SORMA WEST 2008

2008 Symposium on Radiation Measurements and Applications

June 2-5, 2008 Berkeley, California, USA

Oral Program as of June 2 , 2008

We invite you to Berkeley for the first West Coast meeting of the Symposium on Radiation Measurements and Applications.

SORMA West 2008 is hosted jointly by the University of California, Berkeley and the Lawrence Berkeley and Lawrence Livermore National Laboratories. It is made possible by the generosity of our agency sponsors and private-sector supporters.

We gratefully acknowledge the cooperation and advice of the original SORMA, now SORMA East, hosted by the University of Michigan and next scheduled for 2010.

Note: the Monday opening plenaries (in International House) and Thursday summary or rapporteur plenaries are described in a different document.

Monday's plenaries will be held at International House, which is also the location of the poster session and reception. The parallel oral sessions Tuesday through Thursday, and the closing plenary, will be in Stanley Hall (rooms 105 and 106) and Bechtel Engineering Center (Sibley Auditorium).

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Monday, June 2
Plan of the Day

Monday's venue will be International House, at the east side of the campus.

Sessions AM I and II will have featured speakers in plenary session, in the Chevron Auditoriom of International House.

Lunch (on your own) is 12 - 2. Those holding a Monday ticket for an LBNL tour will be guided to the shuttle-bus stop.

Monday afternoon will be dedicated to posters. In the same area, you can visit the tables of the private-sector supporters whose sponsorship has done so much to enhance SORMA West 2008.

> *Notes to poster presenters: A place to store your posters in the morning will be available so that you do not have to carry them around all day. We anticipate that the poster hanging period (and vendor-table setup period) will begin at 1:30. A diagram will show the location of your posterboard (a 4 x 4 foot corkboard). Pushpins and related office supplies will be available.*
>
> *The posters will remain up all afternoon and throughout the evening's poster reception. Contributors with odd-numbered posters are asked to present them (remaining there for as much of the time period as is reasonable) in Session PM I. Those with even-numbered posters should do this in Session PM II.*

Buses back to the Doubletree will begin boarding at 7 p.m.

8 a.m. - noon	Registration	I-House/Chevron Auditorium Foyer
9 - 10:15 am	Plenary Session	I-House/Chevron Auditorium
10:15 -10:45am	Break	
10:45 am - noon		Plenary Session
noon -2 pm	Lunch *(on own)* and LBNL Tours	
2 - 5 pm	Poster Session *Session I (2:00pm-3:30pm)* *Session II (3:30pm-5:00pm)*	I-House/Chevron Auditorium and Great Hall
5 - 7 pm	Poster Session Reception	I-House/Chevron Auditorium

Tuesday, June 3
Plan of the Day

SORMA West 2008 moves from International House to an adjacent part of the campus: Stanley Hall and Bechtel Engineering Center, Sibley Auditorium. Contributed orals in parallel sessions will be given in the morning.

Early in the noon hour, after a brief break (not long enough to return to the Doubletree or explore the campus), buses will load for the San Francisco and Muir Woods tours. Box lunches will be provided. The buses will return to the Doubletree.

Those who did not sign up for a tour are free for the afternoon and may wish to stop by the information desk for maps, restaurant guides, etc.

8:00am-12:00pm	Information Desk	Sibley Auditorium Foyer
9:00am-10:15am	Parallel Sessions	Stanley Hall and Bechtel/Sibley Aud.
10:15am-10:45am	Break	
10:45am-12:00	Parallel Sessions	Stanley Hall and Bechtel/Sibley Aud.
Noon-Afternoon	Lunch (Boxed) SF Tour/ Muir Woods Tour	

New Scintillators

Tuesday AM I: Stanley 105

Chair: Chuck Melcher, Univ. of Tennessee

Tuesday AM I: Stanley 105-1

Crystal Growth and Scintillation Properties of Strontium Iodide Scintillators

Edgar Van Loef, Radiation Monitoring Devices, Inc. (RMD)
Cody M. Wilson; Nerine J. Cherepy, Giulia Hull, Stephen A. Payne (LLNL); Woon-Seng Choong, William W. Moses (LBNL); Kanai S. Shah (RMD)

Security applications and nuclear non-proliferation depend on the rapid identification of highly enriched uranium, weapons grade plutonium, radioactive sources and other special nuclear materials. Efficient detection of their gamma-ray signature is the most common method for identification and requires a scintillator that has a high light yield, good energy resolution, fast scintillation decay and high effective atomic number. Currently, LaBr3:Ce and CeBr3 [1-3] provide the best combination of these properties. However, both are moisture sensitive and are prone to cracking during crystal growth [4]. Recently, the alkaline-earth iodides doped with divalent europium, i.e. SrI2:Eu and BaI2:Eu, have been rediscovered as inorganic scintillators that may rival LaBr3:Ce and CeBr3. Initially discovered by Hofstadter in 1968 [5], our recent research indicates that these materials exhibit high light yields and shows good energy resolution [6]. In this paper we report on the crystal growth and scintillation properties of strontium iodide scintillators doped with Eu2+ and Ce3+. Single crystals were grown from anhydrous alkaline- and rare-earth halides by the vertical Bridgman technique in evacuated silica ampoules. Growth rates were of the order of 5 - 30 mm/day. Radioluminescence spectra of SrI2:Eu2+ and SrI2:Ce3+ exhibit a broad band due to Eu2+ and Ce3+ emission, respectively. The maximum in the luminescence spectrum of SrI2:Eu2+ is found at 435 nm. The spectrum of SrI2:Ce3+ exhibits a doublet peaking at 404 and 440 nm attributed to Ce3+ luminescence, while additional impurity - or defected - related emissions are present at 524 and 601 nm. The strontium iodide scintillators show very high light yields of up to 100,000 photons/MeV, have energy resolutions of less than 4% at 662 keV (FWHM) and exhibit excellent light yield proportionality with a standard deviation of less than 5% between 6 and 460 keV, measured as a function of electron energy.

[1] E.V.D. van Loef, P. Dorenbos, C.W.E. van Eijk, K. Kramer and H.H. Gudel, Appl. Phys. Lett. 79, 1573 (2001).
[2] K.S. Shah, J. Glodo, M. Klugerman, W.W. Moses, S. E. Derenzo, M. J. Weber, IEEE Trans. Nucl. Sci. 50, 2410 (2003).
[3] K. S. Shah, J. Glodo, W. M. Higgins, E. V. D. van Loef, W. W. Moses, S. E. Derenzo and M. J. Weber, IEEE NSS Conf. Rec., 4278 (2004).
[4] W.M. Higgins, A. Churilov, E. van Loef, J. Glodo, M. Squillante and K. Shah, J. Crystal Growth, In Press, Accepted Manuscript.
[5] R. Hofstadter, "Europium-activated Strontium Iodide Scintillators," US Patent 3,373,279 (1968).
[6] N. J. Cherepy, G. Hull, A. D. Drobshoff, S. A. Payne, E. van Loef, C. M. Wilson, K. S. Shah, U. N. Roy, A. Burger, L. A. Boatner, W.-S. Choong and W. W. Moses, Appl. Phys. Lett, To be published.

Tuesday AM I: Stanley 105-2

Scintillators with Potential to Supersede LaBr3

Nerine Cherepy, Lawrence Livermore National Laboratory
Stephen Payne, Giulia Hull, Joshua Kuntz, Jeffery Roberts, Stephen Asztalos, Douglas Manatt, Alexander Drobshoff, Robert Sanner, Thomas Tillotson, Scott Fisher (LLNL); Edgar van Loef, Cody Wilson, Kanai Shah (RMD); Utpal Roy, Rastgo Hawrami, Arnold Burger (Fisk Univ.); Lynn Boatner (ORNL), Woon-Seng Choong, William Moses (LBNL)

Use of gamma ray spectroscopy for isotope identification requires adequate energy resolution, and is also enhanced by the high effective atomic number of the detector material. The inorganic scintillator currently providing the highest energy resolution is LaBr3(Ce), ~2.6% at 662 keV,1-3 but it is highly hygroscopic, possesses intrinsic radioactivity due to the presence of primordial 138La, and its crystal growth is still challenging. We have identified new materials offering higher effective Z than LaBr3(Ce), light yields adequate to achieve energy resolution in the 2-3% range, and no intrinsic radioactivity. Methodology for selecting promising candidates, as well as progress in growth and performance of new iodide crystals and oxide ceramics will be discussed. Our search has been guided by potential for high resolution, prospects for good light yield proportionality, stopping power, crystal growth/phase transitions, deliquescence, optical properties, photodetector spectral response and noise, and other considerations. We selected the alkaline earth halide family for study, since CaI2, while difficult to grow due to its hexagonal structure, exhibits an excellent light yield (~100,000 Ph/MeV). We have found both BaI2 and SrI2 to be readily growable. The first SrI2(Eu) crystal we tested provided energy resolution of 3.7%, which we expect can be improved based on its light yield (>85,000 Ph/MeV) and its excellent light yield proportionality (Fig. 1, 2).4 For selection of oxide ceramics candidates, cubic structures that accommodate Ce3+ were identified. We found that Gadolinium and Terbium-based garnets are amenable to ceramics processing, exhibit very high light yields and (Fig. 3) adequate proportionality, but have defect populations that lead to afterglow which must be suppressed. Ultimately, the energy resolution from scintillator detectors will reach achievable limits with the use of scintillators exhibiting the most proportional and highest light yields, and when light collection and detection are optimized. To this end, we have identified several technological advances to maximize optical transfer and uniformity that, combined with the promising new scintillator materials we are developing, could lead to a 2% resolution scintillator detector.

Tuesday AM I: Stanley 105-3

Novel Mixed Elpasolite Halide Scintillators for Gamma Radiation Detection

Steven Duclos, GE Global Research
Samual Camardello, Holly Comanzo, Adrian Ivan, Alok Srivastava (GE Global Research)

In this paper we report on novel mixed elpasolite compositions with general formula A2BLnX6:Ce, and describe the influence on the Ce3+ scintillating efficiency and phase formation with increasing concentration of I- substitution on the anionic sub-lattice. The results show that the scintillating efficiency of the Ce3+ ion in iodine-substituted

materials exceeds that of the pure chloro and bromo-elpasolites. These compositions are currently being optimized and several specimens have already been grown as single crystals. We will report on the optical properties of the obtained compounds, in particular the Ce^{3+} emission under UV excitation, the light yield under X-ray excitation, and the light yield and spectral resolution under gamma radiation. Due to their performance under high-energy radiation, its high effective Z, the lack of natural radioactive elements in their composition, and reduced thermal anisotropy upon cooling, these compositions may become an important class of materials for radioisotope identification, in particular when integrated into HPRDS and ASPs.

This work was supported by the Domestic Nuclear Detection Office at the Department of Homeland Security.

Scintillation Properties of Undoped and Cerium Doped $LiGdCl_4$ and $NaGdCl_4$

Yetta Porter-Chapman, Lawrence Berkeley National Laboratory(LBNL)
LaToria Wiggins, Floyd James (North Carolina A&T State University); Edith Bourret-Courchesne, Marvin Weber, Stephen Derenzo (LBNL)

We report the scintillation properties of two compounds: $LiGdCl_4$ and $NaGdCl_4$. Powder samples of the undoped and cerium-doped (0.0 - 20.0 molar %) phases exhibit significant scintillation under x-rays. Previous studies of ternary lanthanide halide scintillators of general formulas A_3LnX_6 and A_2LnX_5 have revealed significant light outputs originating from their undoped STE and lanthanide doped luminescence.[1-6] $LiGdCl_4$ and $NaGdCl_4$ scintillators have higher densities than their ternary counterparts in the A_3LnX_6 and A_2LnX_5 families[1-2] and are less hygroscopic than $GdCl_3$. Powder samples of these materials were synthesized by solid state methods from a 1:1 molar ratio of lithium or sodium chloride and gadolinium chloride. The physical, optical, and scintillation properties of these materials were analyzed by powder x-ray diffraction, photoluminescence, pulsed x-ray, and x-ray excited luminescence measurements. Increases in light yields and decreases in light decays are observed as the concentration of cerium increases. In particular, $LiGdCl_4$: 0.5 % Ce^{3+} exhibits a high light yield resulting from a combination of Gd^{3+} and Ce^{3+} luminescence. The highest light yields and shortest decay times occurred at 20 % cerium doping for both compounds. At larger concentrations neither compound formed, indicating a breakdown of the lattice with the addition of large amounts of cerium cations. At 20.0% cerium, $LiGdCl_4$ and $NaGdCl_4$ display scintillation light 3.5 times and 2.1 times the light yield of YAP : Ce^{3+} standard phosphor powder, respectively. Both emit at approximately 350 and 370 nm and display multi-exponential decays with major components at 29 ns ($LiGdCl_4$) and 40 ns ($NaGdCl_4$).

[1] Inorganic Crystal Structure Database (ICSD), Karlsrube, Germany: Fachinformationszentrum Karlsrube, 2006.
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[3] H. J. Seifert, J. Sandrock, and G. Thiel, "Ternary chlorides in the systems $ACl/GdCl_3$ (A = Na - Cs)," Z. Anorg. Allg. Chem., vol. 598/599, 1991, pp. 307-318.

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[5] C. M. Combes, P. Dorenbos, C.W.E. van Eijk, K.W. Kramer, H.U. Gudel, "Optical and scintillation properties of pure and Ce3+ -doped Cs2LiYCl6 and Li3YCl6 : Ce3+ crystals," J. Luminescence, 82, 1999, 299-305. [6] P. Dorenbos, "Scintillation mechanisms in Ce3+ doped halide scintillators," Phys. Stat. Sol. A202, 2005, 195-200.
Acknowledgements: This work was supported by the U.S. Department of Homeland Security and carried out at the Lawrence Berkeley National Laboratory under U.S. Department of Energy Contract No. AC02-05CH11231 and by a grant from the Department of Energy, National Nuclear Security Administration NA-22 (Non-proliferation) program.
Funding for the work of LaToria Wiggins and Floyd James was provided by the the Director, DOE Office of Science FaST program.

Tuesday AM I: Stanley 105-5

High Light Yield Scintillator: YI3:Ce

Jarek Glodo, Radiation Monitoring Devices Inc. (RMD)
E. V. D. van Loef, K. S. Shah (RMD)

YI3 doped Ce is a new addition to family of high light yield rare-earth iodide scintillators that are being actively explored at RMD. This family includes LuI3, GdI3 and recently examined solid solutions of these compositions. It has been showed that these materials not only exhibit high light yield [1], but they are also capable of achieving high energy resolution (3.3% FWHM at 662 keV [2]). Investigated YI3 crystals were grown at RMD using the Bridgman method. A typical boule size was 6 mm diameter and a ~2-3 cm long. The grown crystals have a greenish color. Similar to other iodides in the family YI3 has a layered structure. We grew and tested crystals with Ce3+ concentration varying from 0.5% to 5%. The emission spectra, energy spectra, non-proportionality and decay times were collected. Typical emission spectrum of YI3:Ce spans a broad band from 450 to 700 nm peaking at 530 nm, and unlike the emission of LuI3:Ce, its spectral distribution is practically independent of the Ce concentration. The scintillation under gamma excitation is fast and decays with the time constant between 30 and 45 ns (major component), depending on the Ce concentration. The rise time changes with the concentration, as well. It is the slowest for the 0.5% sample, and becomes faster as the Ce concentration increases. The light yield of all investigated crystals reaches 100,000 photons/MeV, with the exception of the 0.5% sample.

Silicon Detectors

Tuesday AM I: Bechtel

Chair: Gianluigi de Geronimo, BNL

Tuesday AM I: Bechtel-1

Characteristics of 3D Micro-Structured Semiconductor High Efficiency Neutron Detectors

Steven L. Bellinger, Kansas State University
Douglas S. McGregor, Walter J. McNeil, Eric L. Patterson, Troy C. Unruh (Kansas State University)

Silicon diodes with large aspect ratio perforated micro-structures have been filled with 6LiF and show a dramatic increase in neutron detection efficiency beyond that of conventional thin-film devices. This work employs the same technology, but with increased structure depths to achieve unmatched solid state neutron detection efficiency. The highest efficiency devices thus far have delivered over 30% thermal neutron detection efficiency at an operating bias of 3 volts. Sinusoidal trench and straight trench perforated devices of 200 microns in depth have been fabricated and filled with 6LiF neutron absorber material. Neutron response for the sinusoidal and strait trench devices have been theoretically modeled and experimentally found. This work is part of on-going research to develop a solid state semiconductor neutron detector with high detection efficiency and a uniform angular response.

Tuesday AM I: Bechtel-2

Monolithic Pixel Sensors in 0.15micron Silicon-On-Insulator Technology

Professor Marco Battaglia, UC Berkeley and LBNL
Devis Contarato (LBNL, presenting), Dario Bisello (INFN Padova, Italy), Peter Denes (LBNL), Piero Giubilato (LBNL and INFN Padova, Italy), Lindsay Glesener (UC Berkeley and LBNL), Chinh Vu (LBNL)

A monolithic pixel sensor has been design and fabricated in a novel deep-submicron fully-depleted Silicon-On-Insulator (SOI) CMOS technology. A thin layer of silicon electronics is isolated from a high-resistivity silicon substrate. The latter can be contacted from the electronics layer by means of vias through the buried oxide, so that pixel implants can be created and, above all, the substrate can be depleted as in standard reversely-biased silicon detectors. Hence, this technology is of great interest for its potential to implement complex architectures, featuring high speed and low power dissipation designs, combined with a high-resistivity, depleted substrate ensuring large signals and fast charge collection. The first prototype chip features pixels of 10 micrometer pitch arrayed in two analog sections (with 1.0 V and 1.8 V operating voltages) and one digital section with a comparator and a latch integrated in each pixel. The prototype response has been extensively tested with infrared lasers and with the 1.35 GeV electron beam extracted from the injection booster at the LBNL Advanced Light Source (ALS). A significant effect of back-gating of the CMOS electronics has been observed. This is due to the electric field present in the high resistivity substrate, and limits the maximum depletion voltage that can be applied to the sensor substrate. Despite that, a signal to noise ratio of 15 and good detection efficiency were found with the analog sections of the chip for depletion voltages up to 15 V. The digital section of the chip also proved to be functional and higher substrate biases, up to 30 V, could be used. The circuitry in the digital pixels is indeed active only when the pixels are triggered, and is thus less sensitive to back-gating. Irradiation tests with low energy protons and neutrons have been performed at the LBNL 88-inch Cyclotron facility. The test of single transistor structures revealed an increased effect of back-gating as a function of the delivered proton dose, hinting at the build-up of charge trapped in the buried oxide. Moderate doses of low energy neutrons showed no significant degradation of the chip performance. These results are very encouraging for the further development of monolithic pixel sensors in SOI technology. A second prototype has been submitted in a similar fabrication process at the beginning of 2008. The potential applications for this technology range from fast and high resolution silicon detectors for high-energy physics applications to imaging in electron microscopy and synchrotron radiation applications.

