in particular searching for undeclared sources, is of interest to nuclear non-proliferation, international safeguards, and homeland security. To that end, the Mobile Adaptive Time-encoded Asymmetric Dual-particle One-D Rotating imager (MATADOR) is a system intended to detect and image radiological sources using time encoding. By implementing a cylindrical, dual-material mask that rotates around a single, non-position sensitive, PSD-capable detector, MATADOR leverages both neutron and gamma signals to reconstruct an image. Moreover, a x-y linear stage allows the detector to move freely to any x-y position inside the cylindrical mask during acquisition. This enables real-time, scenario specific adaptation of the mask and detector axis to improve imaging performance. For example, at the start of an acquisition, the detector may be placed at the center of the mask and collect some preliminary data to reconstruct a crude image. Given a rough localization of the source(s), the system can zoom into the area of interest by moving the detector directly away from the source and increasing the mask to detector distance. This improves angular resolution and generates a new view of the source while utilizing the same mask pattern. Adaptively changing the mask and detector arrangement during acquisition is a largely unexplored area of research, and accordingly, the system design presented here is intentionally highly flexible to easily explore new arrangements and algorithms. This instantiation of MATADOR is expected to have imaging resolution better than ~ 11 for fast neutrons while being mobile via a cart.

Poster IV - Physics, Security Applications, and Signal Processing - Thursday 9:30 - 10:30 am in Ballroom with Angela Di Fulvio

Developing of Dual Radiation Rotating Scattering Mask to Detect and Localize Neutron and Gamma Sources

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Locating a set of unidentified radiative sources can be a challenging feat. A possible way to extract the information on the location of a source is to use a maximum likelihood method assuming that the source of radiation is a point-like object. Assuming that radiation intensity depends on the distance from source rays to detector (R) as $\sim 1/R^2$, and by systematically detecting the radiation intensity at multiple locations, one could determine the most probable location of the source. If it is needed to differentiate sources of gamma radiation from sources of neutron radiation, two different types of detectors should be deployed. The gamma ray imaging system based on the rotating modulating collimator (RMC) approach was proposed for various gamma-imaging tasks in. RMC based systems were used before in astrophysical research, medical research, and in applications to address various homeland security problems. The development of advanced radiation detection systems with location and imaging capabilities for gamma and neutron sources of radiation is a needed technology. The objective of this research project is to develop and build laboratory prototype of the system capable of simultaneous the neutron and gamma source detection, identification, and location. In addition to measurement of gamma and neutron radiation fields, the system will allow for the locating and imaging of sources. For example, the neutron source location determination will be achieved using both the neutron signal and gamma signal emitted by a material surrounding neutron source. When irradiated by neutrons that surrounding material emits gamma rays during de-excitation processes. This gamma signature can be used together with observed neutron signal to locate neutron source. The proposed detection system is based on the novel neutron and gamma detector equipped with a specially designed Dual Radiation Rotating Scattering (DRRS) mask to identify, locate, and generate simultaneously images of a gamma and neutron sources. The DRRS mask consists of two different types of materials: one to scatter high-energy gamma rays, and the second one to scatter neutrons. Our MCNP model of the DRRS mask is developed in order to find the optimal configuration of scattering materials. The mask was fabricated and tested in laboratory environment with various neutron and gamma sources. To detect neutron and gamma signals simultaneously, we used a CLYC detector which is based on the elpasolite Cs2LiYCl6:Ce3+ (CLYC) (coupled with a photomultiplier tube) and an eMorpho digitizer. The CLYC detects neutrons via ^{6}Li(n,α)^{3}He reaction. Besides detector enabled neutron measurements due to pulse shape discrimination (PSD) properties: a fast core-to-valence (CVL) and a prompt Ce3+-decay which follows a gamma-ray action with the 1-ns and 50-ns decay constants, respectively; this CLYC detector system takes advantage of a neutron excitation with a cerium self-trapped excitation (Ce-STE) component with a lengthy 1,000-ns decay constant. References for the detectors and system methodology are given in the paper. Here, we will discuss results obtained in MCNP simulations, as well, as experimental results on the systems ability to detect and localize various neutron and gamma ray sources.

Poster IV - Physics, Security Applications, and Signal Processing - Thursday 9:30 - 10:30 am in Ballroom with Angela Di Fulvio

A coded aperture imager with DOI scintillators: Monte Carlo simulation

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In recent years, 3D position-sensitive scintillator detector which could measure depth-of-interaction (DOI) has been introduced. A number of DOI scintillator detectors coupled silicon photo-multipliers (SiPM) have been utilized for nuclear medicine and industrial applications. In this study, a coded aperture imager with DOI information in the scintillators was designed and its performance was evaluated by using Monte Carlo simulation. The DOI coded aperture imager consisted of a modified uniformly redundant array (MURA) and four layers of the 16 16 matrix of 2 mm cubic scintillator. In order to improve its performance, the reconstructed images from each layer were combined using hybrid maximum likelihood expectation maximization. The DOI coded aperture imager showed higher signal-to-noise ratios (SNRs) in the reconstructed images, as compared to conventional coded aperture imager with 2D pixelated scintillator. In addition, various types of scintillators were tested and compared with each other in terms of their angular resolution, detection efficiency, and SNRs.

Poster IV - Physics, Security Applications, and Signal Processing - Thursday 9:30 - 10:30 am in Ballroom with Angela Di Fulvio

A Study on the Construction Method of Color X-ray Image Using Different Energy Domain Images Obtained by Applying Different Filters

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A typical X-ray detector cannot distinguish the energy of an incident x-ray photon because it forms an image by charge integration. The x-ray image thus represents the density and thickness information of the object. At present, the distribution of the internal matter of the subject cannot be known through the x-ray image. In the industrial and medical field, it is essential to get additional information about internal materials from X-ray images. Over the past several decades, research has been actively conducted to acquire images that can distinguish materials inside the subject. There are various methods for substance discrimination such as dual energy CT, different filtration or stacked sandwich detectors. In this study, we propose a method to represent image information obtained by different filters on RGB channels. Images were acquired using Dexela 1512, an x-ray CMOS image sensor. Images were independently acquired with two sets of filters. Each set consisting of three filters to apply the proposed method to a pixel-by-pixel filter. Thus three filters are applied to four pixels to obtain an image, and these images are combined and displayed as one pixel. The purpose of this study is to identify the internal substances by combining the obtained information. Therefore, as described above, four images are obtained using different filters, but the experimental conditions are the same as a pixel-by-pixel filter condition such as resolution degradation. The first set of filters has the same material and different height and the second filter set has the same height and different materials. Images were taken four times per filter set. We obtained three images with different filters and one image without filters. The changing values due to the filter effect are expressed in the RGB channels. The images displayed on the RGB channels were able to express different materials that cannot be distinguished from ordinary x-ray images.

Poster IV - Physics, Security Applications, and Signal Processing - Thursday 9:30 - 10:30 am in Ballroom with Angela Di Fulvio

Scintillator Performance for Fast Neutron Transmission Radiography at the Los Alamos Neutron Science Center

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Radiography and computed tomography using fast neutrons can provide imaging contrast of large, dense, or heavily shielded materials that are unobtainable by x-rays or thermal neutrons. However, fast neutron imaging is difficult in practice due to the scarcity of fast neutron sources and the difficulty of producing fast neutron sensitive detectors, thus requiring specialized equipment for both the source and detector aspects of radiography. A world class neutron radiography and computed tomography facility has been developed at the Los Alamos Neutron Science Center to study the use of fast neutrons for non-destructive testing. Two fast neutron detector configurations were recently investigated for use in this facility: an a-Si flat panel with permanently mounted polypropylene plus ZnS:Cu scintillator, and a CCD camera optically coupled to various scintillator screens. Results of detector performance metrics, such as the modulation transfer function and the noise power spectrum, are presented. These metrics are reported as a function of shielding thicknesses, and as a function of the scintillator material chosen for use with the camera system.

Poster IV - Physics, Security Applications, and Signal Processing - Thursday 9:30 - 10:30 am in Ballroom with Angela Di Fulvio

Development of 4π sensitive Compton gamma imaging for detection of radioactive materials

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Detection of hidden or shielded radiation sources is highly demanded for anti-terrorism measures in homeland security and in decommissioning process of Fukushima Daiichi nuclear station. In Compton imaging, several measurements are required to obtain gamma-ray images for all direction due to its small field of view. For quick 3D imaging, we have developed 4π sensitive gamma-ray imager. Using a prototype based on a 3D pixel array CdTe detector, we demonstrated determination of radioactive source position such as ^{60}Co, ^{137}Cs, and natural uranium metal by 3D imaging. In addition, origin ensemble algorithm was applied to image reconstruction in the 4 π sensitive gamma ray imager to improve signal to background ratio in the gamma-ray image. The signal to background ratio in the reconstructed image by origin ensemble algorithm was improved by factor 3 than the simple back projection image. In addition, energy spectrum of gamma rays incident to the detector from a specific region can be extracted with less interference from other area.

Poster IV - Physics, Security Applications, and Signal Processing - Thursday 9:30 - 10:30 am in Ballroom with Angela Di Fulvio

Gamma-Ray Tracking for High Energy Gamma-ray Imaging in Pixelated CdZnTe

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Sequencing gamma-ray interactions within a detector system is an integral component of Compton imaging. In detectors with poor timing resolution compared to the time interval of successive interactions, algorithms which order gamma-ray interactions must be implemented using only energy and position information. This work examines previous algorithms and inspects interaction kinematics to increase the sequencing algorithm's speed and effectiveness. The proposed method, in which the first interaction is assumed to deposit the largest energy, has improved sequencing performance by greater than 20% for incident gamma-rays larger than 1 MeV with decreased computational cost in sequence reconstruction. Experimental results show an almost twofold increase in the signal to noise ratio (SNR) for simple backprojection images of a ^{22}Na source. Additional measurements of the 2.2 MeV gamma-ray from H^1 (n, γ) D^2 neutron capture shows the proposed algorithm's superior performance.

Poster IV - Physics, Security Applications, and Signal Processing - Thursday 9:30 - 10:30 am in Ballroom with Angela Di Fulvio

Characterization of a Large-Area iQID Imager for Safeguards Applications

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Environmental sampling and sample analysis by the International Atomic Energy Agency (IAEA) is a critical method for verifying declarations in international safeguards agreements. Quantitative Digital Autoradiography for Environmental Samples (QDARES) is a new method developed by Pacific Northwest National Laboratory (PNNL) to examine environmental swipe samples (ESS) prior to subsequent analysis. QDARES is completely passive and noninvasive for imaging beta and gamma emissions which readily transmit through the plastic bags containing the ESS. It can also image alpha particles. This technology is based on a portable, real-time, event-counting, high spatial resolution system called iQID (ionizing-radiation Quantum Imaging Detector). The iQID is made from commercial, off-the-shelf (COTS) components, including a scintillator in direct contact with a micro-channel plate (MCP) image intensifier and a lens for imaging the intensified scintillation events onto a CCD/CMOS camera. The QDARES large-area iQID includes the addition of a fiber-optic taper coupled to the image intensifier which increases the imaging area to a 10 cm square. In this paper, we describe new characterization results of the QDARES iQID, including spatial resolution, and minimum detectable activity (MDA) for several isotopes. With an effective pixel size of 60 m, the spatial resolution for alpha particles (Pu-239) was found to have a line spread function (LSF) full width half maximum (FWHM) of 94.7 m, whereas the spatial resolution for beta particles (C-14) was calculated as LSF FWHM of 146 m. The MDA was found to be 0.002 Bq/mm^2 over a one-hour measurement for Pu-239 alpha particles. For two beta sources, Sr-90/Y-90 and Tc-99, the MDAs were 0.004 and 0.012 Bq/mm^2 for a one-hour measurement, respectively. PNNL-SA-132674

Poster IV - Physics, Security Applications, and Signal Processing - Thursday 9:30 - 10:30 am in Ballroom with Angela Di Fulvio

Uranium enrichment determination using long-lived delayed neutron time emission

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The enrichment level of uranium is one of its most important characteristics. Enrichment is typically determined by measuring the ratio of the spontaneously emitted intrinsic γ rays from ^{235}U and ^{238}U. Another valuable, less exploited fission signature are long-lived β-delayed neutrons. These neutrons have been used to infer enrichment levels in the past, but opportunities to explore their full potential still exist. We experimentally demonstrate a new measurement technique that uses fast neutron active interrogation and a composite neutron scintillation detector to determine the enrichment level of uranium. A depleted uranium, a highly enriched uranium, and a tungsten sample were interrogated with 14.1 MeV neutrons. The long-lived buildup and decay of delayed neutrons were measured with a heterogeneous composite detector consisting of scintillating Li-glass rods and polyvinyl toluene. For the first time, the technique uses both the buildup and decay of β-delayed neutron emission as a means to determine enrichment and, because of excellent agreement with simulation, does not require the use of calibration standards. The results of the measurements and the performance of the technique will be presented.

Poster IV - Physics, Security Applications, and Signal Processing - Thursday 9:30 - 10:30 am in Ballroom with Angela Di Fulvio

Information driven safeguards approach for spent fuel dry cask storage using a new remote monitoring system

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With spent fuel pools reaching their design capacity and lack of a long term storage solution for spent nuclear fuel (SNF), dry cask storage is currently the practiced option for the nations nuclear power reactors. SNF could contain up to 20 significant quantities (SQ) of special nuclear material (SNM, in this case plutonium) in a single dry cask with 32 pressurized water reactor (PWR) assemblies. Dry cask storage allows for SNF to be stored that has been cooled in a pool for more than one year. However, a disadvantage of using dry casks from a safeguards perspective is that there is no effective way of re-verifying its contents after it has been sealed. Current safeguards measures rely on containment and surveillance (C&S) techniques primarily by using seals and optical surveillance systems. Nonetheless, if a seal is broken and the continuity of knowledge (CoK) on the content of the dry cask is lost, there is currently no method to re-verify the contents of a cask without opening it. This endeavor of opening the cask would expose one to high levels of radiation in addition to being expensive and undesirable. Hence, a new remote monitoring system (RMS) is proposed. RMS combines nondestructive assay (NDA) and C&S to collect and transmit data continuously to the authorities. RMS falls under Information Driven Safeguards (IDS) which is a vital portion of the International Atomic Energy Agencys (IAEA) analytical capability to prevent diversion of declared SNM and the absence of undeclared nuclear material and activities in a State. Hence, with continuous monitoring, the IAEA can fulfil its requirement of maintaining CoK and thus verifying the contents of the dry casks without opening them. Simulations of the RMS design for this study includes removal of SNF assemblies from the multipurpose canister (MPC) and substitution with dummy assemblies. Eight diversion scenarios are tested by removing either one or two SNF assemblies from different locations within the MPC. Also, a case where the concrete lid is open is tested. A reference run which includes all 32 SNF assemblies serves as the comparison for each of the diversion scenarios. Two fission chambers positioned geometrically above the SNF assemblies serve as the signal detectors. A false alarm probability, of 5% was set for the reference case to determine the threshold. Using the calculated threshold, non-detection probabilities, are calculated for each diversion scenario. Simulations of all eight diversion scenarios and the open lid scenario proved to have low non-detection probabilities, thus, serve as a proof of concept that even a single abrupt diversion of one SQ can be detected. In addition, 32 point sources of ^{252}Cf with source strengths mimicking that of SNF are simulated in a similar configuration within the MPC. This study is a proof of concept in order for an experiment to be conducted due to the tight regulations involving SNF. The same methodology is applied to calculate the non-detection probabilities and again it is concluded that even a single diversion will be detectable.