Tuesday AM I: Bechtel-3

Development of a 4-Element Large Area Silicon Drift Detector Array for Synchrotron Applications

Liangyuan (Larry) Feng, SII NanoTechnology USA Inc.
V. D. Saveliev, C. R. Tull, S. Barkan, M. Takahashi (SII NanoTechnology USA Inc); J. S. Iwanczyk (Photon Imaging, Inc.), M. Rivers (Center for Advanced Radiation Sources, University of Chicago, Argonne, IL 9); G. Srajer, A. Miceli, K. Attenkofer, J. Maser (Advanced Photon Source, Argonne National Laboratory)

We will introduce a novel, 4-element Silicon Drift Detector (SDD) array for use in synchrotron applications in place of traditional liquid nitrogen cooled multi-element germanium detectors. The SDD element is fabricated on ~0.35 mm thick, high resistivity n-type silicon with an active area of ~45 mm2, featuring extremely low capacitance (~0.06pF) and thus excellent energy resolution (optimum Mn K-alpha FWHM < 130 eV) and up to ~500 kcps output rate at 0.25 microsecond peaking time. The 4-element SDD array offers a total of ~180 mm2 active area with a maximum output rate up to 1.5 - 2 mcps. Vacuum-sealed by a 12.5 micron beryllium window, the four SDD elements are in a square-arrangement around the center and are cooled using separate Peltier coolers with the heat removed through an innovative heat pipe heat transfer system. The SDD array spectrometer utilizes the X-ray Instrumentation Associates (XIA) 4-channel digital pulse processor, DXP-xMAP, in conjunction with the National Instruments PXI/CompactPCI module, offering 4 MB on-board high speed memory and ~100 MB/sec data transfer speed.

Tuesday AM I: Bechtel-4

Characterization and Calibration of PILATUS II Detectors

Philipp Kraft, Paul Scherrer Institut (PSI), Switzerland
Anna Bergamaschi (PSI); Christian Broennimann (Dectris Ltd. and PSI); Roberto Dinapoli (PSI); Eric Eikenberry (Dectris Ltd., Switzerland); Beat Henrich, Ian Johnson, Aldo Mozzonica, Bernd Schmitt (PSI)

PILATUS is a silicon hybrid pixel detector system for detecting X-rays in single photon counting mode with a dynamic range of 10^6 per pixel. The PILATUS detectors are modular with 16 radiation tolerant PILATUS II chips bump-bonded to one single Si-Sensor. The active area of a module is 84 x 34 mm^2 comprising 94'965 pixels with a pitch of 172 mu^2. We achieve bump-bonding yields of 100 %. The maximum frame rate of the modules is 200 Hz. The modules were calibrated and characterized with monochromatic X-r ays. An algorithm to adjust pixel thresholds individually based on X-ray flat-field images was developed improving the threshold dispersion of a module to 47 eV. By the means of trim files and a threshold-energy calibration any required threshold can be set above the noise between 2.14 keV and 22 keV. The dead time of the pixel was determined allowing for online rate correction and the maximum detectable incident rate was found to be 8 x 10^6 photon/s/pixel. Based on the Pilatus modules, different detector geometries have been realized, ranging from 6 megapixels (Pilatus 6M), 2 megapixels (Pilatus 2M) to 0.5 (Pilatus 500K) and 0.1 megapixels (Pilatus 100K). The PILATUS modules are applicable for various applications such as X-ray diffraction, small angle X-ray scattering (SAXS) and X-ray imaging techniques.

Tuesday AM I: Bechtel-5

Charge Collection Efficiency Measurements of Heavily Irradiated Segmented P-Type Silicon Detectors for Use at the Super-LHC

Anthony Affolder, University of Liverpool
Gianluigi Casse, Prof. Phil Allport (Oliver Lodge Laboratory, Department of Physics, University of Liverpool)

The planned luminosity upgrade of the Large Hadron Collider at CERN (Super-LHC) will provide a challenging environment for the tracking and vertexing detector systems. With a proposed nearly 10-fold luminosity increase to 10^35 square centimetres per second, the innermost devices will have to be able to withstand a charged hadron dose on order of 1x10^16 1 MeV neutron equivalent particles per square centimetre over the anticipated 5 year lifespan of the experiments. Planar, segmented silicon detectors with n-strip readout are one of the many radiation tolerant technologies under consideration for use for the Super-LHC tracking detectors in either pixel or strip geometries. This presentation details measurements made with n-strip planar devices that have been irradiated to doses as high as 1x10^16 neq cm-2 with reactor neutrons and fast protons. The doses under study cover the expected range of final fluences for the different tracking systems of the ATLAS and CMS experiments at the Super-LHC. The measurements have been carried out using analogue, high-speed (40MHz) electronics and a Strontium electron source. The effects of the initial substrate resisitivity and of the choice substrate type (float zone or magnetic Czochralski) on the collected charge have been measured. These measurements are intended as a reference of the expected collected charge by segmented devices at these extreme doses and as an input to the design of the readout electronics necessary for the various pixel and micro-strip tracking subsystems planned to be used at the Super-LHC.

Gas-Based, Light, and Radio Detectors

Tuesday AM I: 106 Stanley

Chair: David Nygren, LBNL

Tuesday AM I: 106 Stanley-1

Study Of Electroluminescence Light In Low Pressure CS2-Ne And CS2-CF4 Gaseous Mixtures

Kirill Pushkin, Occidental College

The Directional Recoil Identification From Tracks (DRIFT) detector has been proposed to search for Dark Matter in Galaxy. The DRIFT detector is based on low pressure (40 torr) electronegative gas - carbon disulphide (CS2) to drift negative ions instead of electrons to drastically reduce lateral and longitudinal diffusion of the charged tracks what makes this detector unique. One of the current crucial problems of the detector is a natural radioactive background due to 222Ra progeny plating out on the central cathode wires of the DRIFT detector. This alpha decay occasionally producing alphas which deposit their energy in the wire and producing Pb (214Pb, 210Pb, 206Pb) recoils in the gas which mimic the WIMP recoils DRIFT seeks to detect. We show that Pb recoils exiting the central cathode wires can be made to scintillate, providing us with a veto for such events, by adding Ne or CF4 to the CS2 gas.

Tuesday AM I: 106 Stanley-2

Recent Developments Of Micromegas Detectors For Neutron Physics

Samuel Andriamonje, CEA-Saclay DSM/IRFU/SPHN

After a short description of the Micromegas principle, a new concept of neutron detectors based on this technique is presented. It is illustrated by an overall picture of the possible use of these detectors in different domain such as: nuclear physics, inertial fusion and industrial application. A particular description will be devoted to the compact detector named "Piccolo- Micromegas". This detector, able to measure neutron flux in a broad range of energy of neutron, is developed for the measurements of neutrons flux in-core of the future generations of the nuclear reactors.

Tuesday AM I: 106 Stanley-3

Techniques for Radio Detection of Ultra-High Energy Cosmic Rays

Hartmut Gemmeke, Forschungszentrum Karlsruhe

Radio signals emitted from electromagnetic showers in air can be used as an additional new technique for the detection of ultra high energetic cosmic rays or neutrinos at energies above 10**18 eV. The LOPES experiment in Karlsruhe demonstrated that the radio flashes emitted from cosmic showers in the atmosphere can be understood in terms of the coherent radio emission of the geo-synchrotron effect seen in the frequency range of 30 to 80 MHz. More than 90% of the created particles in a high energetic shower are electrons and positrons. These particles are mostly absorbed in the atmosphere but create by their interaction with the geomagnetic field of the earth synchrotron radiation narrowly focussed into the direction of the shower. The atmosphere is transparent to the radio emission, which can be observed at the ground level as bolometric sum of all emissions of the individual particles. In addition, due to the ultra-relativistic shower front with a thickness of one to several meters the radio emission of the shower is coherent. The results from the LOPES collaboration show that it is possible to determine the direction and energy of the incoming cosmic particle, and the composition of ultra high-energy cosmic rays may be also analyzed by the lateral distribution of the emission, which is related to the longitudinal shower development. In addition to the KASCADE-Grande experiment in Karlsruhe the environment of the southern site of the Pierre Auger Observatory is now used to test this new technique up to the highest energies. Cosmic rays with energies above 10**18 eV are rare and need a large antenna array for sufficient detection efficiency. To guarantee the application of an antenna array as instrument for the detection of air showers cost effective new antennas, and on line self-trigger systems have to be developed. In a larger field of detection an overall radio quiet region can't be guaranteed. Therefore trigger with effective suppression of radio interferences and transients had to be developed. A FPGA based self-trigger was designed with the help of external triggered data. As antenna a logarithmic periodic dipole antenna is under use and a simple cross-polarized short-loaded Beverage-antenna is now proposed. This type of antenna has the right direction sensitivity, has real impedance, and is very cost effective as it is necessary for a larger array. The frequency-dependency of the antenna gain fits perfectly to the atmospheric and galactic noise level. The overall electronics including trigger has a power budget as low as 5W. The applied techniques and experiments will be described. Furthermore the amplification effect of thunderstorms on radio signals from cosmic showers was also measured but gives at periods of non-thunderstorm conditions -- including cloudy sky -- no measurable distortion of the radio signal. That is an essential requirement for the application of radio detection of Ultra High Energy Cosmic Rays.

Tuesday AM I: 106 Stanley-4

Detection of Special Nuclear Material with a Water Cerenkov based Detector

Steven Dazeley, Lawrence Livermore National Laboratory (LLNL)
Robert Svobda, Adam Bernstein, Nathaniel Bowden (LLNL)

Special Nuclear Material (SNM) emits both neutrons and high energy gamma-rays either spontaneously or via induced fission. The detection of these signatures within a cargo container has recently become a high priority area of study, however, most cargo radiation detectors being developed rely primarily on the gamma-ray component to detect SNM. High energy gammas (>3MeV) and neutrons are particularly penetrating and may represent the best chance to detect such particles in a shielded cargo scenario. It may indeed be possible to detect SNM within sophisticated shielding with a detector that efficiently covers an extremely large solid angle. The LLNL advanced detector group is designing and building a water Cerenkov based gamma and neutron detector for the purpose of developing an efficient and cost effective way to deploy a large solid angle "car wash" style detector. We have built and deployed a small prototype water Cerenkov detector and tested it with a 252Cf fission source. We will explain the reasons for using water Cerenkov rather than scintillator and present some preliminary results from our prototype detector that indicate that we have detected neutrons.
This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

Tuesday AM I: 106 Stanley-5

Neutron Gas Detectors for Instrumentation on New Spallation Sources

Bruno Guerard, Institut Laue-Langevin
JF. Clergeau, JC. Buffet, S. Cuccaro, F. Horst, G. Manzin, F. Millier, J. Pentenero, M. Platz, P. Van Esch, G. Viande (Institut Laue-Langevin, Grenoble, FR)

Several of the neutron gas detectors recently introduced at the Institut Laue-Langevin or in development are strong candidates for the spallation sources SNS and J-PARC. In particular for SXD (Single Crystal Diffractometry): 1/ The curved two-dimensional MWPC in operation on the D19 instrument is operational since 2006; its main feature is an unequalled angular range of 120 x 29 degrees; 2/ The MILAND (MIllimetre resolution Large Area Neutron Detector) aims to deliver a detector with a sensitive area of 32 cm x 32 cm, and a pixel size of 1 mm x 1 mm; it is based on an MWPC using a sealed double pressure vessel filled at 15 bars and includes 640 individual readout channels, 3/ A new detector concept known as the Multi-blade is currently being studied with a view to designing a cylindrical gas detector. In order to suppress the parallax effect inherent in gas converters and to optimise detection efficiency, it uses solid converters mounted with a small angle to the incident neutrons, 4/ Other detectors currently in development will push forward the limit of counting rate, in particular the "Hexagonal MWPC" which includes an additional readout electrode to solve simultaneous events, and the MSGC with parallel charge division readout. For time-of-flight spectrometry, requiring very large area detectors, the Multitube technique allows good quality mass production at a reasonable cost. For example, the IN5 instrument includes 12 identical detection modules mounted in a very large vacuum chamber, covering a sensitive area of 30 m2 in total. Each module is made up of 32 stainless steel tubes 3 m long, welded side by side on a common gas vessel. The design and manufacture of these detectors, as well as the experimental results, will be presented.

Ceramic Scintillators

Tuesday AM II: Stanley 105

Chair: Steve Payne, LLNL

Tuesday AM II: Stanley 105-1

Sintered Sodium Iodide: High Throughput NaI:TI Process

Kevin P McEvoy, GE Global Research
Steven J Duclos, Carl J Vess, Alok M Srivastava, Hrishikesh Keshavan, Venkat S Venkataramani, Adrian Ivan

NaI (Tl) scintillators demonstrate good energy resolution at ambient temperatures enabling spectroscopic radiation detection of radionuclides. Currently this material is ubiquitous for healthcare and security applications involving single crystal material. However large single crystal applications are limited due to several constraints. It is prohibitive to fabricate high quality large volume single crystals, due to the labor, time and equipment costs. Increases in crystal size result in challenges with TI uniformity and optical quality. Sintered polycrystalline NaI (Tl) material may solve problems associated with traditional processes. The benefits would be reducing manufacturing cost and improved activator homogeneity, without compromising on the scintillation properties. The ability to utilize a sintering process to obtain polycrystalline alkyl halides has been explored. We will discuss the recent results from experiments on processing of polycrystalline sintered NaI (TI).

Tuesday AM II: Stanley 105-2

GE Healthcare's New Computed Tomography Scintillator -- Gemstone

James Vartuli, GE Global Research
Robert J. Lyons, Carl J. Vess, Kevin P. McEvoy, Randy S. Hagerdon, Steven J. Duclos (General Electric Global Research); Mohandas Nayak (General Electric John F. Welch Technology Center, Bangalore, India); Haochuan Jiang (General Electric Healthcare)

GE Healthcare announced its latest Computed Tomography (CT) concept at the 2007 Radiological Society of North American (RSNA) in late November. Called HDCT (High-Definition CT), this new technology has potential for a step-function improvement in image quality while reducing patient dose. One of the key technologies is a new scintillator called "Gemstone." Reformulated from the garnet gemstone structure, this transparent ceramic was invented and developed to meet the stringent demands of artifact-free imaging. The garnet ceramic platform enables precise composition control (at the tens of ppms levels) and greater homogeneity than single crystals. We will discuss the processing steps required to achieve superior performance across all necessary properties: primary speed, afterglow, radiation stability, chemical stability, mechanical strength.

Tuesday AM II: Stanley 105-3

Development of ZnO-based Polycrystalline Ceramic Scintillators for Use as Alpha-Particle Detectors

John S. Neal, Oak Ridge National Laboratory (ORNL)
David M. Devito (ORNL); Mei Hong (University of California, Davis); Banu Kesanli, Joanne O. Ramey, Beth L. Armstrong (ORNL); Xiaocheng Yang, Nancy C. Giles (West Virginia University); Jane Y. Howe, Dariusz J. Wisniewski, Monika Wisniewska (ORNL); Zuhair A. Munir (University of California, Davis); Lynn A. Boatner (ORNL)

ZnO-based scintillators are particularly well-suited for use as the associated particle detector in a deuterium-tritium (D-T) neutron generator. Application requirements include the exclusion of organic materials, outstanding timing resolution, and high radiation resistance. ZnO, ZnO:Ga, ZnO:In, ZnO:In,Li, and ZnO:Er,Li have demonstrated fast (sub-nanosecond) decay times with relatively low light yields. ZnO:Ga has been used in a powder form as the associated particle detector for a D-T neutron generator. Unfortunately, detectors using powders are difficult to assemble and the light yield from powders is less than satisfactory. Single crystal ZnO of sufficient size has only recently become available, and the scintillation properties of these specimens are, as yet, unknown. New applications for D-T neutron generators require better timing resolution and higher count rates than are currently available with associated particle detectors using YAP:Ce as the scintillator. Recent work suggests that ZnO-based scintillators can provide alpha-particle-excited light yields comparable to YAP:Ce scintillators. ZnO-based polycrystalline ceramic scintillators offer the advantages of high light yield, ease of fabrication, low cost, and robust mechanical properties. Precursor powders used in these studies include ZnO and ZnO:Ga powders synthesized using solution phase, urea precipitation, and combustion synthesis techniques as well as ZnO powder from a commercial vendor. Precursor powders have been sintered using uniaxial hot pressing and spark plasma sintering techniques. The best results to date, in terms of dense, stable bodies that scintillate, have come from those sintered bodies using the commercial ZnO precursor powders. X-ray-excited scintillation and photoluminescence measurements have confirmed that the emissions from these sintered bodies consist primarily of slow, visible emissions rather than the desired, sub-nanosecond near-band-edge emissions. Subsequent hydrogen treatments of the ceramic bodies have, as yet, not improved the scintillation characteristics of the ceramic bodies.

Research carried out in the Center for Radiation Detection Materials and Systems at ORNL is supported by the NNSA Office of Nonproliferation Research and Engineering (NA-22), USDOE and by the U. S. Department of Homeland Security, Domestic Nuclear Detection Office.

Tuesday AM II: Stanley 105-4

Transparent Lu2SiO5:Ce Optical Ceramic Scintillator

Yimin Wang, Radiation Monitoring Devices, Inc. (RMD)
Edgar Van Loef (RMD);Bill Rhodes (ALEM Associates), Jarek Glodo (RMD); Charles Brecher, Alex Lempicki (ALEM Associates); John Certorino, William M. Higgins , Kanai S. Shah (RMD)

Lutetium oxyorthosilicate (Lu2SiO5: Ce3+) (LSO) is a well known scintillator that is used in gamma-ray spectroscopy and medical imaging applications such as Positron Emission Tomography (PET) because of its high light output, high gamma ray stopping power and fast response. However, high melting point and modest yield of LSO single crystals elevate the cost of producing high quality single crystals. Alternatively, the relative low processing temperature for polycrystalline ceramic offers the possibility of obtaining inexpensive LSO for PET. However, unlike cubic isotropic ceramic peers such as Y2O3 and rare-earth garnets, the monoclinic-structured LSO ceramic is anisotropic with different refractive indices along different crystallographic planes, which makes obtaining transparent polycrystalline LSO ceramics challenging. In this study, optically transparent LSO ceramic was prepared by a nano-technology approach. XRD examination confirms the presence of single-phase LSO. The density of the ceramic was found to increase with sintering temperature due to the elimination of pores. Further SEM examination confirms the decrease of the porosity with increasing temperature. Finally, to further densify the LSO ceramic and eliminate the porosity, the sintered LSO ceramic was hot isostatic pressed (HIPed). Transparent polycrystalline LSO ceramics are obtained after the final HIPping. XRD examination confirms single LSO phase. Optical characterization and scintillation properties of LSO:Ce ceramic are examined in this study and the results are compared to those of LSO and BGO single crystals. Light output under gamma-ray excitation is investigated by using different excitation sources (137Cs, 22Na, 241Am and 122Co). A light output as high as 30,100 ph/MeV was obtained using a 22Na excitation source. LSO ceramic shows an energy resolution of 15% (FWHM) at 662 keV (137Cs source). LSO ceramic shows a fast scintillation decay of 40 ns due to the 5d to 4f transition of Ce3+. In summary, phase pure transparent LSO ceramic was obtained with its scintillation properties rivaling those of single crystalline LSO, which makes LSO ceramic a promising candidate for gamma-ray spectroscopy as well as medical imaging applications such as PET .

Tuesday AM II: Stanley 105-5

Fabrication of ZnSe:Te by Hot Pressing Techniques

Steven Cool, Radiation Monitoring Devices, Inc. (RMD)
<u>Vivek Nagarkar, presenting</u>
Stuart Miller (RMD); Charles Brecher, Helmut Lingertat (ALEM Associates), Vinod Sarin (Boston University), Vivek Nagarkar (RMD)

We have recently fabricated tellurium-doped zinc selenide (ZnSe:Te) in a robust optical ceramic form, in the first synthesis of this remarkable material from a precursor powder, using powder consolidation techniques. We utilized two techniques in particular -- hot isostatic pressing and hot

pressing --in order to achieve the desired physical and chemical properties, and we are continuing our efforts to refine processing methodologies and parameters to improve this material's physical characteristics and performance. ZnSe:Te promises major advances in radiation imaging and spectroscopy applications with its potential of well over 100,000 photons/MeV brightness, fast emission (~3 usec and ~40 usec), negligible afterglow (<0.05% at 6 ms), high density (>5.2 gm/cc), light emission in the visible range (610-650 nm), and extraordinary radiation hardness (10^6 Gy). This paper will describe our fabrication methods and report our preliminary performance characterization results.

This project was partially funded by Department of Defense/DTRA Grant No. HDTRA 1-07-P-0242. We thank Bruker AXS and Bodycote Hot Isostatic Pressing for their technical assistance and support in this effort.

CdZnTe/CdTe Detectors and Imagers

Tuesday AM II: Bechtel

Chair: Ralph James, BNL

Tuesday AM II: Bechtel-1

Characterization of 10 mm Thick Pixellated Redlen CdZnTe Detectors

Feng Zhang, University of Michigan
Zhong He, Willy Kaye, Yuefeng Zhu, Steve Anderson (University of Michigan)

Ten 20*20*10 mm^3 pixellated CdZnTe detectors fabricated by Redlen Technologies Inc. were characterized using the VAS_UM/TAT ASIC readout system. Three of them have 11 by 11 pixel anodes with a common anode-grid surrounding pixel electrodes, and the other seven have 11 by 11 simple pixels without the grid. All detectors have identical pixel pitch of 1.72 mm. Each detector was connected to a VAS_UM2.3/TAT4 ASIC. Signals of the 121 pixels and the cathode are read out by the ASIC for each triggered event. The cathode break-down bias voltage was determined by observing the break-down pulses in the pre-amplifier signal of the cathode, and was found to be in the range from -1000V to -3000V. It was discovered that the surface resistance between some pixels and the anode grid are low, causing high-noise pixels and excessive grid-pixel leakage current. The single-pixel events energy resolution of these detectors ranges from ~1.0% to ~1.5% FWHM at 662 keV. After being annealed at 90 degrees C for 8 hours, most detectors showed improvements of lower electronic noise, higher cathode break-down voltage and better energy resolution (~0.9% to 1.3% FWHM at 662 keV). The performance of these detectors are presented and discussed in this paper.

Tuesday AM II: Bechtel-2

Investigation of Internal Electric Field Distribution in CdZnTe Detectors By Using X-Ray Mapping Technique

Aleksey Bolotnikov, Brookhaven National Laboratory (BNL)
G. S. Camarda, Y. Cui, A. Hossain, G. Yang, R. B. James

Ideal operation of many CdZnTe devices relies on a uniform distribution of the internal electric field. A uniform E field is especially critical in the case of thick long-drift-length detectors such as large-volume CPG and 3-D multi-pixel devices. Using a high-spatial resolution X-ray mapping technique, we investigated the distribution of the electric field in the real devices. Our measurements demonstrate that the electric field lines have a tendency to bend away from the side surfaces (i.e., a focusing effect). However, in most cases the field line distribution is found to be perturbed by the presence of extended defects and residual strains existing inside the crystals. Data clearly demonstrating the non-uniformity of the internal E field will be presented.

Tuesday AM II: Bechtel-3

The Experimental Results of a Gamma-Ray Imaging with a Si/CdTe Semiconductor Compton Camera

Shin'ichiro Takeda, ISAS/JAXA
Hiroyuki Aono, Shin-nosuke Ishikawa, Hirokazu Odaka, Shin Watanabe, Motohide Kokubun, Tadayuki Takahashi (ISAS/JAXA); Sho Okuyama, Kazuhiro Nakazawa (Univ. of Tokyo); Hiro Tajima (SLAC)

A gamma-ray imaging detector is required in various fields such as high-energy astrophysics, medical imaging and nondestructive inspection. We have proposed a concept of the Si/CdTe semiconductor Compton camera, which consists of many layers of thin Si and CdTe detectors. The Si/CdTe Compton camera features high energy resolution and high angular resolution. Recently, we developed a new Compton camera system for a balloon borne astrophysical experiment. It consists of a 4-layers stack of double-sided silicon strip detector (DSSD) modules (SPIE newsroom 2008. in press) and 32 CdTe pad detectors symmetrically surrounding the DSSD stack. The Compton reconstruction was successfully performed and the gamma-ray images were obtained from 662 keV down to 59.5 keV. The Angular Resolution Measure (ARM) is 3.5 degree (FWHM) and 2.5 degree (FWHM) at 356 keV and 511 keV, respectively. In order to evaluate the causes of the ARM distribution, we performed Monte Carlo simulations based on the Geant 4 simulation toolkit. In the simulation, we assumed the effects of the position and energy resolutions of the detectors, and the Doppler broadening effect. The experimental energy dependance of ARM distribution was well reproduced by the simulation. According to the simulation, the Doppler broadening which determines the theoretical limit of Compton imaging is the dominant cause of the ARM distribution below 350 keV gamma-rays. Thus, our Compton camera achieved the theoretical limit in the energy band. In the higher energy band, the effect of the position resolution is larger than that of the Doppler broadening. The Si/CdTe Compton camera which has such good angular resolution is also attractive for medical imaging and/or nondestructive inspection. An internal structure of about one mm can be resolved when the distance between the camera and a target becomes closer than a few mm. We developed another prototype which enable us to approach the target down to 20 mm. In this presentation, we will show the experimental results of this prototype and also discuss Compton reconstruction methods.

Tuesday AM II: Bechtel-4

High Energy Resolution Gamma-Ray Imagers Using CdTe Diode Devices

Shin Watanabe, ISAS/JAXA
Shin-nosuke Ishikawa, Hiroyuki Aono, Shin'ichiro Takeda, Hirokazu Odaka, Motohide Kokubun, Tadayuki Takahashi (ISAS/JAXA); Kazuhiro Nakazawa (University of Tokyo)

We have developed new CdTe diode imaging spectrometers using aluminum (Al) or nickel (Ni) electrodes as anodes. Conventional In/CdTe/Pt diode detectors have good spectral performance due to their extremely low leakage current under high bias voltage (> 1 kV for ~ 1 mm thick). However, since it is difficult to divide an In anode into pads, pixels or strips, only cathode segmented detectors are available. Ideally, electrons, which

have a larger mobility and a longer lifetime than holes in CdTe, have to be collected for high energy resolution, therefore, the anode side should be divided. Recently, as an electrode material, Al and Ni have been found to be good alternatives to In. In addition to low leakage current and high energy resolution comparable to those of In/CdTe/Pt detectors, Al/CdTe/Pt and Ni/CdTe/Pt detectors have an advantage that anodes can be divided. Firstly, we constructed the Al-pad/CdTe/Pt and Ni-pad/CdTe/Pt detectors, which have a pad pitch of 1.4 mm and 8x8=64 pads on the anode side. The full-width-half-maximum (FWHM) energy resolution of 1.1 and 1.8 keV at 59.5 and 122 keV, respectively, were successfully obtained, when the Al-pad/CdTe/Pt detector with a thickness of 0.75 mm was subjected to a bias voltage of 400 V and was operated at -20 degree C. The spectral performance obtained with the Al-pad/CdTe/Pt exceeded that obtained with the conventional In/CdTe/Pt-pad detector, under the same operating conditions. By dividing both anode and cathode into strips, the double sided CdTe strip detector is available. It provides a large area and a high position resolution with a relatively small number of readout channels. We developed the first prototype of the double sided CdTe strip detector by applying Al and Pt to anodes and cathodes, respectively. The prototype has 64 strips on each side. The strip pitch is 0.4 mm and the thickness of the detector is 0.5 mm. We successfully operated at -20 degree C and obtained gamma-ray images with a position resolution of 0.4 mm.

Tuesday AM II: Bechtel-5

Assessment of the Radiation Tolerance of CdZnTe and HgI2 to Solar Proton Events

Alan Owens, Advanced Studies and Technology Preparation Division, ESA/ESTEC)
V. Gostilo (Bruker Baltic Scientific Instruments), V. Ivanov (RITEC), R.W. Ostendorf (Kernfysisch Versneller Instituut, University of Groningen), F. Quarati (Advanced Studies and Technology Preparation Division, ESA/ESTEC) L. van den Burg (Constellation Technology)

Radiation effects caused by solar proton events will be a common problem for many types of sensors on missions to the inner solar system because of the long cruise phases coupled with the inverse square scaling of Solar particle events. In support of the BepiColombo and Solar Orbiter missions we have undertaken a comprehensive series of tests to assess the effects on a wide range of sensors. In this paper, we report on a comparative study of the radiation tolerance of two commonly used compound semiconductors -- cadmium zinc telluride and mercuric iodide, both of which have been proposed to form the detection planes of hard X-ray imaging systems intended for inner solar system missions. Single crystals of CdZnTe and HgI2 of dimension 10x10x2 mm^3 were fabricated into planar detectors. In total, four detectors were produced for each compound. Each set of detectors were then exposed to simulated solar proton events over the energy range 60 MeV to 200 MeV having a spectral shape approximating that of the August 1972 solar particle event but with four different fluences. One pair of detectors (a CdZnTe and HgI2) was exposed to an integral fluence of 10^8 protons cm^-2, a second to 10^9 protons cm^-2, a third to 10^10 protons cm^-2 and the fourth to 10^11 protons cm^^-2. The latter corresponds to an absorbed dose in silicon of 100 krad or in SI units 1 kGy. The tests were carried out at the Kernfysisch Versneller Instituut in Groningen, The Netherlands. A 190 MeV proton beam was extracted from the AGOR super-conducting cyclotron [1] and transported to the irradiation hall whereupon it was expanded and spatially linearized using a dual scatterfoil method. The incident spectrum at the detector was then shaped using a computer controlled energy degrader system. The detectors were characterized both before and after the irradiations in terms of energy resolution and background count rate. The energy resolutions were determined using 241Am, 57Co and 137Cs radiation sources. Typical pre-irradiation FWHM energy resolutions of 3 keV and 4 keV were recorded at 60 keV for the CdZnTe and HgI2 detectors, respectively

Cryogenic Detectors and Techniques

Tuesday AM II: 106 Stanley

Chair: Michael Rabin, LANL

Tuesday AM II: 106 Stanley-1

Liquid Xenon Time Projection Chamber for LUX

Adam Bradley, Case Western Reserve University

[Adam Bernstein, LLNL, will present a substitute talk regarding LUX]

LUX is a new dark matter search experiment to be carried out in the renewed underground laboratory at the Homestake (SD) old gold mine. The detector's large size supports effective internal shielding from natural radioactivity of the surrounding materials and environment. The LUX detector consists of a cylindrical vessel containing 350 kg of liquid xenon (LXe) cooled down using a novel cryogenic system. We tested a small-scale four PMT prototype utilizing over 200 gm of active xenon, installed in the full-sized cryostat. We report the efficiency of a unique internal heat exchanger and liquid level stabilizer system, with standard gas phase purification with a heated getter, which allows for very high flow purification without requiring large cooling power. A stable LXe surface is required for good energy resolution. Such a system is required for multi-ton scale up.

Tuesday AM II: 106 Stanley-2

Ultra-High Resolution Alpha Particle Spectroscopy Using Superconducting Microcalorimeter Detectors

Robert Horansky, National Institute of Standards and Technology (NIST)
J.N. Ullom, J.A. Beall, G.C. Hilton, K.D. Irwin (NIST); D.E. Dry, M.W. Rabin, E. Hastings, S.P. Lamont, C.R. Rudy (Los Alamos National Laboratory)

Alpha spectroscopy is the preferred technique for analyzing trace samples of radioactive material because the alpha particle flux from many materials of interest is significantly higher than the gamma-ray flux. Traditionally, alpha spectroscopy is performed with silicon detectors whose resolution is limited to 8 keV FWHM or higher for 5 MeV alpha particles. Here, we describe the design and operation of a superconducting microcalorimeter alpha detector with energy resolution of 1.4 keV FWHM at 5 MeV. We demonstrate the ability of the microcalorimeter to clearly resolve the alpha particles Pu-239 and Pu-240 at 5.157 and 5.168 MeV, respectively, in a mixed isotope Pu sample. The Pu-239/Pu-240 ratio differentiates reactor-grade Pu from weapons-grade and is a vital identifier for safeguards and materials accounting applications. Hence, our detector may eliminate the need for costly and time-consuming mass spectrometry analysis of trace Pu samples. We also demonstrate the first direct observation of the 4.885 MeV alpha decay of Po-209 to the ground state of Pb-205 which has traditionally been obscured by a much stronger alpha line 2 keV away. The unprecedented resolution of microcalorimeters may allow elements in mixed actinide samples to be individually identified and would eliminate the need for time-consuming chemical separation of these elements prior to alpha counting. Measurements of mixed actinide samples are currently under way and will be presented. Finally, the 1.4 keV resolution observed for alpha particles is far worse than the 0.12 keV resolution predicted from thermal fluctuations and measurement of lower energy gamma-rays. The cause of the resolution degradation may be ion damage in the detector. We will present modeling of ion damage statistics and compare to experiments that are now possible due to the fine resolution achieved with the microcalorimeter. The alpha particle microcalorimeter may provide a new tool for studying ion damage and lattice displacement energies in bulk materials. We also discuss the limits these phenomena impose on detector resolution and possible routes to improvement.

Tuesday AM II: 106 Stanley-3

Large-area microcalorimeter detectors for ultra-high-resolution x- and gamma-ray spectroscopy

Minesh Bacrania, Los Alamos National Laboratory
D.E. Dry, E.P. Hastings, A.S. Hoover, P.J. Karpius, C.R. Rudy (LANL); L.R. Vale (NIST, Boulder, CO); S.P. Lamont, J.H. Rim, M.W. Rabin , D.T. Vo (LANL); J.A. Beall, W.B. Doriese, G.C. Hilton, R.D. Horansky, K.D. Irwin, J.N. Ullom (NIST); C.A. Kilbourne, J.M. King, F.S. Porter (NASA Goddard Space Flight Center)

We will present a summary of our experience developing and operating the next generation of microcalorimeter spectrometer for x- and gamma-ray measurements. This spectrometer consists of an array of up to 256 ultra-sensitive cryogenic transition-edge sensors, coupled to multiplexed SQUID circuitry for readout. The entire system is located inside a mechanically-cooled cryostat, and is operated at approximately 100 mK. Our measurements to date have demonstrated unprecedented spectral resolution. Our best single-pixel resolution has been 22 eV (FWHM) at 103 keV, a factor of ~20 times better than typical high-purity germanium (HPGe) performance. We have also achieved 45-eV (FWHM) resolution with an 11-pixel array. This instrument will be valuable for nuclear materials analysis and forensics. Specifically, our current system is extremely suitable for the determination of Pu isotopic compositions, through the analysis of the 100-keV region of the gamma-ray energy spectrum. For example, we are able to separate the 98.78-keV and 98.95-keV gamma rays emitted by 239Pu and 241Am, respectively. Such performance is vital to understanding the fabrication history and intended purpose of nuclear material. We are in the process of upgrading our detector with a new 64-pixel TES array, as a step towards populating the microcalorimeter detector at full capacity with 256 pixels. A fully-populated detector will achieve efficiency comparable to a small planar HPGe detector. Along with presenting the details of our x- and gamma-ray measurements with this array, we will discuss new developments in microcalorimeter signal analysis, long-term detector system performance, and future prospects.