Poster IV - Physics, Security Applications, and Signal Processing - Thursday 9:30 - 10:30 am in Ballroom with Angela Di Fulvio

Nuclear disarmament verification via resonant phenomena

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The current regime of nuclear arms control agreements account for nuclear weapons indirectly via the limitation of nuclear-capable delivery systems. Here we present a technology for directly verifying the authenticity of nuclear warheads that leverages isotope-specific nuclear resonance phenomena to authenticate a warheads fissile components by comparing them to a previously authenticated template. All information is encrypted in the physical domain in a manner that amounts to a physical zero-knowledge proof system. Using Monte Carlo simulations, the system is shown to reveal no isotopic or geometric information about the weapon, while readily detecting hoaxing attempts. This nuclear technique can dramatically increase the reach and trustworthiness of future nuclear disarmament treaties.

Poster IV - Physics, Security Applications, and Signal Processing - Thursday 9:30 - 10:30 am in Ballroom with Angela Di Fulvio

Prompt Fission Neutron Anisotropy in Low-Multiplying Subcritical Pu Metal Assemblies

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Fission neutron anisotropy, due to the kinematics of the fission process has been thoroughly studied for non-multiplying and highly-multiplying subcritical Pu-metal assemblies (i.e. relatively long fission chains). These types of assemblies show an anisotropic distribution for single fission events, and an isotropic distribution for highly-multiplying assemblies. No data exists, however, that investigates the dependence of neutron anisotropy on multiplication for low-multiplying assemblies. Here, an array of 16 organic scintillators was used to measure weapons-grade Pu metal assemblies (95% 239Pu, by mass) exhibiting a leakage multiplication of less than two. Full angular distributions were extracted, and the fission neutron anisotropy was quantified with the ratio of neutron coincidences observed at 180 and 90. The results show that the angular distribution becomes more isotropic as the multiplication increases. Additionally, energy-angle correlations were also characterized showing that the angular distributions are more anisotropic when observing neutrons of higher energy.

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Algorithm development for the non destructive assay of nuclear waste

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Broad Energy Germanium detectors are routinely used for gamma ray spectroscopic analysis of nuclear waste streams to ascertain the type and relative activity of radionuclides that are present. Challenges arise when low activity radionuclides, which are of interest, are obscured by the presence of higher activity radionuclides. A key example is when Compton scattered gamma rays from ^{137}Cs conceal the presence of low energy gamma rays from ^{241}Am in the γ-ray spectrum. The Compton scattering events manifest in a continuum within the spectrum, elevating noise. Current methods to overcome this problem include mechanical Compton suppression systems. An example of such a system is one that uses a central Broad Energy Germanium detector surrounded by a guard ring of additional detectors. In this talk, the development of an algorithm to perform digital Compton suppression (DCS), together with its benefits in gamma-ray spectroscopy will be discussed. The development of the algorithm has been achieved by distinguishing low energy γ-rays that are absorbed in the surface region of the germanium detector, from Compton scattering events that are as a result of higher energy γ-rays interacting throughout the bulk of the detector. The technique exploits the knowledge of how the detector signal varies as a function of γ-ray interaction position, characterised by position-dependent charge collection times. The DCS algorithm will enable significantly reduced counting times together with improved low energy isotope identification when in the presence of large backgrounds, without the requirement for Compton suppression shielding. The DCS will also allow for a one detector system to be utilised. Presented results will include the dependence of charge collection times on both radius and depth (z) within a Broad Energy Germanium detector. Additionally, the results of the application of the DCS algorithm to data that has been acquired using a variety of point sources at Central Labs, National Nuclear Laboratory, Sellafield, UK will also be presented. The results show that the DCS algorithm is successful and has enabled an improvement in excess of 20% in the Minimum Detectable Activity of the detector. The improvement in the minimum detectable activity for the detector will provide waste producers with a tool that can allow them to re-characterise some of the low-level waste that falls close to the low regulatory lower boundary as very low-level waste. Rather than sending this waste to the Low Level Waste Repository in Cumbria, UK, the re-characterised very low-level waste can be diverted to licensed landfill sites or licensed incineration facilities. Other areas that the DCS may be applied to include applications in the fields of security measures and environmental monitoring.

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Detection of U-235 in uranium dioxide using TMFDs in active neutron interrogation and implications for HEU interdiction

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Abstract Special Nuclear Material (SNM) interdiction and detection using active interrogation is critical to counter nuclear terrorism and treaty verification, particularly for the detection of highly enriched uranium (HEU) in cargo situations. Threshold Energy Neutron Analysis (TENA) using Tensioned Metastable Fluid Detectors (TMFDs) has already proven a lower minimum detectable limit versus state of the art. Abstract Previous experimental work used 5 centrifugal TMFDs (CTMFDs) to unequivocably detect small amounts of U-235 in LEU. Ten additional CTMFDs were constructed and one "panel" of 5x3 units was commissioned. This was used to interrogate naturally and 10% enriched uranium, with and without a flexible boron shield. Detection of the $\sim$ 600g LEU mass with approximately 50 grams of U-235 content, occurred in 300 seconds with 1 sigma uncertainty. Abstract High fidelity simulations of this work were performed for insights regarding a realistic cargo scanning application. The simulation, using MCNP-Polimi and MCUNED described accurately Purdue's solid-target d-d neutron generator in deuteron energy spectrum and neutron energy, directional yield, and directionally dependent spectrum. This simulation, particularly in the energy-direction domain, was validated against Be(p, n) experiments performed at Edwards Accelerator Laboratory at Ohio University, and directional tests performed using Purdue's d-d neutron generator. These results verify that the large interrogating neutron detection efficiency gradient at approximately -3 bar is due to the detection of $\sim$ 2.5 MeV neutrons, and that the directionally dependent neutron spectrum is an important parameter of interest for optimization of the TENA method. Abstract The simulations also provided the fast fission to thermal fission ratio in TENA experiments. This has

implications for false alarm rate (if detection of LEU, NU, or DU would be considered a false alarm by border control agencies). The simulations indicate that, while no intentional moderation was introduced, biological shielding provides significant moderation of the interrogating neutrons. The fast neutron flux was 8 times higher upon the fissile object than the thermal flux, however the fast fission rate was 3 times lower than the thermal fission rate. Coupled with results showing a reduction in counts between experiments performed with and without flexible boron for thermal neutron removal, this shows that thermal neutrons are important for the TENA method. This also shows that the detection is of U-235 via its large thermal fission cross section, not of the relatively larger amount of U-238. This also shows that incidental neutron moderation, as might happen in a realistic cargo scanning situation, is acceptable and even advantageous for TENA. Abstract In performing this work, an improved estimate of the minimum detectable limit was developed, $\sim$ 50 g U-235 detectable using 15 CTMFDs in 5 minutes. However, there is interest in detection of 1 kg of HEU in a small amount of time with a probability of detection of 95% and probability of false alarm of 5% or less. This work represents technological achievements that enable a detection time of 1 kg HEU with the required PD and PFA to within 18 seconds. Abstract Additonal work utilizing time based active neutron interrogation techniques and acoustic TFMDs will also be discussed.

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Verification and Validation of Atmospheric Transport Models with the UF Training Reactor

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The University of Florida Training Reactor (UFTR) is a 100-kW ARGONAUT type reactor with a unique design such that a large volume of air passes through the core, producing and releasing significant quantities of ^{41}Ar. Once released, the radioargon is dispersed throughout the atmosphere and decays through a 1294 keV gamma ray emission. Since the UFTR can create this quantified, validated, and controlled ^{41}Ar plume for testing, we can utilize it to verify and validate atmospheric transport models (ATMs) for various nuclear applications. However, the significant production of ^{41}Ar is also the limiting constraint on full-power operation time for the UFTR. In order to improve the operation time, a newly verified and validated ATM can replace or become an alternative to the current dose model utilized by UFTR personnel. This model is very conservative, does not take into account the effects of nearby buildings, and does not output position and concentration information. At the university we have been testing an in-house Gaussian dispersion model along with the EPA approved AERMOD code. Both ATMs are coupled with MCNP6 and verified and validated with experimental data at different locations taken near the UFTR. The results from the ATMs and MCNP6 output estimated ^{41}Ar count rates which will be compared with experimental values. After testing each code, sensitivity analysis is performed in order to better understand the sources of error in each model.

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Measurement Challenges and Approaches in Cargo Scanning to Clear SNM with a 9 MV Bremsstrahlung Beam

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Some of the key difficulties in cargo scanning for shielded special nuclear material (SNM) sensing include the high radiation background environment, the inability to estimate the expected active background in a timeframe that matters, and the inefficiency in sensing SNM emissions in the presence of said background, especially since many of these emissions interact in the cargo. In response, gaining a better understanding for the following is key: the active background environment, challenges of measuring in this environment, whether components of this background could be estimated well enough in a time period of tens of seconds, and detector system designs that could more efficiently sense SNM emissions. In this paper, results are reported from measurements of x-rays and gammas observed using fused silica, BaF2, and CLYC detectors in the radiation environment produced by a Varian M9 Linac setup with collimation and dose ratio appropriate for cargo scanning. The paper also discusses said challenges as well as ideas and approaches informed by initial measurements and simulations that could lead to more rapid and robust clearing of cargo from shielded SNM.

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A PIXE/PIGE Facility at the 2-MV KIST Tandem Ion Accelerator: Design and Simulations

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Particle induced x-ray emission (PIXE) and Particle-induced gamma emission (PIGE), are powerful yet non-destructive elemental analysis techniques now used routinely by geologists, archaeologists, art conservators and others to help answer questions of provenience, dating and authenticity. The PIXE/PIGE system has been designed and evaluated the performance and characteristic by using the CAD program and Monte Carlo simulation packages (MCNP6, PHITS, and TRIM). The components of systems as a target vacuum chamber dimension, beams collimator and beams nozzle and Si(Li) and HPGe detectors were considered in the design. The design of the PIXE/PIGE will be turned to appropriate with the requirements of the purpose based on the simulated results before installation at the KIST Tandem Ion Accelerator (Republic of KOREA). Keywords: PIXE, PIGE, Simulation, Accelerator.

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Enrichment and Multiplication Estimation of Shielded Uranium Assemblies Under Active Interrogation Using Inverse Methods

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The current state of the art in characterization of uranium assemblies is represented by technologies such as Active Well Coincidence Counters (AWCC) and active tagged neutron systems such as the Nuclear Materials Identification System (NMIS) developed at Oak Ridge National Laboratories. Analysis of AWCC measurements relies on point kinetics, a simplified neutron transport model which is fast to calculate but neglects the geometric variations of uranium assemblies and shielding. Data taken by NMIS currently relies on detailed Monte Carlo studies using a full neutron transport model requiring several skilled scientists and long computation runs. Neither of these methods are suited for rapid, in-field use needed for nuclear material control and accountability, dismantlement and arms control. To bridge between point kinetics and a full 3D physics model of neutron transport, an image reconstruction framework has been developed which incorporates the response of neutrons created from induced fission chains.. This framework models the transmission of an initial neutron from active interrogation and calculates the probability for creating one or additional neutrons exiting the shielded assembly. The neutron multiplicity distribution is modelled by the fission probability and related to the neutron detection probabilities in an imaging plane. A spatial image of total neutron attenuation and the attenuation due to fission, which relates directly to uranium enrichment, is estimated using linear inverse methods. The estimation of the fission probability, relating to multiplication and affected by shielding and self-multiplication, can be estimated using non-linear inverse methods using derivatives provided by a closed form expression. Quantities such as enrichment, fissile mass, and multiplication can then be estimated in shielded and complex assemblies of uranium. The current results of this work will be presented for several different geometries, comparing Monte Carlo and point kinetics-based estimates.

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Overburden monitoring with muon detection

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Muon detection for overburden monitoring has been used for various applications, such as tracking volcanic activity and aquifer variations. There have also been efforts to use muons to detect tunnels, however the amount of noise in such measurements has prevented any significant features from being accurately located. A method of muon overburden monitoring, which includes background subtraction, is being developed to enable tunnels as small as 1.5 m in diameter to be identified. The proof of concept for this technique is being performed through simulations with GEANT4. A reconstruction method has been developed to analyze the large amounts of data generated and produce side-view images of the moun trajectories that allow for information about the tunnel position and size to be extracted. Details about the methodology and the results of a parameter study quantifying the effects of variations in the overburden on tunnel identification will be presented.

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New generation PIPS detector with improved efficiency for low energy beta counting

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Traditionally CANBERRAs Passivated, Implanted, Planar Silicon (PIPS) detectors have a high noise threshold ($\sim$ 125 keV for a 20cm^2 at 20C) as compared to gas flow detectors ($\sim$ 25keV) which are used in high efficiency alpha/beta counting applications. A reduction in low energy threshold would make PIPS detectors a great upgrade for many applications, e.g. alpha/beta counting, beta spectroscopy, and radiation monitoring systems. This work presents a new generation PIPS detector with a lower beta threshold comparable to gas filled detectors. A CAM PIPS detector with an area of 20 cm^2 and a thickness of 500 m is fabricated by the planar process using oxide passivation and photolithographic techniques for defining device geometries. Ion implantation is used to form the accurately controlled junctions necessary for low reverse leakage currents and thin entrance windows. Carbon-14 and Chlorine -36 with an endpoint of respectively 156 keV and 710 keV are selected for performance testing. The distance between the radiation source and detector was $\sim$ 2mm. The diameter of the sources are 100 cm^2 (C-14) and 20mm^2 (Cl-36). The generated signal is read out by a CANBERRA 2003BT charge-sensitive preamplifier and a CANBERRA Lynx MCA. The spectrum data was analyzed using CANBERRA Genie2000 software. The efficiency results are compared with a traditional PIPS detector with similar geometry conditions. The threshold of a detector is, among others determined by leakage current and capacity of the detector. Through pre-process material qualification, increased process control using life-time monitoring and the redesign of the detector geometry we are able to consistently reduce the leakage current by a factor of 20 (80nA to 4 nA) and set a new standard. Calculations show a significant decrease in low energy threshold from 125 keV to 30 keV and an increase in C-14 4π-efficiency from 5 to 17%. These calculation are confirmed with measurements: the threshold of the detector at room temperature was measured to be 26.5 keV. Measurements with a C-14 source and Cl-36 source at room temperature resulted in an 4π-efficiency of respectively 16% and 37%. This efficiency is on par with the gas flow detector which has 4π-efficiency of 20% (C-14) and 45% (Cl-36) as measured in an LB4200 low background system. This new generation PIPS detector is an upgrade from the gas flow detector in an alpha/beta counting system by eliminating the dependency on P-10 gas usage and has spectroscopic capabilities to perform radon compensation. Similarly the new PIPS detectors could be used in radiation monitoring applications where it is very beneficial to have spectrum that has low threshold for beta radiation.

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Determination of Neutron Flux Anisotropy from a Compact DT Generator and its Implications for Shielding Design

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Design and construction of radiation facilities involving deuterium-tritium (DT) neutron generators is often based on assumption of isotropic distribution of neutron flux around the generator. However, it has been shown in the past that the neutron flux around a neutron generator can be anisotropic. The anisotropy can result from a combination of the angular dependence of DT fusion reaction cross-section and the design of the generator tube. We first present results from characterization of a commercially available DT generator (Thermo Fisher Scientific, Model P211) by measuring the angular distribution of neutron flux using a liquid organic scintillator and confirm its anisotropy. We then use this flux information and construct a Monte Carlo simulation to examine the impact of anisotropy on the radiation shielding effectiveness by considering one practical example, where the shielding design is governed by incorrect assumption of isotropic flux. It is found that, although the shielding designed using the assumption of isotropy is acceptable for some orientations of generator, it can be inadequate for others.