Tuesday AM II: 106 Stanley-4

Superconducting High- Resolution High-Speed Tunnel Junction Spectrometers for Soft X-Ray Spectroscopy

Stephan Friedrich, Lawrence Livermore National Laboratory
Simon J. George, Stephen P. Cramer (LBNL); Ludwig Fritzsch, Ronny Stolz, Viatcheslav Zakosarenko (Institute for Physical High Technology Jena); Owen B. Drury (LLNL)

Superconducting tunnel junctions (STJs) are being developed as X-ray detectors because they combine the high energy resolution of cryogenic detector technologies with the high count rate capabilities of athermal devices. We are developing STJ spectrometers for chemical analysis of dilute samples by high-resolution soft X-ray spectroscopy at the synchrotron. The instruments use 36 pixels of 200 x 200 micron Nb-Al-AlOx-Al-Nb STJs with 165 nm thick top Nb absorber films. They are operated in an adiabatic demagnetization refrigerator at the end of a cold finger at a temeprature below 0.5K within 1 cm of a room temperature sample. We have recently upgraded the cryostat to a liquid-cryogen-free refrigerator that attains the required operating temperature at the push of a button. The STJ X-ray detectors have achieved an energy resolution of ~10 - 20 eV FWHM for X-ray energies below 1 keV, and can be operated at a total count rate of ~10^6 counts/s. For increased sensitivity and operation at higher energies, we are currently developing larger STJ arrays with higher quantum efficiency. Initial results show extremely low leakage currents in the subgap region and correspondingly low electronic noise. We will discuss the performance of the instrument in fluorescence-detected X-ray absorption spectroscopy, and the most recent results on detector upgrades. We will also present speciation measurements on dopants in novel scintillator materials to illustrate the potential for STJ spectrometers at the synchrotron.

Tuesday AM II: 106 Stanley-5

Fabrication of Large Uniform Arrays of Superconducting Ultra-high Resolution Gamma Detectors

Stephan Friedrich, Lawrence Livermore National Laboratory
Presenter: Miguel Velazquez
R. Soufli, O. B. Drury, J. C. Robinson, J. G. Dreyer, S. L. Baker (LLNL)

Ultra-high energy resolution Gamma-ray detectors based on superconducting transition edge sensors (TESs) can improve the accuracy of non-destructive isotope analysis in fundamental science and nuclear non-proliferation applications. We are developing molybdenum-copper multilayer TESs that have achieved an energy resolution of ~50 - 90 eV FWHM at 100 keV and can be operated at count rates about 100 counts/s per pixel. To address concerns about the uniformity of the detector response over cm2-sized arrays, we have developed a velocity modulation algorithm during the Mo/Cu multilayer sputtering process where the 4-inch-diameter substrate is passing at a variable velocity under the sputtering target during deposition. This produces multilayers with extremely high homogeneity and lateral thickness uniformity < 0.6 % peak-to-valley across 90 mm diameter. The Mo/Cu ratio sets the transition temperature and the Mo/Cu thickness is adjusted for a resistivity matched to the readout electronics. We will present results on 112-pixel array fabrication on 4-inch substrates and discuss scaling to larger array sizes.

Wednesday, June 4
Plan of the Day

Contributed orals in parallel sessions will be given in both the morning and the afternoon.

All start and finish times in Wednesday's technical program are 30 minutes later than usual due to the Chabot dinner event. Session AM I begins at 9:30 rather than 9, and so on throughout the day.

Lunch (on your own) is 12:30-2:30. Those holding a Wednesday ticket for an LBNL tour will be guided to the shuttle-bus stop.

At 5:40 (ten minutes after the end of Session PM II) everyone signed up for the dinner event at Chabot Space and Science Center should prepare to board buses. Afterward (leaving Chabot at approximately 10 PM) the buses will return to the Doubletree, not to the campus venue. Maps will be available at the information desk for those traveling to Chabot independently.

Those who did not sign up for the Chabot dinner event may wish to ask conference staff for restaurant guides, maps, etc.

Neutron Detection with Scintillators

Wednesday AM I: Stanley 105

Chair: Marek Moszynski, Soltan Institute for Nuclear Studies

Wednesday AM I: Stanley 105-1

Improved Capture-Gated Neutron Spectrometers

J. Bart Czirr, MSI Photogenics

We have continued to improve the efficiency and extend the energy range of a heterogeneous dual-signal neutron spectrometer that was first introduced in 1989. The latest manifestation utilizes small crystals of lithium gadolinium borate scintillators to provide a confirmation signal when a neutron is captured at low energy. Incident neutron energy is obtained from the sum of several proton-recoil pulses arising in a plastic scintillators matrix containing the inorganic crystals. Incident MeV neutrons that remain within the detector body lose almost all of their kinetic energy within 50 ns and are perceived as a single light pulse from the plastic scintillators. After slowing down, the neutrons diffuse for several microseconds before capturing in Li, Gd, or B in the borate crystals. The scintillator decay time of the inorganic crystals is approximately 200 ns and is easily distinguished from the narrow recoil-proton sum pulse. In the past, we have utilized only 6Li or 10B capture pulses and have achieved a capture efficiency of 12% for fission spectrum neutrons. This capture efficiency has been improved to 15% by including Gd capture pulses. The prompt-gamma energy released upon low-energy neutron capture in Gd is approximately 8-MeV, with an average gamma energy of 1 MeV. Several gamma rays (from a single neutron capture) Compton scatter in the detector body and provide a detectable signal indicating that the neutron deposited its kinetic energy in the hydrocarbon scintillators. To extend the detector energy range beyond 10 MeV, we have performed MCNP-X Monte Carlo calculations up to 150 MeV neutron energy. The calculations indicate a dual-signal efficiency of 0.3% at 150 MeV. Experimental confirmation will be obtained at LANL later this month. It is hoped that the spectrometer will be useful for neutron dose measurements in manned space flights, and may provide measurements of neutron spectra that are presently unavailable.

Wednesday AM I: Stanley 105-2

Development of New Composite Scintillation Materials Based On Organic Crystalline Grains

Nikolai Z. Galunov, Institute for Scintillation Materials (ISM)
Eugenia V. Martynenko, Nikolai Z. Galunov, Boris V. Grinyov, Natalya L. Karavaeva (Institute for Scintillation Materials of the National Academy of Science of Ukraine); Jong Kyung Kim, Kyun Kim (Innovative Technology Center for Radiation Safety, Hanyang University), Oleg A. Tarasenko (ISM)

To have a sensitive and convenient detection technique for fast neutron spectrometry it is necessary to obtain a large area non-hygroscopic detector, which has a high efficiency of fast neutrons detection and allows discriminating neutron scintillations from background gamma radiation. Molecular organic scintillators are the most effective for detecting short-range ionizing radiation, as well as for spectrometry of fast neutrons. The main problem of such applications can be the very low flux of radiation under detection. This means that such a detector can be thin, but must have a large diameter to increase the solid angle of detection. Recently, we have proved the idea of design of new type of organic composite materials as the detectors of large area. The single crystal with perfect structure is grinded and organic single crystal grains of different sizes is obtained. A set of sieves allows selecting the fraction of these grains of necessary sizes, which has to be comparable with the range of the ionizing particle. If the chosen fractions of the grains are introduced inside a transparent polymer ma-trix, then we obtain a composite scintillator. In this work we present both the main aspects of the proposed technology, and the results of investigation of composite scintillators up 200 mm in diameter based on stilbene (or p-terphenyl) grains as detectors of short-range and fast neutron radiation.

Wednesday AM I: Stanley 105-3

New Copolymer Architectures for Next Generation Plastic Neutron Scintillators

Banu Kesanli, Chemical Sciences Division, Oak Ridge National Laboratory (ORNL)
John S. Neal, presenter
Banu Kesanli, Fengjun Hua, Kunlun Hong, Sheng Dai (Chemical Sciences Div.,, ORNL)

A new class of plastic neutron scintillators was developed based on lithium-doped polystyrene and polyethylene oxide (PS-b-PEO) amphiphilic block copolymers. In general it is challenging to synthesize lithiated plastic scintillators as hydrophilic lithium is chemically incompatible with the hydrophobic plastic host material and the organic scintillator (e.g. PPO). Our custom-designed polymer architectures allow incorporation of both hydrophobic and hydrophilic components in nano domains via controlled microphase separation, yielding novel transparent neutron scintillators. These unique plastic neutron scintillators are relatively inexpensive and potentially could be doped with sufficient concentrations of lithium without destroying the scintillator's light yield and optical transparency. Another advantage of our amphiphilic block copolymers is their compatibility with high quantum yield organic fluorophors. Novel PS-b-PEO copolymers with varying PS weight % were synthesized and doped with Li-6 and an organic fluorophor to study the effect of PS content on the light output of the plastic neutron scintillators. In addition, different forms of Li-6, namely LiOH, LiCl and Li3PO4 nanoparticles were explored to achieve high dispersion of large quantities of Li-6 into the polymer scintillators. Lithium phosphate nanoparticles showed enhanced solubility in the polymer matrices due to their small particle sizes compared to the conventional bulk solids. Samples containing about 10 weight % Li-6 were prepared without significant loss of transparency. Am-Li thermal neutron source was used to evaluate the light yields of copolymer samples. The best light yields have been achieved when Li-6 has been incorporated in the form of lithium phosphate nanoparticles rather than LiCl and LiOH. Studies are in progress to prepare new copolymer architectures having conjugated aromatic groups such as naphthalene and diphenyloxazole (PPO) for improved light yield. Funding for this work is through the support of the Department of Energy/NNSA NA-22, Office of Nonproliferation research and Engineering program. The Oak Ridge National Laboratory is managed for the Department of Energy under contract No. DE-AC05- 00OR22725 by UT-Battelle, LLC.

Wednesday AM I: Stanley 105-4

New Organic Crystals for Pulse Shape Discrimination

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Natalia Petrovna Zaitseva, Nerine J. Cherepy, Jae-hyun Park, Wolfgang Stoeffl, Stephen A. Payne (LLNL)

Efficient, readily-available, low-cost, high-energy neutron detectors can play a central role in detecting illicit nuclear weapons since neutrons are a strong indication for the presence of fissile material such as Plutonium and Highly-Enriched Uranium. The main challenge in detecting fast neutron consists in the discrimination of the signal from the background represented by gamma radiation. At present, the choice for scintillator organic crystals for fast neutron detection, in a n/gamma mixed field, is limited to stilbene. While offering a good pulse shape discrimination (PSD), stilbene is grown from melt, and thus the availability of large-size crystals is limited and they are expensive. In this work we will report on the development of new organic crystals that are not toxic and are easy to grow, for fast neutron detection as an alternative to stilbene. In particular, we identified several compounds that offer effective PSD, good optical quality, light yield comparable to or higher than stilbene. All the developed crystals are good candidates for the rapid solution growth, which is generally the lowest cost option for producing large-size optical crystals, and thus they represent promising organic scintillators for a widespread deployment for high energy neutron detection.
This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

Wednesday AM I: Stanley 105-5

Use of a Lithium-6-Glass/Plastic-Scintillation Detector for Nuclear Nonproliferation Applications

Marek Flaska, University of Michigan
Sara A. Pozzi (Department of Nuclear Engineering and Radiological Sciences, University of Michigan), J. Bart Czirr (MSI/Photogenics), W. H. (Bill) Ulbricht (ULTRONICS Instrument Co.)

Capture-gated organic/inorganic scintillation detectors have recently attracted the attention of researchers for their potential use in the fields of nuclear nonproliferation and nuclear safeguards. These detectors are based on standard organic scintillators that are coupled with materials with a high absorption cross section for thermal neutrons (boron-10, lithium-6, etc.). Therefore, these detectors are sensitive to fast neutrons and gamma rays, but also to thermal neutrons. Fast neutron detection occurs as follows. First, the neutron interacts with the hydrogen and carbon nuclei present in the scintillator, generating a scintillation pulse. Then, the neutrons that have lost most of their energy in the scintillator are captured in the neutron-absorbing medium - usually boron, lithium, or gadolinium compounds. This technique is referred to as capture-gated neutron spectroscopy, because the acceptance of the pulse from the scintillator is gated by the subsequent neutron capture. The capture pulse occurs most probably after the neutron has lost most of its energy in the prompt pulse. In this case, the prompt pulse amplitude is strongly correlated with the incident neutron energy, and this fact can be used to estimate

the incident neutron spectrum. The elapsed time between the scintillator pulse and the subsequent neutron capture is of the order of a few microseconds. In this work we present measurements and Monte Carlo simulation results obtained with a lithium-6 (Li-6) glass capturing material. We will discuss the use of the Li-6-glass/plastic-scintillation detector for the detection of special nuclear material and radioactive sources. Although these materials simultaneously emit a well known number of neutrons and gamma rays, some gamma rays and/or neutrons can be shielded by surrounding material. In addition, the presence of naturally occurring radioactive materials can also play an important role. Therefore, the accuracy of material detection can be increased by detecting neutrons and gamma rays at the same time. In addition, the detection system based on both neutrons and gamma rays is less vulnerable to false alarms, especially in the presence of shielding. We describe a Monte Carlo approach to detector characterization, and its validation through measurements in the laboratory. The signals are recorded and analyzed by a waveform digitizer. In the full paper, the simulation results will be compared to the measurements for several typical neutron and gamma-ray sources, and in various source-shielding configurations.

Ge Detectors and Imagers

Wednesday AM I: Bechtel

Chair: Mark Amman, LBNL

Wednesday AM I: Bechtel-1

Gamma-ray Imaging with the High-Resolution Si+Ge Compact Compton Imager

K. Vetter, Lawrence Livermore National Laboratory
L. Mihailescu, presenting

A Compton scatter camera, the Compact Compton Imager (CCI) is being developed by our group. The imager is based on position sensitive segmented planar Ge and Si detectors. All detectors are implemented in double-sided strip configuration which - along with digital signal processing - provides the necessary three-dimensional position information to perform Compton imaging. We have recently assembled our second-generation instrument, CCI-2, that consists of 2 large-volume Si(Li) and two large-volume HPGe detectors. We report on measurements we have performed with this instrument, including the determination of basic performance parameters, such as detection, imaging efficiencies, and image resolution. We have also performed experiments to demonstrate the capability of unmasking threat sources in the presence of a complex environmental background. With imaging efficiencies of 1.5% to almost 18% that have been deduced for energies between 200 keV and 2614 keV, CCI-2 is one of the most efficient Compton instrument existing today. Imaging angular resolution values of 2 degrees have been deduced. Such a gamma-ray imaging capability can be an important tool to support homeland security, international safeguards and nuclear non-proliferation efforts.

The work was performed under the auspices of the U.S. Department of Energy by University of California Lawrence Livermore National Laboratory under contract No. W-7405-Eng-48.

Wednesday AM I: Bechtel-2

Pulse Shape Analysis of a p-Type Point Contact Germanium Detector for Dark Matter and Neutrinoless Double-beta Decay Searches

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Craig E. Aalseth, Martin E. Keillor, Jeremy D. Kephart, Harry S. Miley (PNNL); Juan I. Collar (University of Chicago)

Recent development of a bore-hole free, 0.5 kg high purity germanium gamma-ray spectrometer advances the capability of pulse shape analysis techniques for background rejection in searches for dark matter and neutrinoless double-beta (0nuBB) decay of Ge-76. This p-type point contact (PPC) germanium crystal has a cylindrical geometry, but substitutes a small point contact in place of the typical coaxial bore hole, resulting in a greatly reduced detector capacitance. This physical configuration of electrodes results in a low energy threshold and increased time separation of pulses from the charge-cloud collection of individual interactions within the crystal. The low energy threshold (~0.3 keV) makes the detector a candidate for future dark matter searches. At the low energies investigated for dark matter, pulse shape analysis may assist in distinguishing true energy deposition pulses from microphonic or other electronics noise sources. Furthermore, a "radial" parameter determined from pulse shape analysis may permit a fiducialization of the germanium crystal volume, separating events in the bulk of the crystal (dark matter candidates) from those on the crystal's outer edge (low energy photon backgrounds). The greater differentiation of charge-cloud collections will assist neutrinoless double-beta decay searches by distinguishing single-site energy deposition events at 2039 keV (0nuBB decay candidates) from multi-site energy deposition events (high energy photon backgrounds). The pulse shape characteristics of this new detector design are presented and analyzed for their advantages in performing background rejection in searches for dark matter and neutrinoless double-beta decay of Ge-76.

Wednesday AM I: Bechtel-3

The Use of High Purity Germanium (HPGe) detectors for Single Photon Emission Computed Tomography

Helen Boston, University of Liverpool
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In the last decade Germanium has evolved to a point where it is now possible to implement this material for use in medical imaging and security scanning. A dual head scanner (SmartPET) system has been built at the University of Liverpool, UK demonstrating that Germanium is a viable material for use in Positron Emission Tomography[1]. SmartPET utilises two orthogonal strip High Purity Germanium (HPGe) detectors, which were manufactured by Ortec. Each detector has an active volume of 60x60x20mm which is electronically segmented into 12 x 12 strips, each with a strip pitch of 5mm. Using digital Pulse Shape Analysis (PSA), it has been shown that the detector spatial resolution that can be obtained from this system is 1x1x2mm.

Wednesday AM I: Bechtel-4

Inter-strip position interpolation in a high-purity germanium double-sided strip detector

Jason P Hayward, The University of Tennessee
David K Wehe (University of Michigan)

One fundamental design issue in the HPGe double-sided strip detector is the gap between strips, which makes up 1/6 of the 3 mm strip pitch in the UM detector. When an interaction occurs in the gap between strips, charge-carriers from the resulting charge cloud may be split between adjacent strips. Additionally, up to 6% of the carriers may be lost. Furthermore, use of the signals obtained for interactions that occur in gaps is complicated by: 1) their sensitivity to the change in charge cloud geometries and 2) the difficulty of distinguishing single interactions from multiple close interactions. In this work, a Bayesian method for inter-strip interpolation is described for interactions which fall in detector gaps. This method exploits charge-splitting and charge loss, yielding interaction position with lateral resolution of ~160 micron FWHM at 356 keV and ~310 micron FWHM at 662 keV. According to simulation, lateral resolution in the 500 micron gap is fundamentally limited to these values due to charge cloud size, and lateral resolution < 100 micron FWHM may be achieved at 200 keV. When a second interaction falls beneath an adjacent strip, lateral resolution for the gap interaction is still finer than the width of the gap, and simulation shows potential for further improvement. For interactions that occur in the gap between strips, the position resolution and the ability to discriminate single interactions from multiple close interactions are limited by the depth resolution of the detection system.

Wednesday AM I: Bechtel-5

Acquisition of Contrast Images using a Segmented Planar Germanium Detector

David Oxley, University of Liverpool
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The application of semiconductor detectors in medical imaging is an area which currently attracts interest from a wide range of fields. An investigation into whether a planar germanium detector could be utilized in absorption imaging has been conducted. The detector [1] has a germanium crystal with an active volume which is electronically segmented into two sets of twelve orthogonally aligned channels. This creates a raw voxel segmentation of 5x5x20mm. In the experiment three objects were placed upon the detector surface while a 241Am source was suspended 25cm above. The height ensures the radiation is incident both uniformly and perpendicularly to the whole detector surface. The contrast in detected radiation intensity created by attenuation within the object was constructed into an image. This process is analogous to a diagnostic X-ray scan. By implementation of digital pulse shape analysis (PSA) [2] techniques the spatial resolution in the detector and the resolution of the image were enhanced, allowing the fine structure detail of the objects to be resolved. Furthermore the experiment was designed to establish a limitation of the applied technique. This was found at the sub-millimetre level where finer detector pixilation failed to increase image quality. Analysis of a collimated characterization scan confirmed a non-linear relationship between position and the PSA parameter utilized. The results show how, despite limitations, employment of simple PSA techniques can enhance spatial resolution down to a sub-millimetre level and confirm the potential for planar germanium detectors to be employed in absorption imaging. The images of the chosen objects will be presented along with the quantification of the discovered limitation to the pulse shape analysis technique and its implications for position resolution.

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Simulation and Analysis of Radiation Interactions

Wednesday AM I: 106 Stanley

Chair: Todd Palmer, Oregon State Univ.

Wednesday AM I: 106 Stanley-1

A First Application of the FRAM Isotopic Analysis Code to High-Resolution Microcalorimetry Gamma-Ray Spectra

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Gamma-ray spectrometry systems based on High-Purity Germanium (HPGe) have been the long-standing leader in terms of resolution since their introduction many years ago. The application of this technology to the spectroscopic assay of special nuclear material led to the development of several isotopic analysis tools, including the advanced software package FRAM, which was, and continues to be, developed at Los Alamos National Laboratory. Although FRAM can be applied over a wide range of energies, the significantly higher intensity of the X-ray region in the neighborhood of 100 keV makes analysis of this area of the spectrum advantageous, especially in the case of plutonium. However, even with HPGe, the multitude of gamma-ray, and x-ray peaks that exist in the 100 keV region are sufficiently convoluted so as to preclude determination of plutonium isotopic composition without the introduction of some systematic error. The novel technology of microcalorimetry, shown to have an order of magnitude better spectral resolution than HPGe, has recently opened new doors with respect to these difficulties. Now, for the first time, the powerful capabilities of FRAM have been paired with the unparalleled resolution of microcalorimetry in the analysis of plutonium spectra. Preliminary results of these analyses, as well as an outlook for future measurements, heretofore unobtainable with HPGe, will be presented.

Wednesday AM I: 106 Stanley-2

Cosmic-Ray Background Generator (CRY) for Monte Carlo Transport Codes

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Chris Hagmann , David Lange (LLNL)

In many basic science and homeland security applications the natural cosmic-ray background is the limiting factor for the sensitivity of a particular detector system. In order to study this background in the development of new detection techniques we have produced and distributed a free, open-source fast simulation of cosmic-ray particle showers. Our simulation is based on precomputed input tables derived from full MCNPX simulations of primary cosmic rays on the atmosphere and benchmarked against published cosmic-ray measurements. Our simulation provides all particle production (muons, neutrons, protons, electrons, photons, and pions) with the proper flux within a user-specified area and altitude. The code generates individual showers of secondary particles sampling the energy, time of arrival, zenith angle, and multiplicity with basic

correlations, and has user controls for latitude (geomagnetic cutoff) and solar cycle effects. We provide a function library, callable from C, C++, and Fortran, and interfaces to popular Monte Carlo transport codes: MCNP, MCNPX, Geant4, and COG. The CRY software package is open source and can be downloaded from http://nuclear.llnl.gov/simulation.

Wednesday AM I: 106 Stanley-3

Monte Carlo Assessment of Active Photon Interrogation Systems for the Detection of Fissionable Material

Shaun D. Clarke, University of Michigan
Sara A. Pozzi (University of Michigan); Scott J. Thompson, Alan W. Hunt (Idaho State University)

Active interrogation techniques are well established for identifying concealed nuclear material using delayed neutron detection because the presence of delayed neutrons uniquely signifies the presence of fissionable material. Sufficient quantities of uranium or plutonium, for example, will generate a signal after interrogation has ceased (due to delayed neutron emission and subsequent fission reactions) whereas non-fissionable materials will not. This effect has been previously illustrated at the Idaho Accelerator Center (IAC) by Kinlaw and Hunt using bremsstrahlung photons up to 22 MeV with uranium targets. However, delayed neutron emission is rare compared to prompt neutron emission and the delayed neutrons have a lower average energy (500 keV compared to 2 MeV). The detection of the more abundant, higher-energy, prompt neutrons would be easier in complex shielding environments. However, prompt neutron emission during active interrogation is not unique to fissionable material, because photoneutron reactions (gamma, xn) also may occur in common benign materials. Consequently, accurately simulating the production and detection of these prompt photoneutrons is paramount in designing an effective interrogation system. The unique capabilities of the MCNP-PoliMi code system are ideal for simulating such behavior. MCNP-PoliMi accurately models the correlations between individual interactions and the corresponding particle production. These capabilities preserve the exact particle interaction on an event-by-event basis leading to a very accurate prediction of the detector response. This code, however, has only recently been applied to problems involving photon interrogation. The full paper will present the most current simulation results related to active photon interrogation systems. These results will be analyzed to assess the feasibility and limitations of currently proposed active interrogation systems. Consideration will also be given to the efficacy of the method in terms of real-world measurement times and projected false-alarm rates.

Wednesday AM I: 106 Stanley-4

Intrinsic Properties of CsI and CdZnTe: Monte Carlo Simulations

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Y. Xie, L. W. Campbell, A. J. Peurrung, W. J. Weber (PNNL)

Different radiation sources, such as X-rays, gamma-rays, energetic electrons and ions, initially ionize detector materials by creating fast electrons. These fast electrons lose their energy though indirect (bremsstrahlung) and direct energy transfer (phonons, plasmons, interband excitations, excitons, and electron-electron scattering). These quantum-mechanical processes controlling the energy partitioning of fast electrons need to be scientifically understood in the condensed state. We have developed a Monte Carlo (MC) method to study electron cascades, and to evaluate intrinsic properties of semiconductors and scintillators, including the mean energy required to create an electron-hole pair, W, the intrinsic variance (or Fano factor, F) and the spatial distribution of electron-hole pairs In the present work, the MC code has been employed to simulate the interaction of photons with CsI and CdZnTe (CZT) over the energy range from 50 eV to 2 MeV, and the subsequent electron cascades. CsI has been experimentally investigated from the viewpoint of possible applications as a scintillator with fast timing characteristics, while CZT semiconductor detectors are of great interest because they can provide high resolution X-ray and Gamma-Ray spectra at room temperatures. One of the objectives of this work is to investigate the differences in the intrinsic properties of these two representative materials that could explain the factors contributing to fundamental performance limits and nonlinearity. In general, W decreases with increasing photon energy from 18.46 to 13.8 and from 5.7 to 4.7 for CsI and CZT, respectively, whereas F increases with increasing photon energy to the values of 0.28 and 0.22 at high-energy regions for CsI and CZT, respectively. However, these intrinsic properties show greater non-linear behavior in CsI than in CZT, which suggests that the non-proportionality of CsI response may be partially associated with intrinsic properties of the crystal. Furthermore, one of the striking results is that the spatial distribution of electron-hole pairs exhibit very different behavior in CZT and CsI. In CZT, the density of electron-hole pairs created by plasmon decay along the main electron track is very high, and the electron-hole pairs produced by interband transitions are distributed at the periphery of the cascade volume, which leads to a dispersed distribution. In CsI, the density of electron-hole pairs is relatively low, and they are mainly distributed along the fast electron track. It is found that a significant proportion of the electron-hole pairs are produced by ionization and corresponding relaxation processes in CsI, but not in CZT. The spatial distribution and density of thermalized information carriers in along the primary and secondary tracks are important for large scale simulations of electron-hole pair transport, electron-hole annihilation, trapping in activator centers and defects, and recombination of excited carriers. Although the code has been benchmarked for CsI and CZT, it can be easily applied to other scintillator and semiconductor materials.
The research was supported by the Radiation Detection Materials Discovery initiative under the Laboratory Directed Research and Development Program at the Pacific Northwest National Laboratory.

Wednesday AM I: 106 Stanley-5

Monte Carlo Simulation on Early Breast Cancer Detection Using Wire Mesh Collimator Gamma Camera

M Iqbal Saripan, Universiti Putra Malaysia
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In this project, we concentrate on a functional imaging technique in nuclear medicine using a gamma camera. Primarily, nuclear imaging has been developed to show the physiological process of an organ and the body system using tracers. One of the applications of nuclear imaging is in tumor or cancer detection. This paper investigates the performance of the new Low Energy High Resolution (LEHR) wire-mesh collimator used with a gamma camera to improve the latter ability in detecting breast cancer, using Technetium-99m agent at 140keV. The limitation of the LEHR conventional multihole collimator is the lacked of sensitivity as a trade-off for obtaining better resolution. By opting to get a better resolution, only photons within a narrow stereo angle will be allowed to pass the collimator, and eventually, less photons are registered by the sequential event. This inherent property of the conventional system reduced the possibility of maximum tumour recognition thus reducing the rate of low metabolic breast tumour detection. The wire-mesh collimator is a new concept of semi-collimator and semi-coded aperture. With such a flexible structure, one may choose to have a good resolution or a good sensitivity or any configuration in between. In this paper, we investigated the performance of the wire-mesh collimator to detect a lesion inside a human breast. The model of photons propagation and detection, as well as the human cells activity are simulated using the Monte Carlo N-Particle (MCNP) code. An abnormal cell inside a simulated breast with different tumour to background ratio (TBR) is investigated and the results from the conventional collimator and wire-mesh collimator are compared. Based on the results, we show that the wire-mesh collimator is able to detect more photons at a lower TBR in comparison to the conventional collimator. The findings in this study indicate that delineation of breast lesions are better. However, the images produced are degraded by artifacts, making the classification of the breast tumour is difficult. To suppress the false hot spots, we imposed a Wiener filtering technique to the images, and the results show that the contrast of the tumour is getting better. It can be concluded that the wire-mesh collimator can provide an alternative solution for early breast cancer detection. More work will be carried out in the future to improve the performance of the image restoration and enhancement algorithm, in order to enhance imaging findings of breast cancer.

Non-Proportionality and Characterization of Scintillators

Wednesday AM II: Stanley 105

Chair: Edgar van Loef, Radiation Monitoring Devices, Inc.

Wednesday AM II: Stanley 105 -1

Light Yield Non-Proportionality and Energy Resolution of Praseodymium Doped LuAG Scintillator

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Scintillation properties of Praseodymium doped LuAG have been investigated. The crystal is a dense (6.7 g/cm3) scintillator with a short decay time (23 ns) and wavelength emission spectrum peaked at 310 nm. Both tested samples were 10 mm x 10 mm x 5 mm pieces, polished on all surfaces. The dopant concentration amounts to 0.23 mol%. A light yield of (15000 +/- 1500) ph/MeV was measured for both samples using a high sensitivity (13.7 uA/lmF) Photonis photomultiplier (PMT) XP5500B. High quantum efficiency of this PMT (35 %) allowed us to register (5200 +/- 200) phe/MeV using 12 us shaping time in the spectroscopy amplifier. The measured energy resolution was 5.0 % and 5.6 % for two samples respectively. Response of LuAG(Pr) to gamma rays was found to be proportional over wide energy range. Deviation from proportionality does not exceed 3 % at 22 keV for the best sample. This results in good intrinsic energy resolution of LuAG(Pr) amounting to 2.7 % measured with 662 keV gamma rays from 137-Cs. This work was performed in cooperation with Materials Research Laboratory, Furukawa Co., Ltd., which supplied us with two samples of LuAG(Pr).

Wednesday AM II: Stanley 105 -2

Comparing Fast Scintillators with TOF PET Potentiality

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The renewed interest in Time-Of-Flight (TOF) Positron Emission Tomography (PET) has been accompanied by new research in the development of fast scintillators, mainly Halides and/or Lutetium based compounds doped with Ce or Pr. A good candidate for TOF PET must offer high density and Z, fast rise and decay time, high light output. Moreover, manufacturing complexity, cost and long term reliability (due, for example, to hygroscopicity) are additional factors that can influence the choice of scintillator. In this work we concentrate on higher density materials (Lu-based) and we focus on some intrinsic properties of the materials, such as decay time and light output, which have a direct effect on time resolution, the key performance parameter for a TOF-grade detector. This work presents measurements performed on a set of materials with TOF potentialities, namely LSO(Ce), LuYAP(Ce), LuAG(Pr), LaBr3(Ce) and LaCl3(Ce). The Lu-based materials have high density, from 6.7 to 7.4 g/cm3, which is associated with

high detection efficiency for the 511 keV used in PET. The La-based materials have lower density, from 3.8 to 5.3 g/cm3, but higher luminosity. All materials are Ce-doped (or Pr-doped) materials with a fast decay time, due to the 5d-4f transition of the Ce3+ (or Pr3+) ions, which ranges from 20 to 40 ns. Several samples of different size were tested: cubic crystals with 5mm or 10 mm side, and long crystals suitable to be assembled in arrays, 5x5x20mm3 and 5x5x30mm3. Polished surfaces with and without reflectant were used. The three scintillators were characterized in terms of absolute light yield, decay time, energy resolution, emission and excitation spectra. Time resolution of single crystals associated with fast NIM electronics was also measured.

Wednesday AM II: Stanley 105 -3

Progress in Studying Scintillator Non-Proportionality: Phenomenological Model and Experiments

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We propose an approach to describe the origin of non-proportional dependence of scintillator light yield on the energy of an ionizing particle. The non-proportionality is discussed in terms of energy relaxation channels and their linear and non linear dependences on the deposited energy. In this approach, the scintillation efficiency (dL/dx) is described as a function of the energy deposition (which depends on the linear energy loss dE/dx) and the kinetics rates of each relaxation channel. This mathematical framework permits both a qualitative interpretation and a quantitative fitting representation of scintillation non-proportionality response as function of kinetic rates. This method was successfully applied to different sets of experimental data: gamma-ray response of pure CsI recorded at low temperatures [1], Tl doped CsI response excited by various particles at room temperature [2], and room temperature electron response of cerium doped lanthanum halides measured with SLYNCI [3], a new facility using the Compton coincidence technique [4]. Finally, attention is given to the physical meaning of the dominant relaxation channels, and the potential causes responsible for the scintillation non-proportionality. We find that one class of materials (e.g. the oxides) behaves as if the non-proportionality is due to competition between radiative exciton decay and non-radiative exciton-exciton annihilation. Another class (e.g. the doped alkali halides) behaves as if non-proportionality is due to competition between radiative recombination and non radiative Auger process of an electron and a hole captured at a doping ion.

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Wednesday AM II: Stanley 105 -4

Ion Technique for Screening Gamma Detector Candidate Materials

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Recent demands in nuclear nonproliferation and global security for new radiation detector materials have prompted research efforts on accelerated material discovery. New detectors with better energy resolution for gamma ray detection at room temperature are highly desirable. At current stage, a slow Edisonian process, such as combinatorial synthesis, is the main approach to new material discovery due to a general lack on fundamental understanding of scintillation mechanisms. For gamma-ray detection, a relatively large high-quality crystal is necessary for complete absorption of gamma-ray energies of interests and for reliable evaluation of the candidate properties. New material discovery has been restricted due to the difficulties inherent to large crystal growth of new materials; whereas high-quality thin films of candidate materials can be readily produced by various modern growth techniques. In this work, an ion-beam approach, applicable to thin films or small crystals, is demonstrated to quickly evaluate various materials and identify scintillation properties relevant to detector performance. The experimental setup of the ion technique consists of a Time of Flight (TOF) telescope coupled with a photo-multiplier tube (PMT). Instead of gammas, energetic charged particles, such as proton or helium ions, are used to deposit all their energy in the materials within a few tens of micrometer depth. Using a forward scatter method, energetic proton or helium ions are produced over a continuous range of energies from a few tens of keV to a few MeV of the primary ion beam. The TOF detectors record the energy of each ion, and a scintillation response in a candidate material is registered by the PMT in coincidence with the TOF measurement. Excellent energy resolution and fast response of the TOF telescope allow quantitatively and efficiently evaluate candidate materials. This ion approach is demonstrated using benchmark materials of bismuth germanate (BGO) and europium-doped calcium fluoride (CaF2:Eu) crystals. The primary assumption under this ion approach is that thin-film materials whose energy resolution for ions is poor are unlikely candidates for gamma detectors, while materials that demonstrate good detector response are candidate materials that may warrant single

crystal growth for further investigation. When considering the energy resolution attainable by a scintillator, intrinsic light yield nonlinearity along with absolute light yield are typically the most significant characteristics. Light output, nonlinearity and energy resolution obtained from the ion technique are, therefore, compared with the gamma results in BGO and CaF2 measured using the same experimental apparatus, as well as the literature data. Good agreements between the ion and gamma measurements are observed. This ion technique is practically efficient in determining the optimized stoichiometry in combinatorial syntheses, since the relative light yield and energy resolution from the candidate materials with various compositions can be compared with each other, or with a known scintillator. Good correlations between the ion and gamma measurements provide a physical basis for using the ion technique to predict scale-up material performance in scintillation-based gamma-ray detectors, and provide a pathway to assist new scintillator discovery.