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A Monte-Carlo simulation on changes of the leakage radiation of X-ray Collimator by various thicknesses of lead shields

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Changes of leakage radiation of the X-ray collimator are simulated by a Monte-Carlo simulation toolkit, GEANT4. Otherwise collimators simulated in other researches are quite simple model, in this paper, a real collimator including mirror to guide LED light, motors to handle system, case, DAP, and, of course, 1st and 2nd blades to guide X-ray is modeled in GEANT4 simulation geometry. To import CAD design of a real collimator, the open source library CADMesh is used. According to simulation results, most of leakage radiation is released through the opening areas of lead shields. Distributions of leakage radiation and shapes of lead shields are resembled to each other. When thickness of lead shield is decreased, values of leakage radiation are increased exponentially. Leakage radiation of real collimators with various thickness of lead shield is also measured to check simulation results. From experimental / simulation results, we can observe that simulation and real experiment have same tendency.

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The study of a small volume fast neutron source realized with the electrodisintegration reactions

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Besides the photonuclear reactions, electrons can also induce nuclear reactions through the exchange of virtual photons with a target nucleus when they pass the vicinity of it. The cross-section of electrodisintegration reactions is usually quite small and neglected by neutron users. However, when a high energy e-LINAC is available to deliver electrons that bombard the target, the number of virtual photons that will produce neutrons through the (gamma, n) reaction will also be increased. Thus, the (e, n) cross section can be gradually increased with the increasing electron energies. The underlying principles and simulation results of using (e, n) to realize neutron source with the high energy e-LINAC will be presented in this paper. The results indicate the (e, n) cross-section will surpass the (gamma, n) cross-section if the energy of electron is as high as decades of MeV. The (e, n) reaction will play a more important role to produce neutrons in the high electron energy region.

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The ABALONE Photosensor Technology

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The ABALONEÎTM Photosensor Technology (U.S. Pat. 9,064,678) has the capability of providing a modern, cost-effective, and uniquely robust photosensor, which provides sensitivity to visible/UV light, exceptional radio-purity (with all-quartz construction), $\sim$ 100 times lower afterpulsing noise, and significantly higher overall detection performance than prior art. Therefore, it can open new horizons in all application areas, including large experiments in fundamental science, as well as new types of scanners for both functional medical imaging and nuclear security. After an overview of our production technology, and a summary of 4 year-long stress tests, we will briefly discuss the ongoing, partly SBIR-supported R&D on the next-generation of neutrino, cosmic ray, and dark matter research projects, based on our large-scale integration solutions (U.S. Pat. 9,064,678 and U.S. Pat. Pending 2017-0123084-A1).

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Fast Timing Micropattern gaseous detector (FTM) simulations for future colliders and medical applications

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The present generation of Micro-Pattern Gaseous Detectors (MPGDs) are radiation hard, capable of dealing with rates of several MHz/cm^2, while exhibiting good spatial resolution (<50 μm), and the use of resistive materials can make them naturally spark protected at a modest time resolution of 5-10 ns, the Fast Timing MPGD (FTM) project seeks to improve the time resolution aiming at a time resolution of the order of 100-500 ps for the detection of muons at future colliders and photons for medical applications. The novel idea is to build a multi-layered detector, consisting of alternating drift and gain regions, using resistive coatings, such that signals from each multiplication stage can be read out by the external readout electrodes through capacitive coupling. The main advantage of this new device is the dramatic improvement of the timing provided by the competition of the ionization processes in the different drift regions, which can be exploited for fast timing in high rate environments as found at the high luminosity accelerators as well as for applications like medical imaging. Intensive simulations have been performed in order to determine the optimal prototype specifications such as: geometry, voltages, gas composition etc. Results for the timing, spatial and energy resolutions as well as detection efficiency will be presented.

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Research and Development of Cold Neutron Microscope in China

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Cold neutron microscope is considered as a very useful tool for non-constructively characterizing spent nuclear fuels in the nuclear energy industry worldwide. It consists of a neutron optics and a neutron imaging system. Currently, research groups from National Institute of Standards and Technology (NIST), USA and Japan Proton Accelerator Research Complex (J-PARC), Japan are working on building a neutron microscope based on a super(Wolter)-mirror coupling with a high spatial resolution neutron imaging system. In our group, two alternative methods for the neutron optics are being investigated. One is using a linear zone plate which is in principle able to focus cold neutrons with different wavelength into one focal point. The new design concept of the zone plate adopts the patented idea of a linear optical zone plate. With this idea, the new designed zone plate can improve the cold neutron focusing efficiency of at least 10. The other is employing the Kumakhov lens made of a new developed Ni-glass fiber capillary with a thin layer of Ni inside the inner wall of the capillary instead of a traditional glass capillary. Due to large reflectivity of such a Ni glass capillary for cold neutrons comparing with the regular one, the new Kumakhov lens can also improve the neutron focusing efficiency. In addition of the research about neutron optics, a new Gd scintillation glass fiber faceplate based high resolution cold neutron imaging detector has been successfully developed. The recent test shows that it has a spatial resolution of 14 microns and a detection efficiency of >94% for cold neutrons. The upgrades of its optical readout system and the fiber diameter of faceplate are under way. The new system is expected to have a micron-order resolution at the time time maintaining the high detection efficiency. The new results and research progress about cold neutron optics and imaging detector will be reported on the conference.

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Investigating the Temperature Dependence in Organic Scintillator Detectors

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Organic scintillator materials are widely used as radiation detectors, largely due to their ability to discrimination between radiation particle types by pulse shape. Previous work demonstrated that the scintillation response to radiation interactions varies with room temperature in anthracene. This paper expands this investigation by characterizing the scintillation response to neutron and gamma-ray interactions in five organic scintillator materials from 10 to 30C: EJ-309 liquid, solution-grown stilbene, SNL organic glass, LLNL PSD plastic, and p-terphenyl. Significant variation in the total light emitted and pulse shape are observed. These measurements demonstrate that the temperature dependence varies across materials in magnitude and behavior, raising the question of which material properties govern the temperature dependence.

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Irradiation of avalanche photodiodes to achieve increased gain in signal output

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Avalanche photodiodes (APDs) have a wide range of applications concerning radiation detection. This investigation examined the radiation resilience of a large area APD with 2 cm^2 active region exposed to 2 MeV protons. A microprobe provided both irradiation and measurement capabilities, with the latter using the Ion Beam Induced Charge (IBIC) technique. Typically, radiation damage produces adverse effects including increased dark current and decreased gain which result from changes in the semiconductor bandgap structure. However, in a sweep of variables including bias and fluence , it was observed that the APD response bucked the normal trends within a tight range of variable space. This occurred using a proton fluence of 6.4 x 10^{11} p+/cm^2 over a region of 1 x 10^4 m^2, with applied bias of 1000 V. In this case, the ratio of signal response from damaged versus undamaged regions, or charge collection efficiency (CCE), could be increased by more than 140%. The effects on dark current also showed reversal. After a series of irradiations made on a single diode, the cumulative radiation effects led to a 30% decrease in dark current at 1000 V bias. Additional tests show that damaged regions are susceptible to change after irradiation. Room-temperature annealing and even the presence of increased electric fields within the diode caused unexpected shifts in the detector response. This study shows that irradiation does not necessarily have detrimental effects. Under certain conditions, irradiation can further improve device performance.

Poster IV - Physics, Security Applications, and Signal Processing - Thursday 9:30 - 10:30 am in Ballroom with Angela Di Fulvio

On operational state classification of nuclear reactor facility by fusion of gaseous effluent measurements

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We consider the problem of inferring the on/off operational state of a nuclear reactor facility by using effluent release concentrations of three radioactive noble gases. These operational state inferences are important for the assessment of a nuclear facilitys compliance with safeguard agreements, which are critical to nonproliferation, safety, and security. Moreover, gaseous effluents continually collected at a facility's ventilation stack typically contain reactor by-products that are indicative of the facilitys operations. We examine ground truth measurements collected over a two-year period (2015 and 2016) at the High Flux Isotope Reactor (HFIR), Oak Ridge National Laboratory (ORNL), and apply fuser methods to individual, pairs, and all three gaseous effluent types in order to assess the effectiveness of fusing multiple effluent types. The classification methods we study are within the areas of pattern recognition, statistics, information fusion, and machine learning. Specifically, we employ fusers based on simple-threshold majority rule, Chow's pattern recognition function, Poisson-distributed radiation counts models, correlation coefficient method, Fisher's combined probability test, and supervised machine learning classifiers. These classifiers and fusers span a broad spectrum of areas and require different levels of development and adaptations to be used with effluent measurements. We exploit (in different ways) the properties of physics-based models in tailoring Poisson, correlation coefficient, and Fisher fusers to the specific characteristics of radioactive gaseous effluents. The other methods are primarily data-driven. In particular, thresholds and probability estimates used in threshold classifiers and Chow fuser, respectively, do not directly exploit the physics characteristics of radioactive effluents. Moreover, machine learning methods are further removed from the physics models in that measurements are treated as pure data. The performance of these classifiers and fusers, when applied to 2015 datasets, shows that incorporating physics-based models provides classifiers that can outperform simple majority rule, Chow fuser, and machine learning methods, as well as when they are applied to individual and pairs of effluent types. Thus, this methodology of incorporating physics-based models provides classifiers that can outperform other methods, and further refinements are possible. Nevertheless, when we test a subset of fusers on 2016 data, there is a decrease in detection performance compared to 2015 results. We present our on-going efforts by comparing dataset distributions and Bayes error estimates for these two years. We explore similarities between 2015 and 2016 effluents and estimate the minimum total error achieved by a classification method, based on these datasets. We first examine the data using quantile-quantile plots to assesses whether 2015 on/off effluent datasets have similar distributions to those of 2016. We then estimate the Bayes error which characterizes the minimum total error achievable by any threshold-based classifier, and hence indicates the inherent complexity of the underlying classification task. Our results show some variability within a subset of effluent types and operational states, which leads to a slight difference in minimum total error. This increase in Bayes error indicates that classification complexity of 2016 data is higher than that of 2015 and provides an explanation for the performance decrease of classification methods.

Poster IV - Physics, Security Applications, and Signal Processing - Thursday 9:30 - 10:30 am in Ballroom with Angela Di Fulvio

The development of an advanced airborne gamma-ray spectrometry system and its applications

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The airborne gamma spectrometry technique is widely used for environmental monitoring or use in emergency response, as well as for studies of the environment of nuclear sites for reference purposes. An advanced airborne gamma- ray spectrometry system has been developed. The system used consisted of optional volume NaI (Tl) spectrometer, an electronics rack containing power supplies and computer, and GPS systems for logging the aircraft position and navigation. The array detectors were designed with optional volume NaI (Tl) of 4 l, 8 l, 16 l, 32l, or some of them to be used in different settings, such as car or unmanned aircraft and airborne surveys, and on the different scenarios. Spectra data are recorded in 1024 channels from 50 KeV to 3 MeV for each individual detector. Optional one or two self-adjustment-stabilization spectrum loops were designed for spectrum stability. Real-time stabilization on natural radioactive elements, 2614KeV (^{208}Tl), or/ and 1460KeV (^{40}K) and stabilization time of less than 30 seconds. An area of nuclear sites has been flown for testing the system feature and radioactive mapping. The area covered 1.5km by 6.5km. The system was installed in a helicopter. The calibrations of the system have been carried out under well-controlled conditions in the metrology station of the nuclear industry. The helicopter was flown at an altitude above the terrain of 80 m. Line direction is North-South.The normal line spacing was 50 m and the velocity was around 120 km/h. Data were recorded each second together with GPS coordinates, and then processed to calculate nuclide radioactivity and gamma -ray dose rate for mapping. The results show the background distribution of the gamma-ray dose rate reflects local geology. Against the background, three localized hot spots observed in the nuclear sites attributed to the solid waste storage, the liquid waste tank and the vent-pipe of known facilities. The data sets also serve as a reference against which future changes can be measured. The authors would like to acknowledge the Ministry of Environment Protection and the Ministry of Science and Technology for the financial support, and the China Institute of Atomic Energy for their contributions. We would like to thank Mr. Pan Ziqiang for his technical supervision.

Poster IV - Physics, Security Applications, and Signal Processing - Thursday 9:30 - 10:30 am in Ballroom with Angela Di Fulvio

Development of innovative radiation detection and instrumentation techniques and assessment methods for Radiological Dispersive Device (RDD)

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The main focus of the research is to combine radiation technology with Unmanned Aerial Vehicle (UAV) technology to generate a UAV with the capabilities to assist first responders when the situation calls for a radiological assessment. This would generally occur if a Radiological Dispersive Device (RDD) has been detonated. A number of technical issues related to both radiation physics and UAV flight will be discussed over the course of the research, including the most prolific source of radionuclides used in the RDDs which happen to be Cesium-137 and Cobalt-60. When these radionuclides decay they both generate beta and gamma radiation which have a range of 10-30 feet. It is by this calculation, that the final UAV iteration must be capable of flying within 10 feet of the ground at all times and maintain steady, level flight even with ground effects and other perturbations coming into play. A focus on the detector is the main goal behind this research. It is felt that the integration between detector and drone will be straightforward due in large part to the UAV hobbyist community. Using current detector technologies, an innovative method of combining UAV and radiation technology is being investigated. This is detector has the ability to recognize individual radionuclides and transmit this data to a static field location. Two main objectives have been identified that will further the overall effectiveness of the research: (1) increase the currently available detectors ability to distinguish between a wider range of radionuclides and (2) to concentrate the detectors overall size and weight, which in effect will make the UAV system more stable. The mechanism to remotely detect and visualize effected RDD detonated areas remains a subset yet fully explored. It is because of this, the research currently being pursued will have a focus on a smaller, more capable detector along with the ability for all relevant information to be overlaid in a user worn goggle system which can currently be found in the Drone racing community. The goggle system would be used so the user/first responder would not need a secondary laptop to visualize what the drone sees.

Poster IV - Physics, Security Applications, and Signal Processing - Thursday 9:30 - 10:30 am in Ballroom with Angela Di Fulvio

^{40}K Background Suppression in KSr_2I_5:Eu^{2+} Scintillators

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The use of a Europium activator in inorganic scintillators results in a variable output response through the shaping electronics that results in high energy tailing and a reduced energy resolution. Further, for a newer scintillator, KSr_2I_5:Eu^{2+}, the problem is further expounded by its $\sim$ 6.5 Bq/cm^3 intrinsic radioactivity. In this paper, we present a novel background suppression algorithm that removes a significant portion of the background during low-to-moderate energy gamma radiation counting, where the transient response is utilized to select only part of the crystal volume for sensing. Current computational and experimental efforts to fully exploit this novel technique will be presented.

Poster IV - Physics, Security Applications, and Signal Processing - Thursday 9:30 - 10:30 am in Ballroom with Angela Di Fulvio

Design Optimization Studies for Hemispherical Rotational Modulation Collimator (H-RMC)

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The Rotational Modulation Collimator (RMC) is a simple and useful imaging system which enables to track the orphan sources locations. The advantages of the image acquisition using the RMC is to obtain the image-information based on the non-position sensitive detector. Since the image using the RMC is based on the information modulated with time, which is obtained from detector, position information of the radiation source can be obtained without using a position sensitive detector. However, since typical RMC had a limitation having low FOV($\sim$ 20), hemispherical RMC (H-RMC) was proposed for enlarging FOV into 2. In present study, we performed optimization of collimator masks for H-RMC system. We first configured Hemispherical RMC system by using MCNP6. Various masks were researched by according to varying the slit/slat interval and diameter of the mask. Inner diameter of inner collimator was set to 5 cm, 10 cm, 15 cm each and the clearance between slit and slat was set to 4, 7, 10 respectively while inner diameter of outer mask was set to 19 cm fixed. Thickness of collimator masks were set to 0.5cm-thick lead. In MCNP6 simulation, a point source of 356 keV gamma rays was used and set to 30, 60, 90 degrees based on central axis of mask, and the distance between collimator front end and source was set to 100cm. Detector used here is a CZT (cadmium zinc telluride) semiconductor detector which dimension is 111 cm$\hat{3}$. Mask performance was evaluated by the three criteria such as modulation efficiency, transmission efficiency and spatial resolution. Modulation efficiency was obtained as a ratio of maximum counts and minimum counts. Transmission efficiency was obtained as a mean value of counts per rotation angle. And spatial resolution was obtained by comparing two modulation patterns. One was obtained from placing radiation source at the angle of 30 alone, and the other was obtained from placing two radiation sources at the angle of 30and 31 each with respect to collimator central axis. The larger the difference exists, the better the spatial resolution is. By analyzing those three criteria comprehensively, we finally found out the best performance was obtained when inner collimators inner diameter is 5cm and the slit/slat is 7 degrees. In present study, we demonstrated feasibility of the hemispherical design by obtaining pattern through Monte Carlo simulation. As the following study, analytical model is developing based on the MCNP results in order to acquire wide range of modulation patterns in a short period of time. MATLAB will be used to configure mathematical model of the hemispherical RMC. By counting the number of detector pixels seen at the source position during 360 degrees of rotation, we will generate modulation pattern obtained by MATLAB and compare with MCNP result to verify its integrity. Also, by using the analytic model, image reconstruction process applied with MLEM algorithm will be implemented henceforth. Detailed results of analytic model and subsequent work would be presented at the conference. Electronic mail: gkim01@sejong.ac.kr

Poster IV - Physics, Security Applications, and Signal Processing - Thursday 9:30 - 10:30 am in Ballroom with Angela Di Fulvio

Study on Zinc Tungstate Crystals for Dark Matter Search

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ZnWO4 single crystals with diameters of $\sim$ 0.5 inch were grown by the Czochralski process as anisotropic scintillation material for Dark Mater search. Since we discuss the mechanism of anisotropic scintillation, we show the uniformities of material composition and optical properties such as transmittances, light outputs for each orientation and several positions (i.e. seed side and tail side). As results, we find good uniformities of material composition and transmittance for the sample, while anisotropic scintillation properties were observed; light outputs of the crystal irradiated with alpha rays into c-axis orientation was larger than other direction. We discuss the mechanism of this anisotropic effect using also crystal structure data and other information in this presentation.

Poster IV - Physics, Security Applications, and Signal Processing - Thursday 9:30 - 10:30 am in Ballroom with Angela Di Fulvio

Development of high efficiency multi-element gaseous microdosimetric detector

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We present development of a high efficiency multi-element gaseous neutron dosimeter using the THick Gas Electron Multiplier (THGEM). The detector is aimed at real-time neutron dosimetry, particularly for weak fields. Nuclear energy workers are exposed to mixed neutron-gamma fields, which make real-time dose measurements challenging. The traditional tissue-equivalent proportional counters have suffered in measuring weak neutron fields due to their low detection efficiencies in contrast to popular moderator-based neutron dosimeters. To overcome this shortcoming, the idea of building a multi-element detector, dividing the gaseous sensitive volume into many smaller volumes, was proposed [1]. However, only a few multi-element detectors have been attempted due to the complexity of the detector structure [2]. Our prototype THGEM multi-element detector consists of three alternating layers of tissue-equivalent plastic hexagons and each layer houses a hexagonal array of seven cylindrical gas cavities with equal heights and diameters of 17 mm, which resulted in 21 gaseous sensitive volumes. The absence of the wire electrode structure made building a multi-element detector simple and easy with THGEM [3]. Following the prototype detector, a high efficiency multi-element neutron dosimeter consisting of 95 sensitive volumes was recently constructed. Its signal performance and dosimetric response are currently under investigation using the McMaster Tandetron ^{7}Li(p,n) neutron fields. Monte Carlo simulation of the detector response by MCNP6 will also be presented. [1] H. Rossi, Multi-element dosimeters for radiation protection measurements, Health Physics, vol. 44, no.4, pp. 403-405, 1983. [2] P. Kliauga, H. H. Rossi, G. Johnson, A multi-element proportional counter for radiation protection measurements. Health Phys 57(4):631. [3] Z. Anjomani, A.R. Hanu, W.V. Prestwich, and S.H. Byun, Monte Carlo design study for thick gas electron multiplier-based multi-element microdosimetric detector, Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, vol. 757, pp. 67-74, 2014.

Poster IV - Physics, Security Applications, and Signal Processing - Thursday 9:30 - 10:30 am in Ballroom with Angela Di Fulvio

Automated Drones for Radiation Source Searching with Reinforcement Learning

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Anomalous radiation source detection in urban environment is challenging due to the complex nature of background radiation. When a suspicious area is determined, a radiation survey is usually carried out to search for anomalous radiation sources. To deliver a comprehensive and efficient survey, different survey approaches have been studied such as manually scan the area by human or human operated robots, as well as automatically scan the area with robots under the navigation of pre-defined survey paths. However, these approaches either require human efforts or are not efficient and flexible enough to adjust survey paths based on recent measurements. Recent developments of reinforcement learning and drone technologies provide an alternative data-driven solution to conduct radiation detection tasks with zero human intervention. Reinforcement learning studies the problem of how agents ought to take the optimized action so that a goal can be achieved efficiently. It has shown great success in applications including games, driving vehicles, and controlling robots to name a few. Drones are light-weighted, fast, and efficient in carrying out field surveys. This paper integrates a drone, a radiation detector, and reinforcement learning into an automated radiation source detection platform such that it automatically searches for radiation sources efficiently without any human intervention. In this paper, we introduce the hardware components of the automated radiation source detection platform, and present preliminary results of applying reinforcement learning to navigate the drone for automated radiation source detection.

Poster IV - Physics, Security Applications, and Signal Processing - Thursday 9:30 - 10:30 am in Ballroom with Angela Di Fulvio

Conversion Electron Probabilities of Emission Per Decay for Isotopic Analysis of Special Nuclear Material

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Special nuclear material (SNM) isotopes primarily decay via alpha particle emission, making alpha spectroscopy the most common radiometric measurement technique. However, alpha spectroscopy cannot distinguish, for example ^{239}Pu and ^{240}Pu peaks, peaks without peak deconvolution. Conversion electron spectroscopy offers complimentary information relative to alpha spectroscopy by allowing SNM isotope quantification possibly without peak deconvolution techniques. Currently, probabilities of emission per decay for SNM conversion electrons have only been theoretically determined. Silicon drift detectors (SDD) potentially offer sufficient energy resolution to experimentally quantify these probabilities for SNM isotopic analysis. Conversion electron spectra were collected using a silicon drift detector (SDD) mounted in a conflat vacuum chamber. The chamber was evacuated to 10^{-6} Torr using a turbo pump system. Conversion electron plus x-ray spectra were collected with an unshielded source. X-ray only spectra are then acquired using the same setup with a conversion electron shield between the source and detector. The x-ray only spectrum was subsequently subtracted from the unshielded source spectrum to obtain a conversion electron spectrum. Conversion electron probabilities of emission per decay were within 30% of theoretical values for M- and N-shells of the 51.6 keV conversion electron for 239Pu. L-shell conversion electrons were experimentally 92% greater than theoretical results; however, continuum subtraction and signal-to-noise optimization are likely to improve these results. Besides the nuclear safeguards and forensics applications, these data indicate that probability of emission per decay for SNM isotopes can be experimentally obtained using an SDD.

Poster IV - Physics, Security Applications, and Signal Processing - Thursday 9:30 - 10:30 am in Ballroom with Angela Di Fulvio

Energy Calibration of β/γ Events in Low Temperature Detection for Crystal-based Neutrinoless Double Beta Decay Experiment

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Advanced Molybdenum-based Rare-process Experiment (AMoRE) is an international collaboration searching for the neutrinoless double beta decay ($0\nu\ \beta\ \beta$) of ^{100}Mo. It utilizes metallic magnetic calorimeters (MMCs) in the detection of radioactive decay in the enriched $^{40}Ca^{100}MoO_4$ crystals at milli-kelvin temperature. Due to its high linearity and high precision, MMCs allow high resolution measurement of the radiation energy of the rare event. In this presentation, we introduce a systematic study of energy calibration of β/γ events and an estimation of energy resolution near the region of interest (ROI) for AMoRE-Pilot experiment, the commissioning phase of the AMoRE experiment that is currently running in the 700-meter-deep Yangyang Underground Laboratory (Y2L) in South Korea.

Poster IV - Physics, Security Applications, and Signal Processing - Thursday 9:30 - 10:30 am in Ballroom with Angela Di Fulvio

Characterisation, Performance Assessment and Improvement of Small Anode Germanium (SAGe) Well Detector for Environmental Radio-assay Applications using Pulse Shape Analysis.

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In applications such as environmental gamma-ray spectroscopy, a detector with high efficiency as well as excellent energy resolution is required. This requirement is needed for accurate assessment, identification and quantification of radionuclides present in any particular sample of interest. The characterisation of a SAGe well detector has been performed experimentally to assess its spectroscopic and position-dependent signal formation characteristics. The energy resolution and sample fill depth-dependent efficiency inside the detectors well have been measured. The peculiarity of the SAGe well detector geometry and its point-like P+ contact configuration gives rise to signals that are position dependent. The front and side of the detector was irradiated with a collimated beam of gamma-ray to obtain information for pulse shape analysis (PSA). The collimated gamma-ray source used is mounted on a fully automated scanning system. The detector preamplifier signals are fully digitised using a Caen v1724 100MHz 14bits digitiser and stored for offline processing. The digitised data have been used to extract the risetimes for signals generated at different regions within the germanium crystals. Since low energy gamma-rays incident on the crystal deposit all of their energy in the crystal near the surface, the position dependent signal risetime is then used to implement a discrimination algorithm to eliminate low energy interactions deep inside the crystal thereby improving the spectroscopic performance of the detector. In this work, we have reported the measured detector properties, investigated its signal characteristics and applied PSA to discriminate low energy interactions deep inside the crystals with the goal to improve the detection, sensitivity and quantification of gamma radioactivity in a sample.

6.4.4 Space and Nuclear Physics Applications (Thursday 10:30 - 12:00 pm in Mendelssohn with Zhong He)

Space and Nuclear Physics Applications - Thursday 10:30 - 12:00 pm in Mendelssohn with Zhong He

High Energy Photon Detectors in the Era of Gravitational-Wave Multi-Messenger Astronomy

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The era of gravitational-wave multi-messenger astronomy began on August 17, 2017 when the LIGO and Virgo interferometers detected gravitational waves from the coalescence of neutron stars, nearly simultaneously with detection of gamma rays by the Fermi GBM and INTEGRAL SPI-ACS satellite instruments. That coincident detection not only spurred intense follow-up by other astronomical telescopes across the full electromagnetic spectrum (and in neutrinos), but also allowed exceedingly precise testing of General Relativity. The GW170817 / GRB170817A discovery and follow-up will be presented, with highlighting of the role of space-based gamma-ray and X-ray detectors. The importance of maintaining space-based high energy photon detectors in the coming decade will also be discussed.

Space and Nuclear Physics Applications - Thursday 10:30 - 12:00 pm in Mendelssohn with Zhong He

High Resolution Mapping of Large-Area Pixelated CZT Detector Planes

Allen, Branden (1), Basak, Arkadip (1), Hong, Jaesub (1), Violette, Dan (1), Grindlay, Jonathan (1), Miyasaka, Hiromasa (2), Barthelmy, Scott (3), Harrison, Fiona (2)

Harvard College Observatory (1), California Institute of Technology (2), NASA Goddard Spaceflight Center (3)

The High-Resolution Energetic X-ray Imager (HREXI) program, a follow-on to our ProtoEXIST2 (P2) program, was initiated for the development of a space-qualified, large area detector plane architecture for broad-band (3 200 keV) coded aperture imaging with close-tiled CdZnTe (CZT) detectors. Our HREXI technology development is developing a readout ASIC with 32 x 32 pixel inputs (eventually 64 x 64 pixels) that are epoxy-bonded to to the corresponding array of anode pads on each 20 x 20 x 3mm CZT crystal. The ASIC is both controlled and readout from below by through silicon vias (TSVs) that eliminate the need for fragile wire bonds and the inter-pixel gaps they require. A close-tiled array of 2 x 2 CZT/ASICs are then flip-chip bonded to a common detector crystal array (DCA) readout board, and DCAs are close-tiled on an optical bench to fill the detector plane. This CZT readout and packaging can be scaled to mass production and lower integration/testing costs for many applications. Our motivation is to develop a NASA mission for a constellation of SmallSat coded aperture telescopes in Low Earth Orbit for simultaneous X-ray imaging of the full sky with high spatial and spectral resolution to discover and study black hole transients. We are currently developing a smaller CubeSat Engineering Model as a prototype for such a future mission. Such a mission, at (moderately) low cost, is only possible if each CZT detector plane and sub-systems can be integrated, calibrated and mapped quickly and at relatively low cost. To accomplish this, we have designed and commissioned a scanning beamline equipped with a 50 kV X-ray tube source and a tungsten mask containing 100 um x 100 um square apertures with a 1 cm x 1 cm pitch mounted to a precision XY table for rapid ($\sim$ 1 day) scanning of the entire P2 detector plane and CZT pixel (600um) mapping at the 100 um scale. We discuss the long term performance stability of the P2 imager (flown on our last balloon flight in 2012), present the full 2D maps at 100 um resolution of the P2 detector plane, and compare these results to previous sub-pixel characterizations of the P2 detector conducted with long duration ($\sim$ 3 weeks!) sweeps of a 1D-collimated Am-241 source. Additionally, we discuss future utilization of these mapping techniques and the scanning beamline for use in our program and any which require the swift mass production, calibration and deployment of large numbers of CZT detector planes.

Space and Nuclear Physics Applications - Thursday 10:30 - 12:00 pm in Mendelssohn with Zhong He

Radiation Transport Calculations Supporting the Development of a Compton Imager for Planetary Science Gamma-ray Spectroscopy

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Gamma ray spectroscopy has been proposed as a means of identifying water-ice on the Martian surface by landers, instrumentation in the atmosphere, or satellites in orbit. To date, a variety of instruments have been used to conduct planetary gamma-ray spectroscopy, however each system suffers from either poor energy resolution, lack of stopping power or require low-temperature operation. Pixilated CdZnTe (CZT) detectors are being analyzed to overcome these issues because they possess a high stopping power, high-energy resolution, room temperature operation, no intrinsic background, and the capability to reject noise through imaging techniques such as Compton imaging. Current gamma ray spectroscopy techniques to identify the presence of water involve identifying the 2.2 MeV gamma created through thermal neutron capture with hydrogen. The production rate of these gamma rays is dependent on the neutron population within the Martian soil surrounding the water spot which is driven by galactic cosmic ray (GCR) interactions with the planetary surface. In order to understand the gamma-ray signal created by these GCR interactions, the radiation transport code MCNP6 has been used to develop a realistic model to simulate GCR interactions within the Martian surface and quantify the resultant equilibrium neutron density. Simulation details such as materials, geometry, sources, and physics options are discussed. Results are presented for the neutron production rate, flux, and number density within the Martian soil. Furthermore, the effective area of the Polaris array has been investigated to evaluate the performance of pixelated CZT detectors for planetary science and results are compared to the Mars Odyssey HPGe detector.

Space and Nuclear Physics Applications - Thursday 10:30 - 12:00 pm in Mendelssohn with Zhong He

Time Projection Chamber (TPC) Detectors for Nuclear Astrophysics Studies With Gamma-Beams.