Wednesday AM II: Stanley 105 -5

Scintillation Non-Proportionality of Lutetium and Yttrium Silicates and Aluminates

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Non-proportionality in scintillators is defined as the non-uniform conversion of gamma ray energy to the number of scintillation photons. It has been suggested in recent years that non-proportionality plays a major role in most scintillators exhibiting poor energy resolution with respect to values predicted from counting statistics. This study examines the non-proportionality of scintillators excited by gamma rays and x-rays from radioisotopic sources between 22 keV and 1.3 MeV. The samples investigated measure 10x10x10mm and are composed of single-phase Lu- and Y-based silicates and aluminates with various concentrations of tri-valent Ce or Pr activator ions. In some cases, the material was co-doped with the di-valent calcium ion as it has been shown to enhance conversion efficiency in LSO. This work utilizes Gaussian fitting parameters to determine peak positions from gamma ray spectra obtained via a Hamamatsu photomultiplier tube and standard NIM electronics. Previous work on the non-proportional response of LSO:Ce shows a steady decline in the scintillation light yield as photon energy drops below 300 keV. Initial measurements of LuAG:Pr show a similar trend, although significantly smaller in magnitude. The samples from this study will be subsequently characterized with the Compton Coincidence System (SLYNCI) at Lawrence Livermore National Laboratory.

Other Semiconductor Detector Materials and Techniques

Wednesday AM II: Bechtel

Chair: Uri El-Hanany, Imarad Imaging Systems

Wednesday AM II: Bechtel-1

Developing Larger TlBr Detectors - Detector Performance

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Thallium bromide (TlBr) is a high atomic number (81, 35), dense (7.56 g/cc) wide band gap (2.68 eV) semiconductor. In addition, TlBr has a cubic crystal structure and melts congruently at a relatively low temperature (~ 460 C). Recently, mobility-lifetime product of electrons in TlBr has been reported to be greater than 0.001 cm2/V. These properties make TlBr a promising material for room temperature gamma radiation detection. Employing device designs such as small pixel arrays that depend primarily on the motion of a single carrier type allows fabrication of thicker devices with better energy resolution than planar devices of the same thickness. We report on our recent progress in developing larger TlBr detectors. Over the past several months we have increased the electron mobility-lifetime product of our TlBr by more than one order of magnitude. Electron mobility-lifetime values as high as 3.0 x 10-3 cm2/V have been measured. Devices with small pixel design have been built with 3 and 5-mm thickness and pixel pitch of 1-mm and 1.5-mm respectively. Pulse height spectra have been recorded over a range of energies from 60 keV to 662 keV. Energy resolution (FWHM) as high as approximately 5% at 122-keV and 1.7% at 662-keV has been obtained without any 3-D corrections. Such arrays are well suited for 3-D correction techniques similar to those applied to CZT devices, indicating that further improvement in energy resolution should be achievable. These latest results demonstrate promise for TlBr as a room temperature semiconductor gamma ray detector.

Wednesday AM II: Bechtel-2

Anisotropic III-VI Chalcogenide Semiconductors for Radiation Detectors

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High-quality and large chalcogenide semiconductors GaSe, GaTe, and GaSe(x)Te(1-x) (0.1 <= x <= 0.9) with resistivities up to 4.2 x 10^9 ohms.cm were grown by a controlled vertical Bridgman technique using high purity Ga (7N) and in-house zone refined (ZR) precursor materials (Se and Te). Integrated numerical models for single crystal growth have been developed combining global heat transfer and elastic thermal stress sub-models for the Bridgman growth system. The global heat transfer sub-models account for heat transfer in the multiphase system, convection in the melt, and interface dynamics. The elastic thermal stress sub-model is used to predict the thermal stresses in the growing

crystals caused by non-uniform temperature distribution as well as interaction between the crystal and the ampoule. X-ray diffraction (XRD), scanning electron microscopy (SEM), Raman spectroscopy, low-temperature photoluminescence (PL), x-ray photoelectron spectroscopy (XPS), optical absorption/transmission and electrical charge transport property measurements have been used to characterize the grown crystals. It is observed that indium and silver doping enhances the hardness of the grown GaSe and GaSe(0.9)Te(0.1) crystals, which is very useful for processing and fabrication of large area devices. On the other hand, germanium and tin doping significantly enhances the resistivity of the grown GaTe and GaSe(0.5)Te(0.5) crystals. The crystals harvested from ingots of 8-10 cm length and => 2.5 cm diameter have been used to fabricate single element planar devices up to 1 cm^2 in area and have been characterized by current-voltage (I-V) measurement and pulse height spectra using Am-241 (60 keV) and Cm-243,244 (5.8 MeV) sources. Details of the optimum crystal conditions, various surface processing treatments, different steps involved in nuclear radiation detector fabrication and testing of these devices will be presented.
The authors acknowledge partial financial support provided by the DNDO/DHS under contract number HSHQDC-07-C-00034.

Wednesday AM II: Bechtel-3
Development of 15-mm Thick HgI2 Gamma-Ray Spectrometers
Zhong He, The University of Michigan

HgI2 has been studied for gamma-ray spectrometers since 1970 because of its high stopping power due to high atomic number and high density. Reasonably good gamma-ray spectroscopy has been demonstrated only on thin detectors, typically 1 - 2 mm thick, when conventional planar configurations are employed. Thicker detectors are needed to achieve higher detection efficiency for gamma rays with energy above 400 - 500 keV. In 2007, our group demonstrated about 2% FWHM energy resolution at 662 keV on an array of eighteen 10-mm thick HgI2 detectors using the 3-dimensional position sensitive single polarity charge sensing technique developed by our group. This work describes our latest progress on the development of 15-mm thick HgI2 detectors. An energy resolution of 2.02% FWHM at 662 keV was observed on the first fully working HgI2 detector, having an area of 18mm x 18mm and a thickness of 16 mm. The trapping of electrons in the central region of the detector was estimated using the depth sensing method. Our measurements show that less than a few percent of electrons become trapped through the entire thickness of 16 mm, demonstrating the potential of HgI2 to be a viable candidate for a high-resolution and high-efficiency gamma-ray spectrometer.

Wednesday AM II: Bechtel-4

Novel Quaternary Semiconductor Materials: Growth and Characterization

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Andre Berghmans, David Knuteson, David Kahler, Brian Wagner, Sean McLaughlin, Steve Gottesman (Northrop Grumman Corporation ES)

A great deal of researches have been performed on both semiconductor and scintillation materials. Cadmium zinc telluride and mercury halides are the most prominent materials. The wide range of application has not been materialized due to the cost and quality of crystals. There is a strong need of new material or process to improve the quality and reduce the cost of crystals by an order of magnitude. Over the past few years we have developed several materials including thallium arsenic selenide Tl3AsSe3, thallium arsenic sulfide Tl3AsS4, thallium phosphorous selenide Tl3PSe3, silver gallium sulfide AgGaS2 and silver gallium selenide AgGaSe2. For achieving the maximum performance, these materials must have a unique combination of semiconducting, radiation absorbing, low loss and mechanical characteristics. None of the available materials have all the characteristics needed for high average-power operation. We will describe the details of growth and fabrication of these materials. In addition, we will present a novel class of crystals, their synthesis, crystal growth and some of the relevant properties for its applications into detectors. These are quaternary materials with a large flexibility to design transparency, damage threshold and effective performance. In this presentation we will describe Ag-Ga- Ge-Se class of materials and challenges related to these materials. The two very important materials of this class are AgGa3Se8 and AgGaGe5Se12 stoichiometry. A comprehensive solution to produce its derivatives and experimental results will be presented. These will be compared with In-GaSe class of materials which we developed for many years. We have developed process for purification, synthesis of large batch of materials and crystal growth by vertical Bridgman method. These crystals are grown by using both capillary seeding and oriented and fabricated seeds. The details of growth process, X-ray orientation, cutting polishing, fabrication and electrode bonding and stability for large size crystal will be presented.

Wednesday AM II: Bechtel-5

Proximity Charge Sensing with Semiconductor Detectors

Paul Luke, Lawrence Berkeley National Laboratory
Craig Tindall, Mark Amman (LBNL)

Semiconductor radiation detectors are commonly used for the detection, imaging and spectroscopy of gamma-ray, x-ray and charged particles. In basic form, a detector comprises of a semiconductor crystal with two or more electrodes formed on its surfaces. The electrodes serve as a means to apply a bias voltage to the detector so that an electric field is established within the semiconductor to collect the radiation-generated carriers (electrons and holes). Besides allowing for the application of bias voltage, one or more of the electrodes on a detector also serve as readout electrode. Charge carriers drifting across the detector induce a charge signal at the electrode, which can then be measured by a charge-sensitive amplifier connected to the electrode. Although in general the readout electrodes of a detector are formed on the detector itself, this is not a prerequisite

for charge induction. Charge can be induced on any electrode, even if the electrode is not physically in contact with the semiconductor. Such proximity charge sensing effects can be utilized to achieve a variety of advantages in applications involving semiconductor detectors. In this paper we report on the experimental verification of signal readout using proximity electrodes and demonstrate several possible applications of this technique, including the position-sensitive readout of detectors and the sensing of incomplete charge collection in detectors as a means to reduce spectral background.

Imaging/Directional Algorithms

Wednesday AM II: 106 Stanley

Chair: Cornelia Wunderer, Univ. of California-Berkeley

Wednesday AM II: 106 Stanley-1

The Image Reconstruction Approach for the Nuclear Compton Telescope NCT

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The Nuclear Compton Telescope NCT is a balloon-borne gamma-ray telescope operating in the energy range from 200 keV up to several MeV. It consists of 12 double-sided Germanium strip-detectors (7.6x7.6x1.5 cm3). For September 2008, a 36 hour turn-around balloon flight is foreseen from Fort Sumner, NM. The main science goal of this flight is to observe the polarization of the Crab nebula. Reconstructing images for this telescope is a challenge task, since the origin of the measured gamma rays can only be restricted to Compton cones. The shapes of those cones are a complex function of total energy, scatter angle, incidence angle, and interaction positions. Moreover, Doppler broadening and incompletely absorbed events influence the wings of the distribution. In addition, it is modulated by the geometry of the detector, especially its BGO shields, and passive materials. Since an analytical description of the shape is difficult to achieve, we present a 4D binned response matrix for the general shape of these cones. It describes the shape of the cones as a function of measured energy, scatter angle, and distance between the interactions. A slightly modified List-Mode Maximum-Likelihood Expectation-Maximization algorithm is then applied to obtain reconstructed images from the measured events in conjunction with this response

Wednesday AM II: 106 Stanley-2

Directionality in the GammaTracker Handheld Radioisotope Identifier

Carolyn E. Seifert, Pacific Northwest National Laboratory

We present the performance of several computationally simple methods for determining the direction to one or more point sources using Compton images generated by the GammaTracker handheld radioisotope identifier. Source direction is defined by two quantities: heading and inclination; these quantities are sufficient for indicating to an operator where to look for an unknown source. Two of the presented methods involve collapsing the two-dimensional 4-pi angular image into one-dimensional arrays whose maxima then define the direction. A third method finds statistically significant regions of elevated counts above the image background. The final method uses the deconvolution of the point source response to find source position. The performance of each method against simulated gamma-ray images will be presented.

Wednesday AM II: 106 Stanley-3

Iterative Image Reconstruction Algorithms for Post-processing of Synthetic Aperture Gamma Source Images

Ralph T Hoctor. GE Global Research
Scott Zelakiewicz, Evren Asma (GE Global Research)

This paper deals with imaging of Gamma sources in high background using an imager mounted on a moving platform for standoff applications. We refer to the path of the platform as the imaging baseline, and we investigate methods for forming an image of one or more sources in front of the baseline. The sources are to be localized in both range and cross-range. Prior work [1] in this area of uses "image addition" of multiple far-field images with respect to the imager to produce a near-field image with respect to the baseline. Image addition is a well-known approach to aperture synthesis, and the addition of extended far-field responses as components of such a synthesis is called backprojection. In the present work, we propose backprojection without pre-processing of the imager response as a basic image formation method. Additionally, various kinds of pre-processing can be employed instead of correlation to modify the response prior to backprojection. When no pre-processing is used, the resulting back-projected image is similar to the first iteration of a class of iterative image reconstruction algorithms widely used in emission tomography [2,3]. We investigate the use of multiple iterations of these approaches as a post-processing step in reducing background artifacts and enhancing resolvability of closely spaced sources in the synthetic aperture imaging scenario of [1].

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Wednesday AM II: 106 Stanley-4

Reconstruction of UCL Germanium Compton Camera Data using ITEM

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Images of various Cs-137 source distributions were taken with the UCL Germanium Compton camera and were reconstructed in 3 dimensions. A reduced camera setup was used consisting of 16 pixels of 4 x 4 x 4 mm3 size each in the front detector and 4 pixels of 4 x 4 x 10 mm3 size each in the back detector. Both detector layers were 10 cm apart. The preamplifier signal was digitised by GRT4 VME readout cards. The deposited energy was extracted online using the moving window deconvolution technique implemented in the FPGAs of the GRT4 cards. Simpler extraction techniques leading to worse energy resolutions were applied offline for comparative studies. For the image reconstruction ITEM (Imaginary Time Expectation Maximisation) was used, an iterative algorithm based on quantum mechanics energy minimisation. ITEM is very flexible and can easily be applied to every possible Compton camera geometry. A Hamiltonian needs to be defined. The Hamiltonian proposed for Compton cameras in the original paper is shown not to work for complex source distributions and realistic energy and position resolution of the detector. It has been successfully replaced by a new Hamiltonian based on the backprojected image. The modified version of ITEM is shown to work very fast. An image with 10000 pixels can be reconstructed from 40000 events in 20 s using one 3 GHz Pentium CPU. The reconstruction time scales linearly with the number of pixels and the number of events. Images of a point source were taken in different positions on a plane located at 2 cm distance of the front detector. Through analysis of the point spread function obtained with simple backprojection the angular resolution of the camera was determined to be on average 10 degree. The point source was mounted on a translational stage to simulate linear source distributions. The lines of 2 cm and 4 cm length were oriented in all possible directions in 3 dimensions. Also circular distributions were simulated using a rotational stage. An incomplete circle (270 degree) of 3 cm diameter was used as a model of a heart after a heart attack, the missing part of the circle representing the damaged tissue. A correction for the changing camera sensitivity in the image space is required. A sensitivity map was theoretically calculated based upon differential cross sections and solid angle approximations. A correction was accordingly applied to the Hamiltonian. The source distributions were reconstructed at the expected positions with the right shapes (point, line, part-circle). However those parts of the source distributions which were where there was a rapid drop in sensitivity were not reconstructed. A precise measurement of the sensitivity map could solve this problem. All data sets were analysed with 3 different energy resolutions of the Germanium detector based on the different energy extraction techniques mentioned above (4.0%, 1.7% and 1.2% relative resolution at 356 keV). No dependence of the angular resolution of the camera or the image quality on the energy resolution of the detector could be observed.

Wednesday AM II: 106 Stanley-5

Cross Section and Angular Dependence of a Bonner Sphere Extension

Eric Burgett, Georgia Institute of Technology
Rebecca Howell (M.D. Anderson), Nolan Hertel (Georgia Tech)

Since above 20 MeV, the energy resolution for the standard polyethylene Bonner Sphere Spectrometer (BSS) is not unique, a Bonner Sphere Extension (BSE) has been created. The cost effective system expands upon the existing commercially available BSS system using either LiI(Eu) active scintillator or gold foil. The system is comprised of concentric shells of copper, tungsten, and lead which are used in various combinations with the existing spheres. Each of the sphere combinations has a similar design: An inner core sphere (3 or 5 inch) is surrounded by a concentric aluminum shell filled with approximately 1 inch of a high atomic number neutron multiplying material (Cu, W, or

Pb). The system was modeled in detail in the computer code MCNPX (Monte Carlo N-Particle eXtended). The beta test version of the code v2.6e was used. At high energies, the multiplication reactions are not well k known. The scatter and particle production reactions in copper, aluminum, lead tungsten and carbon have not been thoroughly tested. In addition, the target nucleus cross sections for gold, and lithium have not been investigated at these high energies. The LA150 cross sections have been created for many isotopes up to 150 MeV. Above this, physics models have to be utilized for radiation transport. The dependence on cross section selection for ENDF-VI, ENDF-VII, and LA150 cross sections as well as physics model options will be presented. The system was tested at the Los Alamos Neutron Science Center (LANSCE) on the Weapons Neutron Research (WNR) beam line. The target 4, 15 degrees right flight path at 90 meters was selected for the experimental validation to allow for as large a beam diameter as possible. Here an approximately ten inch square beam spot was obtained. Measured data were unfolded using the MXD-FC33 code and the calculated BSE response matrices. The unfolded spectra using the responses of the individual detectors will be presented. A secondary concern is that the design of the active and passive detectors, the system is not symmetric on all axes. The location for the detector to be inserted cannot be overcome when utilizing the existing BSS system. To compensate for this, the angular dependence of the BSE system was investigated. Measurements parallel to the axis of the detector, at 45 degrees and at a right angle to the detector were made. MCNPX was used to calculate the angular response of the BSE. These measured results are compared to experimental results obtained at the LANSCE facility. In conclusion, there were several aspects of the BSE system that drove the measured uncertainties. Two of the primary contributors to the calculated response of the BSE system were investigated. Correction factors are now known for the BSE to correct for the cross section library and the angular dependence of the BSE system.

National and Homeland Security: Active Technologies

Wednesday PM I: Stanley 105

Chair: Alan Janos, Domestic Nuclear Detection Office

Wednesday PM I: Stanley 105-1

Muon Radiography for the Detection of Special Nuclear Materials in Containers

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Penetrating cosmic-ray muons are a natural radiation background on the Earth. When they traverse a body, such particles undergo coulombian multiple scattering processes, which depend on the material atomic number Z and density. The measurement of the multiple scattering angle can be used to detect and image bodies of high Z without the use of artificial radiation and in a no-destructive way. This method could be relevant for inspection of large volumes (e.g., containers) for nuclear or radioactive substances, composed or contained by high Z materials. To this end the use of large area detectors with excellent tracking capability is mandatory. The Muon Barrel chambers, built for the CMS experiment at CERN, satisfy such requirements. They have an active area of 7 m2 and 12 measurement points with a point resolution of around 200 microns, resulting in an angular resolution of the order of 1 mrad in one direction and of 10 mrad in the other. In Padova (INFN National Labs in Legnaro) we have an apparatus is composed by two such chambers. In the gap between the chambers a container and the target material can be placed. The two chambers gives the entrance and exit direction of the cosmic rays. Other two drift tube chambers, each with 4 measurement points, interleaved by a thick plane of Fe, give a rough determination of the cosmic muon momentum. We present results on the detection capability and performance of the system.

Wednesday PM I: Stanley 105-2

Photofission Signatures in the Prompt Regime for Special Nuclear Material Identification

Sara Pozzi, University of Michigan

Recently, active interrogation techniques based on the use of high-energy photons to induce photonuclear reactions are gaining the attention of researchers interested in homeland security and nuclear material characterization. Past efforts have shown that the delayed emissions of neutrons and gamma rays from photofission can be used to successfully detect and characterize fissile material in a variety of scenarios, for example in the analysis of nuclear waste. More recently, efforts have focused on the detection of prompt neutrons and gamma rays from photofission. The prompt emissions are up to two orders of magnitude greater than the delayed emissions, leading to potentially faster and more robust measurement systems. In this paper, we describe signatures from neutrons produced immediately following photon interrogation that can be used to detect, identify, and characterize the special nuclear material. These signatures are based on the physics of photonuclear interrogation and observable differences in the signals produced by appropriate radiation detectors. In particular, we will discuss a new methodology based on the detection and characterization of prompt neutrons emitted from fissile and nonfissile targets. The method is based on the fact that prompt neutrons emitted by photofission events have a different energy spectrum than prompt neutrons emitted by other photonuclear reactions. One approach for the measurement of the neutron energy spectra is based on time of flight (TOF), and was demonstrated at Idaho Accelerator Center by A. W. Hunt and his group. The approach proposed in this paper is based on the analysis of neutron pulse height distributions measured with liquid organic scintillators, and does not rely on detecting complete TOF information, which is highly dependent on knowledge of the target position. This important characteristic makes the method promising for applications in nuclear nonproliferation and homeland security.

Wednesday PM I: Stanley 105-3

Material Response of Depleted Uranium at Various Standoff Distances from a Hardened 25 MeV Bremmstrahlung Photon Source

David Gerts, Idaho National Laboratory

Material responses to high energy bremmstrahlung photons generated by linear accelerators have become a key technology in finding nuclear material at significant standoff distances in support of national and homeland security missions. For standoff detection, the Idaho National Laboratory (INL) has developed a 25 MeV LINAC in a deployable system. Because of the difficulty in performing experiments with significant quantities of highly-enriched uranium (HEU), the INL frequently uses depleted uranium as a surrogate target material. This system is expected to operate in outdoor conditions over large distances. These significant distances result in significantly hardened photon spectra at the depleted uranium target. Delayed neutron and gamma ray measurements were made at various distances of the target relative to the photon source as well as various distances between the neutron and gamma ray detectors relative to the target, with up to 100 meter separations.

Wednesday PM I: Stanley 105-4

Active Detection of Shielded SNM with 60-keV Neutrons

Christian Hagmann, Lawrence Livermore National Laboratory (LLNL)
Jim Hall, Phil Kerr, Mark Rowland, Dan Dietrich, Les Nakae, Jason Newby, Neal Snyderman, Wolfgang Stoeffl (LLNL)

LLNL-ABS-401525 : We present recent progress in the development of a cargo interrogation system based on the detection of fast neutrons emitted by fissile material. The cargo is illuminated by 60-keV neutrons from a pulsed, directional source employing the Li-7(p,n) reaction. These low-energy neutrons can induce fissions in SNM (e.g. Pu-239 or U-235), but not in other materials. The escaping fast neutrons are detected in a bank of liquid scintillators. Pulse shape information is used to discriminate proton recoils from events caused by gammas created by neutron capture or generated in the source itself. A suitable energy threshold ensures that interrogating neutrons are not counted. Background events in the scintillator due to cosmic neutrons are suppressed by requiring coincidence with the source. The detectability of a given amount of SNM concealed in cargo depends on the shielding material, its thickness, and morphology. Neutron-moderating (low-Z) shields are the hardest to penetrate, since incoming neutrons tend to be captured and outgoing neutrons are moderated. We have constructed a prototype system comprising a neutron source with a rate of ~1e6/s, and a large-area detector array. Using this experimental setup, we were able to cleanly detect kg-quantities of HEU embedded in ton-quantities of either plywood or steel with measurement times of order a few minutes.

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Wednesday PM I: Stanley 105-5

Using CsI and NaI detectors for Beta-Delayed Delayed Gamma-Ray SNM Detection Study

Willem G.J. Langeveld, Rapiscan Laboratories, Inc.
<u>Dan A. Strellis, presenter</u>
Timothy J. Shaw, Tsahi Gozani (Rapiscan Laboratories, Inc.)

To counter the threat of smuggled Special Nuclear Material into the United States, DNDO has recently supported research activities to develop SNM detection systems. Measuring beta-delayed gamma-rays emitted from fission fragments is one of several methods that have been studied for determining the presence of SNM. Organic (plastic) scintillator (OS) detectors offer a low-cost detection method when a proper energy threshold is determined and interfering gamma rays are minimized. More thorough gamma-ray spectroscopy methods can be applied with inorganic scintillation detectors such as CsI and NaI. In addition, lower-cost sources can be used compared to those required by the OS applications. Although more expensive per unit volume than the OS, they offer more discriminating spectral information. Using them in place of OS to detect SNM alone may not in general make practical sense. However, when the spectral features of these detectors are required to detect the presence of other threats (such as explosives or chemical weapons), using them is more plausible. Measurements were performed at

Rapiscan Laboratories by irradiating a 2-kg U3O8, (19.9% enriched) sample buried at several depths in several cargoes interrogated with a spectrum-tailored highly penetrating 14-MeV pulsed neutron source operating at 125 Hz and an average intensity of 10^8 neutrons/sec. Spectral data were collected between pulses with both a NaI and CsI detector (6-in right cylinders) to study the relative merits and shortcomings of each compared to an organic scintillator detector. Despite the activation of the detector material producing gamma-ray backgrounds from the 128I and 24Na decay and the 6.13-MeV oxygen activation gamma-ray line, a delayed gamma-ray signal was observed to be up to a factor of 3 larger than the background for significant cargo burial configurations. For deep burial positions and at the source intensity used, a net signal from beta-delayed gamma-rays was not observed. Using the results in this study and those in published literature, the assessment of sensitivity and appropriate detection means will be presented.

Photodetectors and Scintillators

Wednesday PM I: Bechtel

Chair: Nerene Cherepy, LLNL

Wednesday PM I: Bechtel-1

A Comparative Study of Fast Photomultipliers for Timing Experiments and TOF PET

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The new 1 inch and 1.5 inch in diameter photomultipliers for timing applications from Photonis and Hamamatsu have been tested. The time resolution of XP1020, XP3060, R9800 and R9420 was measured with the 10x10x5 mm3 LSO crystal in coincidence experiments with 511 keV annihilation quanta from 22Na gamma source. Results are discussed in terms of measured photoelectron number and time jitter. Final comparison of the tested tubes and their timing properties are presented in relation to large amount of experimental data of various types of PMTs collected during last few years. Especially, observed linear dependency between time resolution normalized to the number of photoelectrons and time jitter is pointed out. Additionally the optimization of electronics needed to achieve the best time resolution in the case of each tube is presented. Analysis of factors influencing timing performance and connected with production process and construction of the PMTs like quantum efficiency, time jitter and anode pulse shape is also made. Finally, the application of the studied photomultipliers for the future TOF PET and possible level of advancement is discussed.

Wednesday PM I: Bechtel-2

Polycrystalline Mercuric Iodide Photodetectors for Cesium Iodide Scintillators

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We have fabricated polycrystalline thin films of mercuric iodide for use as photodetectors coupled to cesium iodide scintillators. The compound semiconductor mercuric iodide has a large band gap (2.13 eV) causing a peak in its quantum efficiency (570 nm) which is well matched to the output of Cesium Iodide (550 nm). Single crystal mercuric iodide phtodetectors coupled to cesium iodide has demonstrated a full width at half maximum (FWHM) energy resolution of 4.58% at 662 keV. Single crystals providing sufficient surface areas for coupling with scintillators are difficult to grow and are therefore cost prohibitive to use in large field of view applications. Polycrystalline films however can be fabricated quickly and cheaply on a variety of surfaces including curved ones. We have therefore developed a physical vapor transport method of growing polycrystalline mercuric iodide films onto transparent substrates coated with indium tin oxide. A

palladium thin film is thermally evaporated on top of the film and the photodetectors are operated at low voltage (up to 80 V) demonstrating the first use polycrystalline mercuric iodide as a photodetector. The polycrystalline mercuric iodide films have a high resistivity producing a very low dark current typically about 10 pA per square mm. When coupled to cesium iodide a FWHM energy resolution of 9% at 662 keV is obtained. The quantum efficiency at 570 nm is about 40% as compared to single crystal mercuric iodide which is 80%. We are currently optimizing the growth method to improve the quantum efficiency with the ultimate goal of obtaining an energy resolution close to that of single crystal performance.

Wednesday PM I: Bechtel-3

A Comparative Study of Silicone Drift Detectors with Photomultipliers, Avalanche Photodiodes and PIN Photodiodes in Gamma Spectrometry with LaBr3 Crystals

Marek Moszynski, Soltan Institute for Nuclear Studies
Cristina Plettner (ICx Radiation GmbH); Agnieszka Syntfeld-Kazuch, Wieslaw Czarnacki, Antoni Nssalski, Tomasz Szczesniak, Lukasz Swiderski (Soltan Institute for Nuclear Studie); Guntram Pausch, Juergen Stein (ICx Radiation GmbH); Adrian Niculae, Heike Soltau (PNSensor GmbH)

The performance of a silicon drift detector (SDD) with integrated FET, delivered by the company PNSensor, Munich, Germany, was studied in gamma spectrometry with 6 mm in diameter and 6 mm in height LaBr3:Ce crystal. The characteristics of SDD were compared with those measured with Photonis XP5212 photomultiplier, Large Area Avalanche Photodiode (LAAPD) of Advanced Photonix, Inc., and Hamamatsu S3590-18 Photodiode (PD). Energy resolution versus gamma ray energies and its components related to the photoelectron/electron-hole pair statistics and dark noise were measured and compared. It has been showed that at low energies, below 100 keV, photomultiplier gives the best results, while for high energies, above 300 keV, SDD allows getting superior energy resolution. Particularly, the best energy resolution of 2.7% was determined for 662 keV gamma rays from a Cs-137 source.

Wednesday PM I: Bechtel-4

A High-Speed, High Dynamic-Range, Linear Optical Sensor Array

Stuart Kleinfelder, University of California, Irvine (UCI)
Kris Kwaitkowski (Los Alamos National Laboratory), Ashish Shah (UCI)

A high-speed, high dynamic-range monolithic linear optical image sensor system has been designed and fabricated in a standard 0.35 um, 3.3V, thin-oxide digital CMOS process. It consists of a 1-D linear array of 150 integrated photodiodes, followed by fast analog buffers and on-chip, 150-deep analog frame storage. Each pixel's front-end consists of an n-diffusion / p-well photodiode, with fast complementary reset transistors, and a source-follower buffer. Each buffer drives a line of 150 sample circuits per pixel, with each sample circuit consisting of an n-channel sample switch, a 0.1 pF double-

polysilicon sample capacitor, a reset switch to definitively clear the capacitor, and a multiplexed source-follower readout buffer. Fast on-chip sample clock generation was designed using a self-timed break-before-make operation that insures the maximum time for sample settling. The electrical analog bandwidth of each channels buffer and sampling circuits was designed to exceed 1 GHz. Sampling speeds of 400 M-frames/s have been achieved using electrical input signals. Operation with optical input signals has been demonstrated at 100 MHz sample rates. Sample output multiplexing allows the readout of all 22,500 samples (150 pixels times 150 samples per pixel) in about 3 ms. The chip's output range was a maximum of 1.48 V on a 3.3V supply voltage, corresponding to a maximum 2.55 V swing at the photodiode. Time-varying output noise was measured to be 0.51 mV, rms, at 100 MHz, for a dynamic range of ~11.5 bits, rms. Circuit design details are presented, along with the results of electrical measurements and optical experiments with fast pulsed laser light sources at several wavelengths. Applications of this device include very high density optical fiber readout and digital schlieren photography.

Wednesday PM I: Bechtel-5

Luminescence of Heavily Cerium Doped Alkaline-Earth Fluorides

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The maximum light yield of activated scintillators is known to be achievable at the optimum concentration of the activator. Using solid solutions instead that contain rare-earth (RE) ions employed as the lattice-forming components, is realizable as an important tool to be used for clarification on the rare-earth activator concentration role relative to the energy losses at the energy transfer stage. This work devoted to study of Ce-containing M1-xCexF2+x (M=Ca, Sr, Ba, 0.22 < x < 0.5) crystals for which we assumed originally a higher luminescence yield. In particular, it was shown that the absorption and luminescent characteristics of these mixed compounds are similar, although shifted to UV region depending on the forbidden gap (Eg=10.6, 11.2 and 12.1 eV for BaF2, SrF2 and CaF2, respectively). Luminescence spectra typical for d f transitions in Ce3+ are similar for all compounds studied. The excitation spectra consist of a series of overlapping bands in the range 225-325 nm, the most intensive out of which emerging at 306, 312 and 326 nm in Ca1-xCexF2+x, Sr1-xCexF2+x and Ba1-xCexF2+x, accordingly. The complex excitation spectrum can be viewed as a variety or superposition of several possible types of clusters according to [1]. That is to say that the Stokes shift is small and decreases with cerium concentration increasing. The luminescence decay (~25 ns) is typical for d f transitions in Ce3+ ions. However, alongside there is a fast component (tau, approximately equal to 4 ns), the contribution of which varies within the limits 12 to 25%. The emergence of the short component and the similarity of the decay components relationship are found for various concentrations and types of crystals. On the whole, the Stokes shift proved very small in all cases, resulting in the overlap of excitation and

luminescent bands. This tends to cause the re-absorption and irreversible losses in the luminescence yield regardless of the losses at the energy transfer stage.

[1] B.P. Sobolev, A.M. Golubev, and P. Herrero, Crystallography Reports, 48(1) (2003) 141-169

National and Homeland Security: Passive Technologies

Wednesday PM II: Stanley 105

Chair: Robert Mayo, DOE NA-22

Wednesday PM II: Stanley 105-1

A High-Efficiency Fieldable Germanium Detector Array

Dr. James Fast, Pacific Northwest National Lab

Historically, large germanium arrays for field applications have consisted of multiple detectors each housed in their own cryostat. Ruggedized detector mounts for field use have had additional support material introduced that significantly impacted cryogenic performance. This paper presents the development of a new HPGe detector array and cryostat design that achieves outstanding cryogenic performance (~5 W) while providing the high detection efficiency (~500% relative efficiency) required for stand-off measurements and the ruggedization required for use in a variety of field applications.

Wednesday PM II: Stanley 105-2

Directional Detection of Special Nuclear Materials Using a Neutron Time Projection Chamber

Igor Jovanovic, Purdue University

M. Heffner(Lawrence Livermore National Laboratory (LLNL)); L. Rosenberg (University of Washington); N. Bowden (LLNL); M. Howe, M. Hotz, A. Myers (University of Washington); D. Carter, C. Winant, A. Bernstein (LLNL)

High-energy neutrons represent a highly penetrating and reliable signature of the presence of special nuclear material (SNM), and occur both in passive and active interrogation scenarios. Detection of high-energy neutrons shows significant promise as a SNM search method complementary to detection of gamma-rays, since the neutron and gamma signatures of SNM require very different types of materials for effective shielding. Directionally sensitive detection offers additional attractive features: improvement in detection speed compared to proximity searching, powerful suppression of backgrounds, and the ability to map multiple or distributed sources. We report our progress in the development and commissioning of a directional neutron detection system based on a time projection chamber (TPC) detector. The TPC has been used in particle and nuclear physics research for approximately 3 decades. TPC utilizes a convenient, scalable electronic readout system capable of measuring charged particle trajectory over a full solid angle, specific ionization, and energy, which aids particle identification. Over the past year we have designed, constructed, and tested a neutron TPC (nTPC) detector adapted for directional detection of MeV-energy neutrons. Our detector consists of a ~40 cm-diameter, ~50-cm long pressure vessel, which contains the detector gas, drift field cage, amplification region, and the readout 2D plane consisting of crossed 128 anode wires and 64 cathode strips. Low event multiplicity allows the use of a cost-effective readout system employing independent readouts for cathode and anode planes, resulting in a total of 192 channels. 192 preamplified waveforms are digitized in a data acquisition system based on nine 22-channel digitizer cards (FZ Karlsruhe) and ORCA software (University of Washington). Real-time event reconstruction software has been developed and interfaced with the data acquisition system. In our preliminary experiments we activated ~1/4 of the available nTPC volume. The nTPC was filled with hydrogen gas

under ~1 atm pressure. Hydrogen provides favorable recoil kinematics and scattering cross-section, but its pointing ability is stochastic due to the uncertainty in the incident neutron direction, which requires time integration. Future use of the 3He(n,p)T reaction will result in full kinematic reconstruction from a single incident high-energy neutron. We used an internally mounted alpha-emitter and an external Cf-252 source with SNM fission-like neutron spectrum for detector commissioning and testing. Neutron tracks were measured in the nTPC detector, and crude pointing ability in the horizontal plane has been demonstrated. We are proceeding to activate the remaining detector volume and refine the reconstruction to arrive with the measurement of nTPC angular resolution and event rejection based on specific ionization. Scaling of the nTPC to compact, fieldable sizes is of particular interest and will be considered in future work.