Gai, Moshe (1)

University of Connecticut (1)

The development of gamma-ray beams in the USA at the HIgS facility in Duke University [1], and the soon to be inaugurated ELI-NP gamma-beam facility in Bucharest, Romania [2], present new opportunities for studies in nuclear astrophysics; most importantly address the four decades old problem of oxygen formation in stellar helium burning via the 12C(a,g) reaction [3]. The use of gamma-beam is based on detailed balance that allow us to measure the 12C(a,g) reaction by measuring the dissociation of 16O in the 16O(g,a) reaction. Time Projection Chamber (TPC) detectors operating at low pressure (100 torr) are ideally suited for measurement with gamma-ray beam, since they serve as both the target and the detector, leading to close to 100% detection efficiency. The UConn-HIgS Optical Readout TPC (O-TPC) [4], operating at 100 torr with the CO_2(80%) + N_2(20%) gas mixture has been installed and was already used in several measurements. It uses an opto-electronic chain to record events of the dissociation of 12C and 16O. The detector entire volume has been calibrated using 3.18 MeV alpha-particles from a standard 148Gd calibration source. The recorded track pictures are analyzed using pattern recognition and time projection line shape analysis to remove background events from the dissociation of 14N in the 14N(g,p) reaction and cosmic rays. We identify the detected particle, record its energy and angles of emission (theta and phi), allowing the measurement of complete angular distributions with unprecedented accuracy. Such detailed and complete angular distributions are necessary for extracting the amplitudes and phases (e.g. for E1 and E2 interactions) [5]. In order to remove "12C background events" a gas system operating with an 13C isotopically enriched CO_2 gas has been designed. A new electronic readout TPC (the ELITPC) has been designed and proposed for use at the ELI-NP facility in Bucharest, Romania [6]. The electronic readout is achieved via a multi-layered PC-Board that serves as u-v-w readout (instead of the usual three plane u-v-w readout used so far). A proto-type mini-TPC has been constructed and tested at the University of Warsaw [7] and will soon be delivered to the ELI-NP facility. Extensive simulations of the drift field using MAXWELL have been conducted on the UConn High Performance Computing in order to optimize the field cage geometry. The ELITPC is intended to be prepared at the University of Warsaw and delivered to the ELI-NP facility at the end of 2019 when the first gamma-beams are anticipated. We will review both the O-TPC and the ELITPC detectors. [1] H.R. Weller, M.W. Ahmed, H.Gao, W. Tornow, Y. Wu, M. Gai, R. Miskimen, Prog. Part. Nucl. Phys. 62(2009)257. [2] D. Filipescu et al., Eur. Phys. J. A 51, 185 (2015). [3] Moshe Gai, Phys. Rev. C 88, 062801(R) (2013). [4] M. Gai et al., Jour. Instr. 5(2010)12004. [5] W.R. Zimmerman et al., Phys. Rev. Lett. 110, 152502 (2013). [6] O. Tesileanu, M. Gai et al., Rom. Rep. Phys. 68, S699 (2016). [7] M. Cwiok et al., 1st Intern. Conf. Nuclear Photonics, October 19, 2016, Monterey, CA.

Space and Nuclear Physics Applications - Thursday 10:30 - 12:00 pm in Mendelssohn with Zhong He

Next generation experiments with the Active Target Time Projection Chamber

Ayyad, Yassid (1), Macchiavelli, Augusto O. (1), Cooper, Reynold J. (1), Bazin, Daniel (2), Mittig, Wolfgang (2), Cortesi, Marco (2), Zamora, Juan Carlos (2), Dalitz, Christoph (3)

Lawrence Berkeley National Laboratory, Berkeley, CA, USA (1), National Superconducting Cyclotron Laboratory, East Lansing, MI, USA (2), Niederrhein Univesity of Applied Sciences, Institute for Pattern Recognition Reinarzstr. Krefeld, Germany (3)

Active Targets have gained popularity with the advent of state-of-the-art radioactive beam facilities capable of providing the most exotic nuclear species. Several facilities are deploying novel Active Targets as part of their broad and competitive experimental program. At the National Superconducting Cyclotron Laboratory (NSCL) our collaboration has successfully commissioned the Active Target Time Projection Chamber (AT-TPC) with ^{4}He and ^{46}Ar beams delivered by the ReA3 accelerator, to perform elastic scattering reactions on alpha particles and protons, respectively. The performance of the detector, analysis of data and results obtained in these experiments will be discussed during this talk. In addition, future experiments with fast and slow beams will be presented, as well as a novel developments focused on rare gases.

6.4.5 Scintillation Detectors III (Thursday 10:30 - 12:00 pm in Hussey with Marek Flaska)

Scintillation Detectors III - Thursday 10:30 - 12:00 pm in Hussey with Marek Flaska

Handheld Radioisotope Identification Detectors Employing Strontium Iodide and Gadolinium Garnet

Cherepy, Nerine (1), Payne, Stephen (1), Beck, Patrick (1), Swanberg, Erik (1), Wihl, Brian (1), Fisher, Scott (1), Seeley, Zachary (1), Hunter, Steven (1), Kindem, Joel (2)

Lawrence Livermore National Laboratory, Livermore, CA (1), Cokiya, Inc., Poway, CA (2)Lawrence Livermore National Laboratory, Livermore, CA (1), Cokiya, Inc., Poway, CA (2)

Two new prototype scintillator gamma spectrometers have been developed, employing the new scintillator materials, SrI_2(Eu) and GYGAG(Ce). Both of these scintillators were discovered since 2007, and offer improved properties compared to existing scintillators such as NaI(Tl) and $LaBr_3$(Ce). The Mobile Radioisotope Identification Detector (Mr. ID) is a 1.5 x1.5 SrI_2(Eu)-based detector that provides R(662 keV) = 3% and provides radioisotope identification on-the-fly via the LLNL Radionuclide Analysis Kit (RNAK). The Directional Radioisotope Identification Detector (Dr. ID) is a GYGAG(Ce)-based detector that incorporates 1024 scintillator pixels (3 in^3 total volume) on an inexpensive, high efficiency photodiode array, resulting in R(662 keV) = 4.5% and offering rapid directional detection of radioactive point sources. Both detectors are lightweight for portability and offer flexible interfacing via WiFi. This work was performed under the auspices of the U.S. DOE by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344, and has been supported by the US Department of Homeland Security, Domestic Nuclear Detection Office, under competitively awarded IAA HSHQDC-12-X-00149 under Contract No. DE-AC03-76SF00098. This support does not constitute an express or implied endorsement on the part of the Government.

Scintillation Detectors III - Thursday 10:30 - 12:00 pm in Hussey with Marek Flaska

Characterization of wavelength-shifted hygroscopic scintillators using dye-doped polymer films

Suitts, Hayley (1), Tornga, Shawn (1), Adams, Jillian (1), Hehlen, Markus P. (1), Madden, Amanda (1), Trautschold, Olivia (1), Wakeford, Daniel (1)

Los Alamos National Laboratory (1)

Gamma-ray spectroscopy systems used in applications limited by size, weight, and power (such as hand-held or space-based detector systems) commonly include a small, inorganic scintillator detector optically coupled to a photomultiplier tube (PMT). Low-SWaP solid-state readout devices, such as silicon avalanche photodiodes (SiAPDs) and silicon photomultipliers (SiPMs), are not generally considered suitable alternatives to PMTs because the peak emission of many high-performance scintillators is poorly matched to the spectral response of these devices. In previous research, we have developed a method of applying wavelength-shifting dye-doped polymer films to non-hygroscopic scintillator crystals to shift light emission into a region that is more compatible with high-efficiency solid-state readout devices. We present here our application of these methods to a variety of hygroscopic crystals including CLYC:Ce and $CeBr_3$ scintillators. The appropriate dye coating for a given scintillator is determined via our developed figure-of-merit spectrum convolution software that utilizes manufacturer-provided quantum efficiency figures, scintillator emission spectra, and a database of absorption and emission spectra for a variety of dyes. The shift of scintillation light is confirmed via radioluminescence spectroscopy, and gamma ray spectroscopy measurements are made to determine increase in photoelectron light collection. Additionally, SiAPD-coupled wavelength-shifted crystals are measured to have a relative improvement of energy resolution in comparison to unshifted crystals coupled to a variety of commonly used PMTs.

Scintillation Detectors III - Thursday 10:30 - 12:00 pm in Hussey with Marek Flaska

Gd based ceramic scintillators

Glodo, Jarek (1), Wang, Yimin (1), Shirwadkar, Urmila (1), Brecher, Charles (1), Shah, Kanai S. (1)

Radiation Monitoring Devices, Inc (1)

Scintillators require a transparent medium that traditionally is provided by single crystals. But crystal growth is not the only method of obtaining optical quality materials. In 90s ceramic approach to scintillator manufacturing was shown by Greskovich. Since that time a few materials have been developed as viable options, including GOS or $(Y,Gd)_2O_3$ used in medical imaging. In recent years the developments of ceramic scintillators progressed due to increased interest in garnet compositions. Garnets having high melting point and cubic structure are very good choice for ceramic process. At the same time their high light yield (supported by Gd-based energy transfer), good timing combined with developments in red sensitive photo-detectors makes them attractive for medical and other applications. In this talk we will discuss our most recent work on Gd based garnets, including GGAG and GdLuGAG compositions. Related materials will also be discussed. This work was supported by the U.S. Department of Homeland Security, Domestic Nuclear Detection Office, under competitively awarded contract HSHQDC-15-C-B0042. This support does not constitute an expressed or implied endorsement on the part of the Government.

Scintillation Detectors III - Thursday 10:30 - 12:00 pm in Hussey with Marek Flaska

Towards directional sensitivity to reactor antineutrinos with a segmented pulse shape discriminating (PSD) plastic scintillator detector

Dazeley, Steven A. (1), Classen, Tim (1), Mabe, Andrew (1)

Rare Event Detectors Group, Lawrence Livermore National Laboratory, California (1)

Recently, several organic-scintillator-based antineutrino detectors, such as SONGS, NUCIFER, JOYO and PANDA were used to monitor the operational status of nuclear reactors from close range via the inverse beta decay reaction. The inverse beta decay reaction produces an MeV-scale positron and neutron as a result of the antineutrino interaction on a proton in the scintillator. All of the detectors mentioned above combined various arrangements of organic scintillator to detect the positron, and gadolinium to capture the neutron. In each case the $\sim$ few MeV positron signals are followed a few 10's of microseconds later by a neutron capture. The correlation in both position and time is used to positively identify the antineutrinos from the uncorrelated (mostly gamma-ray) backgrounds. The primary source of correlated backgrounds are from cosmogenically sourced fast neutrons, which produce signals from proton recoils followed by neutron capture. Typically, detectors are deployed below ground and surrounded by large volumes of hydrogenous shielding to reduce these backgrounds. An alternative approach might be to reconstruct the direction of the incoming antineutrinos by measuring the relative positions of the positron and the neutron capture. Fine-grained segmentation, made feasible by a form of 6Li-doped plastic PSD organic scintillator, which can be machined into thin rods and coupled with position sensitive photomultipliers, may provide the position resolution needed. The PSD characteristics inherent to the plastic, and particle track length sensitivity (via rod multiplicity) will also add sensitivity. If successful, a detector that exploits this new material may be able to reduce the requirements for bulky shielding and specialized underground deployment locations. Our group is building a detector with the aim of testing these characteristics in a flux of reactor antineutrinos. We will report on progress and some of the challenges involved. This work was performed under the auspices of the US Department of Energy by Lawrence Livermore National Laboratory under contract DE-AC52-07NA27344, release number LLNL-ABS-746899

Scintillation Detectors III - Thursday 10:30 - 12:00 pm in Hussey with Marek Flaska

Development of LuAG Ceramic Scintillator for Future HEP Experiments

Hu, Chen (1), Li, Jiang (2), Yang, Fan (1,3), Zhang, Liyuan (1), Zhu, Ren-yuan (1)

California Institute of Technology, 1200 E California Blvd, Pasadena, CA 91125, USA (1), Shanghai Institute of Ceramics, CAS, 1290 Dingxi Road, Shanghai, 200050, China (2), Nankai University, 94 South Weijin Road, Tianjin, 300071, China (3)

Because of its bright and fast scintillation cerium doped $Lu_3Al_5O_{12}$ (LuAG:Ce) ceramics has attracted a broad interest in the HEP community. Compared to single crystals, fabrication of ceramics is featured at a lower temperature and a more effective use of raw materials, so promises a cost-effective scintillator. Our investigations on LuAG:Ce ceramics show excellent radiation hardness against ionization dose up to 200 Mrad and proton fluences up to 310^{14} p/cm^2. Current status of LuAG ceramic scintillator and future plan are discussed.

Scintillation Detectors III - Thursday 10:30 - 12:00 pm in Hussey with Marek Flaska

Enhancing efficiency of semiconductor nuclear voltaic batteries with scintillators

Xue, Sha (1), Tan, Chuting (1,2), Hlinka, Vasil (2), Kandlakunta, Praneeth (1), Cao, Lei (1)

Department of Mechanical and Aerospace Engineering, The Ohio State University, Columbus, Ohio, 43220, USA (1), Awareability Technologies LLC, Columbus, Ohio, 43212, USA (2)

The Si solar panel and in-house fabricated SiC radiation energy harvest devices were characterized in this work to demonstrate an enhanced efficiency by combining the indirect charge production from lights emitted from scintillating materials with the direct charge production in the semiconductor voltaic devices. To enhance the power conversion efficiency (PCE) of the nuclear batteries, different scintillating materials including ZnS(Ag), CLYC (Cs_2LiYCl_6:Ce) and ultra-thin film scintillator polyvinyl toluene (PVT) were incorporated geometrically with device to obtain increased current output. A 50 kV X-ray tube with a maximum power of 4 W is used as the energy source for the nuclear battery. The I-V characteristics of the nuclear battery with and without the scintillating layers were measured using a Keithley 4200A-SCS Parameter Analyzer. The results show that by adding the phosphor layers, the maximum power output of the Si device increased about 32% compared with the device that without the phosphor layers. The ZnS(Ag) and CLYC are more efficient in increasing the PCE. However, the degree of enhancement using of SiC device depends on the matching of the external quantum efficiency of the device and the emission spectrum of the scintillator. The results demonstrate that, by coupling with the proper scintillating layers, the nuclear batteries' efficiency could be increased significantly compared to that working only in the direct charge collection mode.

6.4.6 Liquid Detectors for Neutrino Detection and Gas Detectors for Nuclear Physics (Thursday 1:30 - 3:00 pm in Mendelssohn with Zhong He)

Liquid Detectors for Neutrino Detection and Gas Detectors for Nuclear Physics - Thursday 1:30 - 3:00 pm in Mendelssohn with Zhong He

An overview of neutrino detection techniques (mostly at low energies)

Bernstein, Adam (1)

Lawrence Livermore National Laboratory (1)

All neutral particles are equally neutral - but some are more neutral than others. As their name was meant to suggest, neutrinos are electrically uncharged, thus entering symposia on ionizing radiation measurements only by stealth, as the progenitors of detectable ionizations (or scintillation, or heat). Yet they are arguably more neutral than their other electrically neutral cousins, photons and neutrons. Neutrinos are unique among Standard Model particles since they participate only in the weak (and, like all Standard Model particles, gravitational) interactions. As a consequence, they are very hard to detect, with typical interaction probabilities some 20 orders of magnitude smaller than photons or neutrons. In this talk, I'll survey techniques for neutrino detection, and explain how these elusive particles, once thought to be either undetectable, or a convenient theoretical conceit, can now be robustly characterized in terms of their flavor, (weak) charge, energy, and direction by a range of sophisticated methods. For reasons of time and predisposition, I'll focus mostly on detection methods for relatively low energy, MeV-scale neutrinos.

Liquid Detectors for Neutrino Detection and Gas Detectors for Nuclear Physics - Thursday 1:30 - 3:00 pm in Mendelssohn with Zhong He

Neutrino Detection in China

Cao, Guofu (1)

Institute of High Energy Physics, Beijing (1)Institute of High Energy Physics, Beijing (1)

Neutrino is one of the elementary particles in the world. To study the properties of neutrinos is one of the research hot topics and frontiers in particle physics and can help us to understand the nature of the universe. China plays an important role in understanding the properties of neutrinos. The DayaBay experiment, closed to the Daya Bay nuclear power plant in China, discovered the last unknown mixing angle θ_{13} to be unexpected large and measured the θ_{13} with the best precision in the world. The DayaBay experiment uses eight identical liquid scintillator (LS) detectors placed in near and far sites to detect neutrinos from the reactors. The Jiangmen Underground Neutrino Observatory (JUNO) is proposed after the discovery of non-zero θ_{13} and currently under construction in the south of China. JUNO is a multipurpose neutrino experiment designed to determine neutrino mass hierarchy and precisely measure oscillation parameters by detecting neutrinos from reactors. The JUNO detector is a 20 kton LS detector covered by $\sim$ 18000 20 inch PMTs, which is currently the largest LS detector in the world with unprecedented energy resolution. JUNO has the potential to detect neutrinoless double beta decays (0vbb) by dissolving xenon or doping tellurium into LS. In China Jinping Underground Laboratory (CJPL), several experiments are proposed to search for 0vbb of ^{136}Xe and ^{130}Te by using tone scale high pressure gas time projection chambers (TPC) or crystals. A 2 kton LS detector is also proposed to precisely measure solar neutrinos and geo-neutrinos in CJPL. In this talk, we will highlight the neutrino detection in Daya Bay and JUNO experiments. The activities related to neutrino detection in CJPL will be covered. In addition, the accelerator neutrino beams, the reactor neutrino spectra and the international cooperation will also be briefly introduced.

Liquid Detectors for Neutrino Detection and Gas Detectors for Nuclear Physics - Thursday 1:30 - 3:00 pm in Mendelssohn with Zhong He

Development of a gaseous proton-recoil detector for neutron flux measurements below 1 MeV neutron energy

Mathieu, Ludovic (1), Aiche, Mourad (1), Marini, Paola (1), Czajkoswki, Serge (1), Jurado, Beatriz (1), Tsekhanovich, Igor (1)

CENBG, CNRS/IN2P3-Universit de Bordeaux 19, Chemin du Solarium, 33175 Gradignan, France (1)

Absolute measurements of neutron fluence are an essential prerequisite for neutron-induced cross section measurements, neutron beam lines characterisation and dosimetric investigations [1]. The H(n,p) elastic scattering cross section is a very well known standard used to infer high precision neutron flux measurements. The use of this standard reaction, with a dedicated proton recoil detectors, is not straightforward below incident neutron energy of 1 MeV, due to a high background contribution to the proton-recoil spectrum. Experiments with neutron sources produced by accelerated ion beams have been carried out to investigate such background and to determine its origin and components. Based on these studies, a gaseous proton-recoil detector (GPRD) has been designed with a reduced sensitivity to background. First tests of this detector has been carried out, and show good performances at measuring neutron flux down to 300 keV. [1] M. Chadwick, M. Herman, P. Oblozinsky, M. Dunn, Y. Danon, A. Kahler, D. Smith, B. Pritychenko, G. Arbanas, R. Arcilla, et al., Nuclear Data Sheets. 2011, 112, 2287

Liquid Detectors for Neutrino Detection and Gas Detectors for Nuclear Physics - Thursday 1:30 - 3:00 pm in Mendelssohn with Zhong He

Development of new micro-pattern gaseous detector for AT-TPC applications

Cortesi, Marco (1,2), Mittig, Wolfgang (1,2), Bazin, Daniel (1,2), Ayyad, Yassid (1,2), Beceiro Novo, Saul (2)

National Superconducting Cyclotron Laboratory (1), Michigan State University (2)

The operational principle and performance of two innovative MPGD architectures, such as the multi-layer Thick Gaseous Electron Multiplier (M-THGEM) and the Multi-Mesh THGEM-type multiplier (MM-THGEM), will be presented and discussed. -) The M-THGEM consist of a single, robust assembly comprising of several THGEM elements stacked together. The electron avalanche processes occur along the successive multiplication stages within the M-THGEM holes, under the action of strong dipole fields resulting from the application of suitable potential differences between the electrodes. The intrinsically robust confinement of the avalanche within the M-THGEM holes provides an efficient reduction of the photon-induced secondary effects, resulting in a high-gain operation over a broad pressure range (down to a few tens of torr), even in pure elemental gas, including pure Hydrogen (H_2), Deuterium (D_2) and Helium (He). -) The MM-THGEM accommodates, in a single micro-structure, the two most popular but very different MPGD concepts: the parallel-plate type micro-mesh and the hole-type (multi-layer THGEM) multiplier. The MM-THGEM comprises of a multi-layer hole-type multiplier (M-THGEM) combined with in-built electrode meshes. The electrons are largely multiplied by a strong uniform field established between the meshes, like in the parallel-plate avalanche geometry. The presence of the two meshes within the holes allows to trap a large fraction of the positive ions that are streaming back to the drift region, reducing ion backflow secondary effects. The results of this work are relevant in the field of avalanche mechanism in low-pressure, low-mass pure elemental gases, in particularly for applications of MPGD end-cap readout for active-target Time Projection Chambers (TPC) in the field of nuclear physics and nuclear astrophysics. Other potential applications may include large-area UV photon detectors, muon trackers, hadron calorimetry, X-ray/neutron, imaging, and secondary scintillation readout for rare event physics.

Liquid Detectors for Neutrino Detection and Gas Detectors for Nuclear Physics - Thursday 1:30 - 3:00 pm in Mendelssohn with Zhong He

Development of a Thick Gas Electron Multiplier based Beta-Ray Detector

Bernacci, Matthew R. (1), Byun, Soo Hyun (1,2), Prestwich, William V. (1,2)

Radiation Sciences Graduate Program, McMaster University, Hamilton, ON, L8S 4K1, Canada (1), Department of Physics and Astronomy, McMaster University, Hamilton, ON, L8S 4K1, Canada (2)

A new beta-ray detector using the Thick Gas Electron Multiplier (THGEM) technology is presented. Traditional proportional counters have been considered the standard for many decades for radiation contamination monitoring. However, it has always been challenging to detect low energy beta-emitters like ^{3}H and ^{14}C. In order to extend the low energy cutoff of these beta particles, it is important to keep the electron multiplication gain as high as possible. To accomplish this goal, we have developed a new gaseous beta-ray detector using THGEMs. Founded on previous THGEM avalanche simulations [1] and predecessor detectors [2][3], a prototype THGEM beta-ray detector was designed and fabricated. Its signal performance, effective gain and gain stability were comprehensively studied for single and double-THGEM configurations using an alpha source. THGEM detector response to beta-rays was measured for various operating conditions and compared with MCNP6 Monte Carlo simulations. [1] S. H. Byun, G. M. Spirou, A. Hanu, W. V. Prestwich, and A. J. Waker, "Simulation and first test of a microdosimetric detector based on a thick gas electron multiplier," IEEE Trans. Nucl. Sci., vol. 56, no. 3, pp. 1108-1113, 2009. [2] A. Hanu, "Development of a THGEM Imaging Detector with Delay Line Readout," Open Access Diss. Theses, 2014. [3] Z. Anjomani, A. . Hanu, W. V. Prestwich, and S. H. Byun, "Development of a multi-element microdosimetric detector based on a thick gas electron multiplier," Nucl. Instruments Methods Phys. Res. Sect. A Accel. Spectrometers, Detect. Assoc. Equip., vol. 847, pp. 117-124, Mar. 2017.

6.4.7 Radiation Detection using Mobile/UAVs (Thursday 1:30 - 3:00 pm in Hussey with Simon Labov)

Radiation Detection using Mobile/UAVs - Thursday 1:30 - 3:00 pm in Hussey with Simon Labov

Mobile Urban Radiation Search (MURS)

Curtis, Joseph (1), Joshi, Tenzing (1), Cooper, Reynold (1), Cosofret, Bogdan (2), Schmit, Thomas (2), Wright, John (2), Rameau, Jonathan (2), Konno, Daisei (2), Brown, Daniel (2), Otsuka, Forrest (2), Rappeport, Eric (2)

Applied Nuclear Physics, Lawrence Berkeley National Laboratory, Berkeley, CA, USA (1), Physical Sciences Inc., Andover, MA, USA (2)

Detection and localization of anomalous radioactive sources in urban environments are key requirements of a mobile detection system when deployed in wide-area-search activities. The Mobile Urban Radiation Search (MURS) system was designed to meet these goals with proven sensor technologies integrated into a mid-sized SUV and coupled to state-of-the-art gamma-ray detection and localization algorithms in order to provide the operators with near-real-time situational awareness in a concise and relevant format. These algorithms require a detailed understanding of the per-detector response to gamma-ray sources. In order to obtain these responses for a range of relevant sources, a detailed model geometry was built to simulate sources placed around MURS via Monte-Carlo methods. In this work, we will discuss the MURS design, sensors, algorithms and simulations with a detailed description of one of the localization algorithms which provides geo-spatially registered images of estimated gamma-ray source position(s) based on a Maximum-Likelihood by Expectation-Maximization (ML-EM) algorithm.

Radiation Detection using Mobile/UAVs - Thursday 1:30 - 3:00 pm in Hussey with Simon Labov

Data Fusion for a Vision-Aided Radiological Detection System: Methods for Tracking Radiological Material

Stadnikia, Kelsey (1), Henderson, Kristofer (1), Koppal, Sanjeev (1), Enqvist, Andreas (1)

University of Florida, Gainesville, FL (1)

This research presents the recent work on the data fusion between 3D vision sensors and radiological sensors for detecting and tracking nuclear material. The 3D vision sensor provides the 3D distance of an object over time. The radiological sensor converts count rate over time to distance over time based on the count rate being inversely dependent on the square of the distance. This inverse square law is the key to making the data streams analogous. Numerous measurements were taken that involved three people walking in a room where one of the persons carried a Cf-252 source in a backpack. The resultant data streams from the vision sensor and radiological detector can then be correlated. Two data correlation methods will be discussed. One method uses the covariance of the radiological and vision vectors, and the other method uses the dot product of the two vectors. The data will also be analyzed using the system calibration which provides a room dependent deviation model and radiological detector pseudo-location. The model and pseudo-location are used to explore the distance converted radiological data using non-ideal radiation behavior due to attenuation, wall-effects and detector properties in comparison to the distance converted radiological data with the ideal inverse square law.

Radiation Detection using Mobile/UAVs - Thursday 1:30 - 3:00 pm in Hussey with Simon Labov

Flight Performance of the Advanced Radiation Detector for UAV Operations (ARDUO)

Chen, Carolyn M. (1,2), Sinclair, Laurel E. (1,2), Fortin, Richard (3), Coyle, Maurice (3), Samson, Claire (1,4)

Department of Earth Sciences, Carleton University, Ottawa, Ontario, Canada (1), Canadian Hazards Information Service, Natural Resources Canada, Ottawa, Ontario, Canada (2), Geological Survey of Canada, Natural Resources Canada, Ottawa, Ontario, Canada (3), Department of Construction Engineering, cole de Technologie Suprieure, Montral, Qubec, Canada (4)

Natural Resources Canada is responsible for the provision of aerial radiometric surveys in the event of a radiological or nuclear emergency in Canada. Manned aerial surveys are an essential element of the planned consequence management operation, as demonstrated by the recovery work following the 2011 Tohoku earthquake and tsunami and their effects in Fukushima, Japan. However, manned surveys are limited to some minimum speed and altitude in order to maintain safe flight conditions for the pilots and other occupants. Flying lower and slower than manned aircraft, an unmanned aerial vehicle (UAV) platform can provide improved spatial resolution. In particular, hot spot activity can be underestimated in manned survey results as the higher flight altitude and wider line spacing effectively average the hot spot over a larger area. Moreover, a UAV can enter an area which is too hazardous for humans, due not only to the radiological threat which is its target, but also to other anticipated hazards such as a potentially explosive environment, an environment with airborne chemical hazards, or open water. For these reasons, Natural Resources Canada has been investigating the inclusion of UAV-borne radiation survey spectrometers into its aerial survey response procedures. The Advanced Radiation Detector for UAV Operations (ARDUO) was developed to exploit the flight and lift capabilities available in the under 25 kg class of UAV. The detector features eight 2.8 x 2.8 x 5.6 cm CsI(Tl) crystals arranged in a self-shielding configuration, read out with silicon photomultipliers, and digitized with miniaturized custom electronics. The ARDUO is flown on the main- and tail-rotor Responder UAV which has a 6 kg lift capacity and up to 40 minute endurance. Point sources of Cs-137, Co-60, Am-241 and Na-22 with strengths of from 0.5 mCi to 5 mCi were arranged in various configurations in a trial area of approximately 100 m x 50 m. Aerial surveys with the Responder + ARDUO UAV system were flown over the trial area at altitudes of 5 m to 20 m and speeds from hover to 15 m/s. As well, surveys were flown over nearby buildings containing radioactive sources. We present here the results of these trials. We show how the directional response of the ARDUO can provide an indication in real time of source location to guide the UAV during flight. As well, we show how utilization of the directional information in post-acquisition processing can result in improved spatial resolution of radiation features.

Radiation Detection using Mobile/UAVs - Thursday 1:30 - 3:00 pm in Hussey with Simon Labov

Autonomous Multi-Robot System for Detection and Localization of Radioactive Sources

Bird, John P. (1), Kochersberger, Kevin (1), Cesar-tondreau, Brian (1), Wagner, Anthony (1), Chaudhry, Haseeb (1), Morgan, Andrew (1), Mclean, Lance (2)

Unmanned Systems Lab, Virginia Tech, Blacksburg, VA (1), Nevada National Security Site, Andrews Operations (RSLA) (2)

A multi-robot system and a set of search algorithms were developed to facilitate autonomous detection and localization of radioactive sources in an unknown environment. An unmanned aerial vehicle (UAV) was used to collect visual imagery to create a map of the environment and collect radiation data. This map and radiation data was used to assign an unmanned ground vehicle (UGV) and the UAV to search areas of interest in the environment to detect and localize the sources. The system was demonstrated for both a single strong point source in the environment and multiple point sources distributed throughout the environment. Three search algorithms were tested during the experiments. An exhaustive search using the UGV (lawnmower pattern) was used as the baseline. The other two search methods used the aerial radiation data collected from the UAV to develop more targeted search paths. One method used an active search that continuously estimates the position and activity of a source. The UGV is controlled to reduce the uncertainty of this estimate. The last method used Laplacian Eigenmaps to reduce the dimensionality of the radiological data to do a K-means clustering to identify points in the test area where sources are likely present. Each of the methods had success finding sources in the environment.

Radiation Detection using Mobile/UAVs - Thursday 1:30 - 3:00 pm in Hussey with Simon Labov

Spectral Methods to Detect and Quantify Airborne and Ground-Based Sources

Detwiler, Rebecca (1), Myjak, Mitchell (1), Gilbert, Andrew (1), Johns, Paul (1), Kernan, Warnick (1), Wittman, Rick (1), Seifert, Carolyn (1), Baciak, James (2), Enqvist, Andreas (2), Cronin, Dan (2)

Pacific Northwest National Laboratory, Richland, WA (1), University of Florida, Gainesville, FLorida (2)

Although infrequent, aerial responses to reactor accidents such as Fukushima may involve encountering airborne radioactivity when performing radiological measurements near the site of these accidents. An encounter with a plume represents both a danger to the crew and a potential to compromise the accuracy of the ground-level exposure rate and deposition calculations. In this effort, we have developed methods to provide aerial measuring systems with a real-time alarm on the presence of a plume and to distinguish ground contamination from airborne radiological material using a combination of hardware and software. The hardware methodology includes an upward looking detector above the existing detector package. The software methodology use the differences in attenuation for specific energy regions of interest to detect, isolate, and quantify the air and ground components for calculation of exposure rate and deposition. These methodologies have been tested with injection studies of single source markers as well as a realistic mixed source for the reactor scenario, using real flight background data taken with an upward looking detector. As well, a real-world flight test of airborne radioactivity is planned with a flyover of the University of Florida Argonaut research reactor, which is capable of an extended release of airborne Ar-41 released at altitudes close to 100 feet for up to 8 hours. The flyover will incorporate a range of altitudes above the release cloud, as well as other cloud geometries as feasible, such as the cloud to the side or on approach. Testing will be conducted to determine both ranges of optimal performance with respect to the cloud, and limitations of the methodology.

Radiation Detection using Mobile/UAVs - Thursday 1:30 - 3:00 pm in Hussey with Simon Labov

Demonstration of Correlations between Radiological Background Source Terms and Panoramic Video Collected from a Mobile Detector System

Bandstra, Mark S. (1), Quiter, Brian J. (1), Meyer, Ross (1), Curtis, Joseph C. (1), Vetter, Kai (1,4), Archer, Daniel E. (2), Peplow, Douglas E. (2), Romano, Catherine (2), Swinney, Matthew W. (2), Hornback, Donald E. (2), Mccullough, Thomas L. (3), Mclean, M. S. Lance (3)

Lawrence Berkeley National Laboratory, Berkeley, CA, USA (1), Oak Ridge National Laboratory, Oak Ridge, TN, USA (2), Remote Sensing Laboratory, Washington, DC, USA (3), Department of Nuclear Engineering, University of California Berkeley, CA (4)

Mobile radiation detector systems are important tools for detecting weak radiological and nuclear sources outside of regulatory control, but due to their mobility, they are subject to complex and varying backgrounds when performing operations in most realistic scenarios. Recent work has found correlations between non-radiological contextual information and gamma-ray spectral features that can be used to decrease false alarm rates, however a more complete understanding of background source terms has been elusive. In 2015–2016, as part of the Multi-agency Urban Search Experiment (MUSE), a measurement campaign was undertaken at Fort Indiantown Gap, Pennsylvania to develop a full radiological characterization of a controlled facility that comprised several buildings and roughly corresponded to two city blocks. As part of the campaign, the Radiological Multi-sensor Analysis Platform (RadMAP) collected extensive multi-sensor data. RadMAP's panoramic video data were used to visually identify several different materials and quantify their potential impact on radiation sensor measurements. Comparison between the fraction of field of view subtended by each visual class and the radiological data generated by the on-board NaI(Tl) detector array demonstrated strong correlations, and the absolute magnitude of the correlations were qualitatively very similar to the ground truth measurements. This paper will briefly summarize the MUSE ground-truthing activities and the RadMAP system before describing the data collection, processing, and analysis of the gamma-ray and video data. The paper will conclude with perspectives on the applicability of such a method to less controlled environments both with respect to achieving better understanding the sources of variability of background radiation in urban environments and whether such methods could be leveraged in operational scenarios.

6.4.8 Plastic Scintillators (DNDO projects) (Thursday 3:30 - 5:00 pm in Mendelssohn with David Wehe)

Plastic Scintillators (DNDO projects) - Thursday 3:30 - 5:00 pm in Mendelssohn with David Wehe

An Overview - Root Cause Analysis and Solutions for Plastic Gamma Detector Degradation in Radiation Portal Monitors (RPMs)

Janos, Alan (1), Payne, Stephen (2), Zaitseva, Natalia (2), Lance, Michael (3), Kouzes, Richard T. (4), Feng, Patrick L. (5), Myllenbeck, Nicholas (5), Mabe, Andrew (2), Carman, Leslie (2), Glenn, Andrew (2), Cho, Herman M. (4), Cowles, Christian C. (4), Dib, Gerges (4), Slovik, Greg (1)
Domestic Nuclear Detection Office, Dept of Homeland Security (1), Lawrence Livermore National Lab (2), Oak Ridge National Lab (3), Pacific Northwest National Lab (4), Sandia National Lab (5)

One of the primary radiation detection systems used at ports of entry along the 7,400 miles of border with Canada and Mexico and the many miles of overseas borders is the Radiation Portal Monitor (RPM). The gamma detection portion of these RPMs usually utilize large scintillating plastic panels based on polymer matrix materials of either polyvinyl toluene (PVT) or polystyrene (PS). Fielded systems exposed to sometimes harsh temperature and humidity cycles over many years have been observed to degrade with time, with temporary fogging sometimes occurring when temperatures fall, and with permanent fogging occurring over longer times. The resulting decreases in performance require regular monitoring of performance and occasional replacement of the plastic panels, both of which result in added costs over the lifetimes of the panels. Water absorption by the plastic was often associated with the fogging and was for some time suspected to be the leading cause. However, definitive proof was not established and in particular the mechanisms by which water entered the plastic and created point-like defects was not fully understood. This presentation is an overview of an effort initiated to reveal the fundamental root cause and dynamics of the degradation and fogging. This understanding is important not only to solve problems for fielded systems, but also to provide direction for future procurements and R&D into advanced plastics with enhanced spectroscopic capabilities or dual particle gamma/neutron capabilities. Unexpected outcomes of this investigation included 1) the capability to predict the onset of fogging based on models using weather data alone, and 2) new modified formulations of PVT and PS which are fog-resistant. This presentation will give an overview of the water uptake and associated mechanisms for various compositions, characterization of resulting temporary and permanent defects, predictive modeling of fogging, and possible solutions including encapsulation, heaters and new formulations. This work was supported by the U.S. Department of Homeland Security, Domestic Nuclear Detection Office, under competitively awarded Inter-Agency Agreements (IAAs) HSHQDN-16-X-00051 and HSHQDCN-17-X-00035. This support does not constitute an expressed or implied endorsement on the part of the Government.

Plastic Scintillators (DNDO projects) - Thursday 3:30 - 5:00 pm in Mendelssohn with David Wehe

Nature of Moisture-Induced Fogging Defects in Scintillator Plastic

Lance, Michael J. (1), Payne, Stephen (2), Zaitseva, Natalia (2), Myllenbeck, Nicholas (3), Kouzes, Richard (4)
Oak Ridge National Laboratory (1), Lawrence Livermore National Laboratory (2), Sandia National Laboratory (3), Pacific Northwest National Laboratory (4)

Polyvinyl toluene (PVT) scintillator plastic may degrade in the field due to water that permeates into the plastic at elevated temperatures which then exceeds the saturation limit at lower temperatures. After many years, this leads to disk-like defects in the plastic that attenuate the scintillation light leading to detector failure. Using fractography and high-magnification optical and electron microscopy on the water-induced defects, a model of the fogging process is hypothesized as follows. Excess water present at low temperatures diffuses to spheroids to minimize contact with the hydrophobic polymer. Through the hydrophobic effect, water gains entropy by forming nano-clusters which minimizes the contact between the water and the PVT. As the water nano-clusters grow, they break and fold the polymer into densely-packed crystalline regions creating more space for water within the spheroids. The polymer outside the spheroid resists the shrinkage which builds up tension within the spheroid. Once the tensile stress exceeds the yield stress of the plastic, the spheroid is torn in half resulting in a defect. Excess water then drains into the cavities along the disk thereby further increasing its entropy. Slower cooling (over 1 day) leads to larger spheroids and hence, larger permanent defects. Freezing causes some defects to further grow due to the expansion of water to ice. This work was supported by the U.S. Department of Homeland Security, Domestic Nuclear Detection Office, under competitively awarded IAA HSHQDN-16-X-00051 and HSHQDCN-17-X-00035. This support does not constitute an expressed or implied endorsement on the part of the Government. The authors wish to offer their gratitude to many additional individuals at ORNL, LLNL, SNL, and PNNL who participated in experiments and activities that provided insight into the nature of fogging for scintillator plastics in RPMs.

Plastic Scintillators (DNDO projects) - Thursday 3:30 - 5:00 pm in Mendelssohn with David Wehe

Environmental Conditions Leading to Fogging in Scintillator Plastics

Myllenbeck, Nicholas R. (1), Feng, Patrick L. (1)
Radiation Detection Materials, Sandia National Laboratories, Livermore, CA (1)

Previous research of environmental aging in poly(vinyltoluene)-based plastic scintillators[1] has identified the presence of hydrothermally-induced light scattering defects that are believed to be detrimental to the gamma detection performance of the material. These defects can appear as a dispersed "fog", or as larger discrete particles, depending on the particular environmental conditions and hydrothermal history of the plastic specimen. We report herein our recent characterization of defect formation and contributing factors in controllably-aged 1" cubes of commercial plastic scintillator materials. Specifically, the intensity of light scattering, due to internal defects, was measured as a function of moisture saturation, aging conditions, cooling temperature and cooling rate of the scintillator materials. Accordingly, the temperature for water/plastic phase separation (T_{fog}) was measured sensitively using a custom-built, temperature-controlled stage in a UV-Visible spectrophotometer, and a predictive tool was assembled for associating defect formation with environmental aging conditions. T_{fog} was found to increase nearly linearly with moisture uptake, and approximately independently of aging temperature, at a rate of 12.2-13.6°C/ 0.01 wt. % moisture uptake. Scatterer size, estimated using an approximation of Rayleigh and Mie scattering ratios, was sensitive to hydrothermal history of the sample, favoring larger, more permanent particles with increased aging time and slower temperature changes. References 1. Cameron R.J., Fritz, B.G., Hurlbut, C., Kouzes, R.T., Ramey, A. and Smola, R. Fogging in polyvinyl toluene. IEEE Transactions on Nuclear Science, 62 (2015) 1-4 Acknowledgement This work was supported by US Department of Homeland Security, Domestic Nuclear Detection Office under the competitively awarded contracts IAA HSHQDC-16-x-00051/ P00002 and HSHQDN-17-X-00035. This support does not constitute an express or implied endorsement on the part of the Government. Sandia National Laboratories is a multi-mission laboratory managed and operated by National Technology and Engineering Solutions of Sandia LLC, a wholly owned subsidiary of Honeywell International Inc. for the U.S. Department of Energys National Nuclear Security Administration under contract DE-NA0003525.

Plastic Scintillators (DNDO projects) - Thursday 3:30 - 5:00 pm in Mendelssohn with David Wehe

Predictive model of scintillator plastic fogging in portals

Payne, Stephen (1), Zaitseva, Natalia (1), Myllenbeck, Nicholas (2), Kouzes, Richard (3), Lance, Michael (4), Janos, Alan (5)

Lawrence Livermore National Laboratory (1), Sandia National Laboratory (2), Pacific Northwest National Laboratory (3), Oak Ridge National Laboratory (4), Domestic Nuclear Detection Office (5)

We have developed a science-based predictive model for fogging of the scintillator plastics deployed in radiation portal monitors (RPMs). The only input required is the weather conditions [i.e. daily high and low, for temperature and relative humidity (R.H.)]. The code utilizes this information, together with a thermodynamic model of the water content in equilibrium with the plastic surface, a diffusion model of the water transport into the interior of scintillator plastic panel, and a comparison of the resulting paired water-content/low-night-temperature points as a function of position in the panel against an empirical fog-line that characterizes the water/temperature criterion for the onset of fogging. Laboratory measurements have yielded the needed diffusion coefficient at a function of temperature, as well as the water uptake as a function of temperature and R.H. We have analyzed the behavior of six portal sites, three of which have evidenced deterioration due to fogging and three which have not. The output of the model analysis is consistent with observation, provided a modest adjustment is applied to the fog-line, entailing a shift of 10 degrees C toward a greater propensity for fogging. The residual discrepancy between model and experiment may be due to the enhanced propensity for fogging known to arise from cycling the temperature many times, as would occur daily in the environment. This work was performed under the auspices of the U.S. DOE by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344 and was supported by the U.S. Department of Homeland Security, Domestic Nuclear Detection Office, under competitively awarded contracts IAA HSHQDCN-17-X-00035 and HSHQDCN-17-X-00051. This support does not constitute an expressed or implied endorsement on the part of the Government. The authors wish to offer their gratitude to many additional individuals at LLNL, SNL, PNNL, and ORNL who participated in experiments and activities that provided insight into the nature of fogging for scintillator plastics in RPMs.

Plastic Scintillators (DNDO projects) - Thursday 3:30 - 5:00 pm in Mendelssohn with David Wehe

Plastic scintillators stable for operating in wide ranges of humidity and temperature variations

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Scintillating plastics are important parts of different radiation detection systems. Many of such systems have to be used in field conditions, being exposed to harsh environmental conditions, with high humidity and abruptly changing temperatures. Avoiding any change in performance of the outdoor radiation systems could greatly extend their service lifetime. To provide efficient and reproducible response to nuclear radiation, scintillating plastics should be prepared as materials of high optical transparency and homogeneity that should remain intact during the long time of their operation. A problem arises when polyvinyltoluene (PVT) or polystyrene (PS) plastics are exposed to repeated low- or high-temperature swings that cause surface and volume defects, resulting in decreased sensitivity of the detection properties. It has been established [1] that changes of the plastics are facilitated by high humidity combined with extreme changes of temperature, especially to very cold temperature. The degradation of plastics under these conditions is exhibited by formation of different defects, resulting in the phenomenon of fogging that leads to the loss of plastic transparency, excessive light scatter, and deterioration of the detection performance. More detailed studies showed that phenomena of fogging are caused by condensation of water followed by growth of water droplets that results in dislocations and, in extreme cases, permanent damage of the polymer chains. In our studies we developed compositions that enable preparation of scintillating plastics resistant to the abrupt variations of environmental conditions. We found that an impressive improvement in plastic stability can be achieved by additions of cross linkers (such as divinylbenzene, DVB), oxygen-containing co-polymers (e. g. polymethylamethacrylate, PMMA) or their mixtures to the traditional PVT or PS polymer matrices. The effects of cross linking are attributed to formation of rigid polymer structures more resistant to the stress introduced by water condensation. Positive effects of oxygen-containing compounds are explained by formation of hydrogen bonds that stabilize water in the molecular state, preventing the condensation upon cooling. Among numerous tested compositions, the best results were obtained with plastics containing 5% PMMA, 5% DVB, and 5% PPO added to PVT or PS matrices that showed no fogging in multiple cycling from +55 C to -20 C. Addition of non-aromatic PMMA introduced a 10-20% decrease in the scintillation light output compared to traditional, commercially produced plastics, such as EJ-200. The loss of the performance is compensated by further composition changes that involve selection of more efficient primary and secondary dyes in combination with modifications of the polymerization procedures to diminish the fraction of residual monomers. 1. Cameron, R. J., Fritz, B. G., Hurlbut, C., Kouzes, R. T., Ramey, A., and Smola, R., Fogging in Polyvinyl Toluene Scintillators; TNS Feb. 2015 368-371 This work was performed under the auspices of the U.S. DOE by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344 and was supported by the U.S. Department of Homeland Security, Domestic Nuclear Detection Office, under competitively awarded contracts IAA HSHQDCN-17-X-00035 and HSHQDCN-17-X-00051. This support does not constitute an expressed or implied endorsement on the part of the Government.

Plastic Scintillators (DNDO projects) - Thursday 3:30 - 5:00 pm in Mendelssohn with David Wehe

Investigations of Degradation and Encapsulation of Plastic Scintillator

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Recent studies have revealed that plastic scintillators can undergo environmentally related material damage that adversely affects detection performance under certain conditions and histories. A significant decrease in sensitivity has been seen in some gamma-ray detectors as they age. Degradation in performance due to such damage is characterized by a change in the signal from the detector, which shifts to lower energy, and ultimately a reduction in the ability to detect gamma radiation. Some studies have found that in extreme cold environmental conditions significant performance loss can be observed, sometimes followed by a recovery in performance when normal warm conditions return. This degradation is due to the permeation of water into the plastic, which can then cause permanent damage to the material. Mitigation approaches that have been proposed for preventing damage to plastic scintillator include heaters to keep the material from getting cold enough to produce damage, encapsulation of the plastic scintillator to prevent water intrusion that leads to damage during cold cycles, and new formulations of the material. This paper presents information on testing of bare and encapsulated plastic scintillator and on diagnostic approaches to measure the nature and progression of the fogging condition.

6.4.9 Active Interrogation Techniques (Thursday 3:30 - 5:00 pm in Hussey with Namdoo Moon)

Active Interrogation Techniques - Thursday 3:30 - 5:00 pm in Hussey with Namdoo Moon

Review of Active Interrogation Techniques

Bendahan, Joseph (1)

Rapiscan Laboratories, Inc (1)

There is a need to inspect vehicles and their contents for Radiological Materials (RM), Special Nuclear Materials (SNM) and general contraband. Radiation Portal Monitors (RPMs) have been widely deployed for detecting mainly radiological materials. Although RPMs can easily detect Pu-239 due it copious neutrons and gamma-ray emission, they have difficulty detecting U-235 due to the high cargo attenuation of the 185keV gamma-ray. Also, RPMs have difficulty detecting partially or fully shielded radioactive sources. The most widely used technology for scanning vehicles, ranging from vans and trucks to railcars, is gamma-ray and X-ray radiography. These systems have been more recently being used for detecting shielded RM and SNM. However, unlike general contraband inspection where only $\sim 4\%$ of the cargo is selected for inspection, all cargo must be inspected for SNM, as lack of detection can have catastrophic results. Radiographic techniques are not highly specific to SNM and currently, result in a relatively high false alarm rate, which is not compatible with points-of-entry operations because it requires performing a secondary inspection for a large volume of cargo to clear the cargo via expensive and time consuming manual inspection. Active interrogation provides an automated method to clear false alarms and confirm the presence of SNM. The most common methods consist of irradiating the cargo with high-energy X-rays and/or neutrons to induce fission and detecting the products. X-Ray systems with energies above $\sim$ 8MV have a reasonable probability to induce fission (photofission) and penetrate dense cargo. High-energy neutrons (1MeV) also produce fission (neutron- induced fission) and have the capability of penetrating metallic and low-density organic cargo. Mixed radiation consisting of high-energy X-rays and neutrons can be used to cover most of the range of cargo compositions and enable other techniques that are complementary, which can increase the detection performance. The most suitable products for detection are prompt neutrons, delayed gamma rays and delayed neutrons. The detection efficiency of these products is dependent on the source characteristics, in particular the type of radiation and whether the source is pulsed or Continuous Wave (CW). Such active interrogation systems must have very high detection performance with very low false alarm rate, require modest infrastructure, have a high throughput (for secondary systems) and have a low cost. Any deviations from these requirements would hinder wide deployment. The Domestic Nuclear Detection Office (DNDO) has performed tests of some of these systems to determine the detection envelope of the various technologies. A summary of active interrogation techniques and selected results of active interrogation systems will be presented. * This work has been partially supported by the US Department of Homeland Security, Domestic Nuclear Detection Office, under competitively awarded contracts. This support does not constitute an express or implied endorsement on the part of the Government.

Active Interrogation Techniques - Thursday 3:30 - 5:00 pm in Hussey with Namdoo Moon

Cyclotron-based Multiple Monoenergetic Gamma Ray (MMGR) Radiography System for Special Nuclear Material Detection

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Passive detection of special nuclear material (SNM) radiation signatures in commercial cargoes is difficult due to the weak signatures of intrinsic radiations that can be easily shielded. Hence, active interrogation and gamma radiography may be much more effective methods for screening cargoes potentially containing shielded SNM. Currently, inspection systems utilizing dual-energy bremsstrahlung beams to determine the screening materials exist. However, these systems induce high doses and may pose a radiation hazard to potential stowaways. Here, we present a new system using ION-12^{SC}, a 12 MeV compact superconducting cyclotron. In order to simultaneously measure the atomic number (Z) and the areal density of the cargo, it utilizes (p,pγ) reactions on various targets to perform Multiple Monoenergetic Gamma Radiography (MMGR).With the appropriate target used, the cyclotron has the potential to leverage neutron-less reactions, thus lowering material activation and radiation doses. The near neutron-less and high energy gamma beam also enables us to measure prompt and delayed signatures from photofission induced in fissile materials as another means of detection. The use of superconducting technology has also resulted in an accelerator weighing less than 2 tonnes. Other advantages include having a footprint of 150 square feet, making it much more compact compared to the other system, and requiring a peak power of only 35 kW in addition to needing no liquid cryogen. More importantly, the proton-based nuclear reactions on carbon-12 and oxygen-16 targets can result in gamma emission intensities on the order comparable to that of bremsstrahlung systems. In this presentation, the cyclotron and the general concept of MMGR and active interrogation will be covered. Current work involving designs of the internal target and techniques of in situ measurements of accelerated proton energy will also be discussed. Preliminary results involving spectral transmission data from homogeneous cargoes will be presented.

Active Interrogation Techniques - Thursday 3:30 - 5:00 pm in Hussey with Namdoo Moon

Characterization of a deuteron-driven boron nitride source for use in active interrogation

Nolan, Terrence (1), Nattress, Jason (1), Mcguinness, Sean (2), Peaslee, Grahm (2), Jovanovic, Igor (1)

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Active interrogation (AI) has been of increasing interest in recent years for detecting special nuclear material (SNM). This is based on an expectation that the increased strength of the fission signature also increases the probability of SNM detection. Low-energy nuclear reactions are a promising AI source which could result in a low-dose, small footprint system used to detect illicit movement of SNM. We present the characterization of a deuteron-driven boron nitride (BN) source that simultaneously produces monoenergetic gamma rays and quasi-monoenergetic neutrons. Measurements were conducted at the University of Notre Dame using a FN Tandem Van de Graff accelerator to accelerate deuteron ions to 3 MeV and direct them to a thick BN target. The photon light output distribution was measured using NaI(Tl) detectors and the neutron time-of-flight distribution was measured with an EJ309 liquid scintillator. Measurements of the photon and neutron signatures from the deuteron-BN source were performed at deuteron energies of 3 and 4 MeV and at various angles. Preliminary results show numerous gamma-ray energies available to perform transmission radiography for material identification. Further, this source has the potential to achieve performance similar to that of traditional bremsstrahlung sources, but at a lower radiation dose. We present preliminary neutron and photon yields and energy spectra of the deuteron-BN source and assess its utility for nuclear security and nonproliferation applications.

Active Interrogation Techniques - Thursday 3:30 - 5:00 pm in Hussey with Namdoo Moon

MV X-ray Compton Scatter Detection System

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X-ray Compton scatter imaging is one of the non-destructive examination techniques. For high density or high Z materials, to achieve deep penetration, high-energy photon source is required. To investigate the potential of scatter imaging, a LINAC, a pencil beam collimator, NaI scintillation detector and a motion stage table were used for spatial localization and detection of photons scattered from the radiation beam. A 4 MV photon pencil beam was used for this research work. A stainless steel MTF step wedge tool was used as the target. The lead shielded and collimated NaI detector provided better contrast between different thicknesses of the same material with as few as 20 MU. A custom built data acquisition electronic board was developed for this experimental setup. The density differences in the step wedges can be correlated to the change in the detector counts. This experiment shows the feasibility of MV X-ray Compton scatter imaging for high Z materials.

Active Interrogation Techniques - Thursday 3:30 - 5:00 pm in Hussey with Namdoo Moon

Niowave X-ray Interrogation System

Boulware, Chase H. (1), Grimm, Terry L. (1), Mamtimin, Mayir (1), Odeh, Faisal Y. (1), Peters, William A. (1), Starovoitova, Valeriia N. (1)

Niowave Inc., Lansing MI 48906 (1)

Special nuclear material (SNM), primarily enriched uranium and plutonium, is easily shielded from the existing passive detection systems at the ports of entry to the United States. Recent technological advances in electron accelerators and nuclear radiation detectors make active interrogation systems for detection of shielded SNM technically and economically feasible. Niowave is in a unique position to address and solve this national security threat by employing a state-of-the-art combined radiography and active interrogation system, currently under development, that will detect even heavily shielded SNM hidden in cargo containers, trains, and trucks. The bremsstrahlung x-ray source is driven by a high-power electron beam from the superconducting accelerator. Key to the feasibility of this combined system is the primary use to image cargo for contraband in the same manner as luggage at an airport check point. The radiographic image will identify conventional targets such as guns, explosives, drugs, smuggled machine parts, and other items not properly disclosed to customs. While the radiograph is being collected, the same x-ray beam used to image the cargo will simultaneously fission any shielded SNM present. Additional radiation detectors are used to detect the neutrons and gammas released during fission and subsequent decay of the fission fragments, thereby giving an unambiguous positive identification of shielded SNM. Coupled with the radiography results, the shape, size, and location of any nuclear device will also be identified. Niowaves superconducting electron accelerator is a transformational enabling technology for systems that can affordably detect shielded SNM in moving cargo containers on trucks and trains. Superconducting accelerators produce high-flux, high-energy x-rays for interrogation. The electron beams have flexible pulse structures, at duty cycles from tens of percent up to continuous wave. Beam power can be rapidly modulated to interrogate both sparse and dense materials at the lowest possible x-ray dose levels. In this talk, an integrated active interrogation solution will be presented including the high-power accelerator, cryogenic refrigerator, x-ray converter, detector suite, detection methods, radiography, and shielding.

Active Interrogation Techniques - Thursday 3:30 - 5:00 pm in Hussey with Namdoo Moon

Laboratory demonstration of IED detection using a high flux neutron source

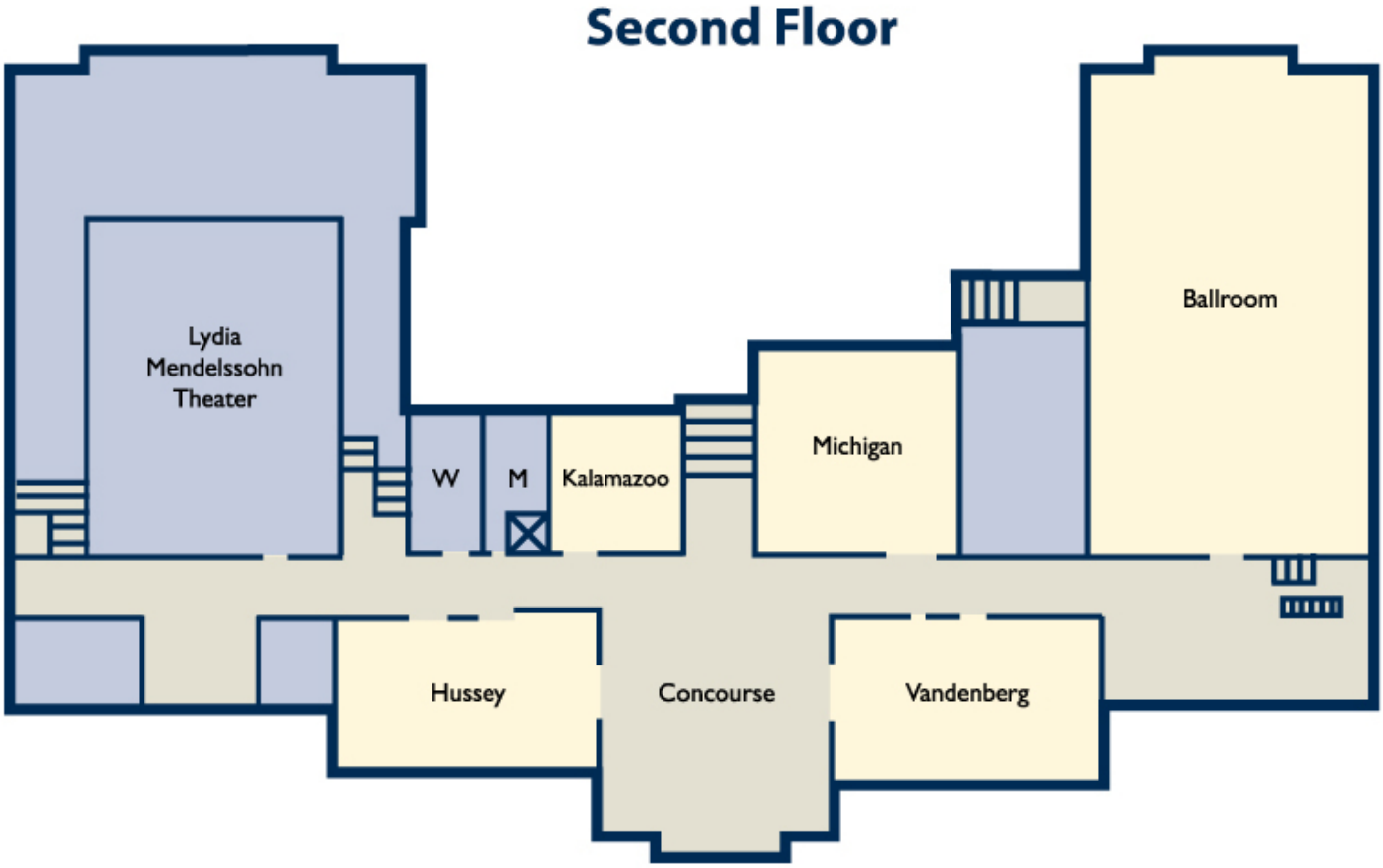
Becerra, Gabriel (1), Cech, Daniel (1), O'connell, Robert (1), Radel, Ross (1), Sengbusch, Evan (1)

Phoenix LLC, Madison WI (1)

Phoenix has demonstrated direct detection of buried explosive material by interrogation with an intense neutron source in a laboratory environment. The technique analyzes neutron-induced emission of characteristic gamma rays by each element, so it senses the explosive material itself. The high yield of the Phoenix neutron generator (up to 3x10$\hat{1}$1 neutrons/second) represents a huge reduction in detection times and standoff distances for neutron-based IED detection technology. Technology can also be applied to SNM detection at ports and porter crossings. Phoenixs source strength has reached a level where active interrogation for SNM has become logistically possible without disrupting throughput. Detection experiments ranged from standoff distances of up to 7 meters, which was the limit of the laboratory space. Simulants for nitrogen-based explosives were buried in sand of different moisture levels at depths of up to 28 cm (distance to top of explosive). The fast, high-resolution gamma-ray detector array is placed 50 cm above the suspect location. The method follows a concept of operations which assumes a selection of high-risk locations have been identified using ground-penetrating radar or satellite. The location is then scanned to determine the presence of explosives. The gamma radiation emitted due to the activation is analyzed to determine a presence of 10.8 MeV nitrogen gammas higher than background. The technique can also be used as a primary detection method. The measurements validate Monte Carlo modeling of neutron-based activation techniques. Example detection times: 1.4 seconds for 30-liter jug of TNT buried 8 cm in wet soil at a standoff of 5 m, or 37 seconds for 10-liter of TNT buried 30 cm in dry sand at a standoff of 10 m.

7 Maps

7.1 Michigan League



Thank you for participating in SORMA XVII !

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