Wednesday PM II: Stanley 105-3

Demonstration of a Dual-Range Photon Detector with SDD and LaBr3(Ce3+) Scintillator

Guntram Pausch, ICx Radiation GmbH
Cristina Plettner (presenting), Claus-Michael Herbach, Juergen Stein (ICx Radiation GmbH, Koelner Str. 99, D-42651 Solingen, Germany); Marek Moszynski, Antoni Nassalski , Lukasz Swiderski, Tomasz Szczesniak (Soltan Institute for Nuclear Studies, PL 05-400 Swierk-Otwock, Poland); Adrian Niculae, Heike Soltau (PNSensor GmbH, Romerstr. 28, D-80803 Munchen, Germany)

A new concept for a compact detector improving gamma ray spectroscopy in homeland security applications is demonstrated. The dual-range photon detector consists of a LaBr3(Ce3+) scintillator with a silicon drift detector (SDD) on top. The SDD works as low-energy photon detector on its own. Higher-energetic gamma rays interact with the scintillator. Here, the striking energy resolution of LaBr3(Ce3+) with SDD readout is available. Pulse shape discrimination (PSD) allows separating the detection mechanisms. Since LaBr3(Ce3+) is distinguished by a short light decay time, PSD benefits only from pulse shape differences due to the irradiation geometry and specifics of the charge collection process in SDD. Two detection systems consisting of 30sqmm SDD modules and encapsulated D=6mm, H=6mm BrilLanCe 380 crystals were built up and have been tested. Energy resulutions of 2.7% and 2.9% at 662keV were measured in scintillation mode at room temperature, while the scintillators exhibited a resolution of only ~3.5% if coupled with common photomultipliers. Measurements with standard sources have evidenced the direct SDD mode uncovers line structures which could never be resolved with a scintillation or CZT detector: In addition to the improved scintillator spectrum due to SDD readout, complementary high-resolution information is gathered in a wide energy range below 100keV. Such detection modules are well suited for application in RID and SORDS.

Wednesday PM II: Stanley 105-4

Development of Flat Panel Amorphous Silicon Imaging Detectors for Cargo Imaging

Clifford Bueno, GE Global Research
Forrest Hopkins, William Ross, Jeffrey Shaw, Daniel McDevitt, William Leue, Robert Kaucic, Donald Castleberry, Douglas Albagli, Bernhard Claus (GE Global Research); Joseph Bendahan (GE Homeland Protection); Edward Nieters, John McLeod (GE Global Research)

Flat panel detectors offer potential advantages for cargo radiography scanning for detection of special nuclear material (SNM). Flat panel detectors based on amorphous silicon read structures mated with optimized scintillators can be employed in a variety of detector configurations to produce enhanced image quality with respect to existing linear detector array (LDA) technology. Flat panel detectors were configured for 9 MV imaging, where multiple panels were coupled to produce larger arrays with minimal gaps between panels. Using this approach, in either continuous or "step and shoot" scanning modes, the flat panel approach offers improvements in spatial resolution, image contrast, and area coverage.

Wednesday PM II: Stanley 105-5

Three-Dimensional Imaging of Hidden Objects Using Positron Emission Backscatter

Laura C. Stonehill, Los Alamos National Laboratory (LANL)
Mark Galassi, Mark Wallace, Ed Fenimore, Wendy Vogan McNeil, Quinn Looker (LANL)

Positron Emission Backscatter Imaging (PEBI) is a technique for three-dimensional gamma-ray imaging of objects when only one side is accessible, such as for objects behind a wall or for buried objects. This technique utilizes a positron source to produce back-to-back 511-keV gammas, one of which provides timing and directionality tagging, while the other backscatters off the object to be imaged. The scattering location can be reconstructed using the relative timing of the two gamma-ray signals and the positions at which they are detected. Excellent timing resolution is required, since the time-of-flight information is essential for reconstruction. Three-dimensional imaging requires two arrays of detectors, one for the 511-keV tagging gamma and one for the backscattered gamma. We are studying the feasibility of a PEBI system using a pixellated LaBr detector coupled to a multi-anode PMT for detection of the 511-keV gamma, and an array of a dozen or more 1-inch LaBr crystals coupled to 1-inch PMTs for detection of the backscattered gamma. This paper will provide an overview of the PEBI concept's capabilities and preliminary results from a laboratory system. We will present one-dimensional position reconstruction measurements demonstrating that the required timing resolution has been achieved. In addition, initial characterization of the pixellated LaBr detectors and multi-anode PMTs will be presented, showing the position resolution measured in the detector plane. Simulation results showing the expected three-dimensional position reconstruction will also be presented.

Silicon Photomultipliers

Wednesday PM II: Bechtel

Chair: James Christian, Radiation Monitoring Devices, Inc.

Wednesday PM II: Bechtel-1

Energy Resolution from an LYSO Scintillator Coupled to CMOS SSPM Detectors

Erik Johnson, Radiation Monitoring Devices, Inc. (RMD)
Christopher J. Stapels (RMD, Paul Barton (Nuclear Engineering and Radiological Sciences, College of Engineering, The University of Michigan), Radia Sia (RMD), David K. Wehe (Nuclear Engineering and Radiological Sciences, College of Engineering, The University of Michigan), James F. Christian (RMD)

SSPMs consisting of arrays of 30- and 50-micron square pixels in 1.5 mm x 1.5 mm total area with high and low fill factors (packing density) were used to measure the photon intensity resolution for a pulsed laser light source. Different sources of noise (i.e. crosstalk, dark counts, and electronic) have a deleterious effect on the energy resolution, and this work looks at the relative sizes of these contributions. The SSPM's performance is investigated by comparing input from light sources and a calibrated input pulse from a tail pulse generator. Using a constant, low-intensity light source on each of the four SSPM designs, the best photon intensity resolution of 7% was obtained for the array of large pixels with a low packing density at an operating bias of 13.4 volts excess bias. This photon intensity resolution is primarily shot-noise limited for approximately 200 detected photons, with fluctuations in the dark counts contributing the majority of the rest of the noise. The apparent optical photon detection efficiency obtained for each of the quadrants at the ideal operating bias was 5.6%, 10.1%, 6.7% and 11.2% for the 29%, 43%, 49% and 61% fill-factor arrays, respectively. The contributions from each noise source are explored. In addition, the energy resolution obtained for an LYSO scintillation crystal is measured and compared to the pulsed laser results to examine all contributions to the energy resolution. To provide insight into the critical detector parameters for device optimization, a detailed analysis of the energy resolution for 662-keV gammas incident on 1.5 mm x 1.5 mm x 3 mm of LYSO will be provided.

Wednesday PM II: Bechtel-2

Features of Silicon Photo Multipliers: Precision Measurements of Noise, Cross-Talk, Afterpulsing, Detection Efficiency

Paolo Finocchiaro, INFN-LNS
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Solid state single photon detectors are nowadays an emerging issue, with applications in the wide field of sensors and transducers. A new kind of planar semiconductor device has slowly but steadily come out, namely the Silicon Photomultiplier (SiPM), with outstanding features that in some respect could even replace traditional photomultiplier

tubes. Based on a Geiger-mode avalanche photodiode elementary cell, it consists of an array of n independent identical microcells whose outputs are connected together. The final output is thus the analog superposition of n ideally binary signals. This scheme, along with the sensitivity of each individual cell to single photons, would allow in principle to have the perfect photosensor capable of detecting and counting the single photons in a light pulse. Unfortunately this is not the case, as this kind of device has several drawbacks, all of them mainly deriving from its noise features: due to its intrinsic properties, in no way can the dark counts be reduced below a given rate. Cooling the device works to a certain extent, but then afterpulsing sets in, due to charge carriers trapped within the semiconductor during the avalanche signal and later exponentially released. The lowest operating temperature becomes a trade-off between random thermal counts and long-lasting afterpulse counts. Even though not capable of totally replacing the traditional photomultiplier tubes, the SiPM already promises to fulfill a wide set of requirements coming from numerous applications. In this paper we illustrate a complete method for the evaluation of dark noise, afterpulsing, cross-talk and detection efficiency of SiPM detectors. In this respect we will then show the performance of our newly developed SiPM (produced by ST Microelectronics), comparing it to another sensor present on the market (produced by Hamamatsu), proving that the device performance is indeed already outstanding.

Wednesday PM II: Bechtel-3

High Performance Solid-State Photodetector for Nuclear Detection and Imaging

Purushottam Dokhale, Radiation Monitoring Devices, Inc. (RMD)
Kanai Shah (presenting), Rob Robertson, Christopher Stapels, James Christian (RMD, Inc., 44 Hunt Street, Watertown, MA 02472. USA)

Current and next generation systems employed in nuclear and particle detection require photodetectors with fast response, high gain and high signal to noise ratio. Photomultiplier tube (PMT) has been playing an important role as a photodetector for last several decades. PMTs, however, have several limitations. They cannot operate under pressures exceeding a few atmospheres and under high magnetic fields, their sensitivity is limited over a small wavelength band, their optical quantum efficiency is relatively low, and they are bulky. To overcome many of the limitations of PMTs in scintillation spectroscopy, we have designed and developed a complementary metal-oxide-semiconductor (CMOS) solid-state photomultiplier (SSPM). Here we present different designs of SSPM and their performance evaluation for scintillation spectroscopy, time-of-flight studies and gamma-ray imaging. The measured FWHM energy resolution for 511 keV gamma rays was 11% for a detector consisting 1.5mm x1.5 mm SSPM coupled to 1.5mm x 1.5mm x 10 mm LYSO. The timing resolution measured was 480ps in coincidence with a detector consisting LaBr3 coupled to PMT. The timing resolution was also measured for four 1.5mm x 1.5 mm SSPMs arranged in a 2x2 array having different designs and density of micro pixels. The measured coincidence timing resolution ranged from 480ps to 560ps, confirming that upon sufficient optimization, these devices would be suitable for fast timing studies. The position sensitive SSPM (PS-SSPM) was also designed, build and evaluated. A flood image was recorded with a 6x6 LYSO array (each LYSO element measuring 1mm x 1mm x 10mm) coupled to a PS-SSPM with 6mm x 6

mm active area. All 36 LYSO elements were clearly visible and well separated from each other in the flood image.

Wednesday PM II: Bechtel-4

Mass Sample Test of HPK MPPCs for the T2K Neutrino Experiment

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The Multi-Pixel Photon Counter (MPPC) produced by Hamamatsu Photonics which is new semiconductor photon sensor is developed for an application in T2K neutrino oscillation experiment starts from April 2009. MPPC has the advantage in the photon-counting capability, stability to the magnetic field, small size, and high photon detection efficiency. About 60,000 channels of detectors are planed to be used in off-axis detector or and in on-axis neutrino monitor, INGRID, in the J-PARC site. About 15,000 MPPCs are produced by Hamamatsu Photonics up to May 2008. For the quarantee of quality to all MPPCs, MPPC checking system at Kyoto University was developed using the custom MPPC reading electronics with Trip-t ASIC chip which can measure 64 MPPCs at the same time. This system can measure gain, breakdown voltage, noise rate, photo detection efficiency, and cross-talk/after-pulse rate in condition of the controlled temparature and bias voltage. We check the device-by-device variation of all MPPCs about these parameters. Our measurement is the first evaluation of a large scale of MPPCs.The information will contribute grately to users who study or consider MPPC or similar device I report the study of the basic performance and the result of mass sample test for more than 10,000 MPPCs compared with the requirement from T2K experiment.

Wednesday PM II: Bechtel-5

Silicon Photomultipliers As Readout for the CEDAR counter of the K+ -> pi+ nu Nubar Experiment P326/NA62 at CERN

Gianmaria Collazuol, Scuola Normale Superiore and INFN Pisa

The K+ -> pi+ nu nubar rare decay experiment P326/NA62 at CERN will employ an unseparated beam of positive hadrons (75 GeV/c in momentum) derived from the primary protons at the CERN SPS. The K+ component in the beam can be tagged positively by using an improved version of the existing CEDAR-type differential Cherenkov counters. The CEDAR volume (5 metres long) will be filled with hydrogen at a pressure below 3 bars. The optical system, consisting of a Mangin mirror and a chromatic corrector reflects and focuses the light on to a narrow and adjustable ring diaphragm, behind which 8 condensor lenses and the readout photodetectors are located (on a circle). The expected K+ rate is 50 MHz and the full beam almost 1 GHz. Approximately 10 Cherenkov photons per K+ will illuminate each of the 8 light spots which are 12 x 12 mm^2 wide. We are investigating the use of matrices of silicon photomultipliers (SiPM) to detect Cherenkov photons at the mentioned rates, with a single photon time resolution below 50ps and with very high effciency (above 50%), which cannot be accomplished with conventional (UV sensitive) photomultipliers. The individual detection of the more than 30 photo-electrons will result in a extremely clean kaon tagging and in a resolution on the single kaon timing at a level better than 10 ps rms. Silicon photo-multipliers (SiPM) are semiconductor devices consisting in matrices of tiny avalanche photo-diode pixels (10^3 / mm^2) grown on a common Si substrate and connected in parallel via integrated resistors. The diodes are operated in Geiger mode (i.e., biased at few volts above breakdown) so that any single carrier, generated either by photons or thermally in the depletion region, might trigger a self-sustaining avalanche which is quenched by the integrated resistors. Because all SiPM pixels work together on a common load, the output signal is a sum of the signals from all fired pixels. So, while each pixel is an independent binary photon counter the SiPM works as an analogue detector able to stand very high rates (several tens MHz) with almost no dead-time. High gain (10^6) and high efficiency (up to 80%) in detecting low optical photon fluxes with unprecedented charge resolution, extreme single photon timing resolution, low voltage operation and insensitivity to magnetic fields and EM pickup make SiPM suitable for many applications, as an alternative to vacuum photo-multiplier tubes, and in particular an excellent detector for Cherenkov counters. There are two issues for the use of SIPM's in our (P326) CEDAR application: (1) the radiation hardness, as the SIPM devices will be illuminated by the halo of an intense hadron beam. (2) the reduction of the dark count rate, which is easily accomplished by moderate cooling. To this purpose it has to be noted that the coincidence of the signals of more than 30 photo-electrons produced by the 80 cherenkov photons per Kaon will allow a very good signal to background ratio. In the talk we'll discuss the first results of the tests finalized to the CEDAR/Cherenkov application made on Hamamatsu and FBK-IRST (Trento, Italy) SiPM devices concerning response to UV light, cooling, ageing, radiation hardness, efficiency and timing properties of the detectors. First results on matrices of SiPM recently produced (only) at FBK-IRST and covering an area of 4 x 4 mm^2 (16 channels) will be also discussed. Finally the fast, low-noise front-end electronics and the high performance 1 GHz sampling FADC system for the signal readout will be discussed. More information about the SiPM's and the CEDAR project can be fund at the web page: http://collazug.home.cern.ch/collazug/seminario_sipm.pdf

Thursday, June 5
Plan of the Day

Contributed orals in parallel sessions will be given in Sessions AM I and II and PM I. Session PM II will be a plenary session featuring summary or *rapporteur* talks, a good way to catch up on highlights of the parallel sessions.

Lunch (on your own) is 12-2. Those holding a Thursday ticket for an LBNL tour will be guided to the shuttle-bus stop.

Buses back to the Doubletree will begin boarding shortly after the 5 p.m. end of the summary session.

That will conclude SORMA West 2008; we wish you a safe trip to the airport or a pleasant evening in the Bay Area, and encourage you to consider SORMA East 2010 as the venue for your next results.

Detector Systems

Thursday AM I: Stanley 105

Chair: Lorenzo Fabris, ORNL

Thursday AM I: Stanley 105-1

IceCube - a Cube Kilometer Radiation Detector

Spencer Klein, Lawrence Berkeley National Laboratory

IceCube is a neutrino detector now being built at the South Pole. The active volume is 1 km^3 of Antarctic ice at depths from 1450 to 2450 meters below the surface, about 2 km from the Amundsen-Scott South Pole station. Cherenkov radiation from charged particles produced by neutrino interactions in this ice is observed by an array of 4800 Digital Optical Module (DOM) detectors. Each DOM contains a 25-cm photomultiplier tube, high-voltage power supply, digitization electronics, 13 LEDs for calibration, and communication system to transmit digital data to the surface. All data are sent to the surface; a trigger there selects time-windows containing interesting events. Data from this trigger is recorded at the South Pole, and a fraction is transmitted north via satellite. The harsh weather (including temperatures below -55 degrees C) and difficult logistics require significant attention to survivability, reliability, and the simplest possible deployment. IceCube construction began in 2005, and the detector is now 50% complete. IceCube can detect neutrinos with energies from about 100 GeV up to 100 EeV, and can separate electron, muon and tau neutrinos on the basis of their distinctive interaction topologies. Muon neutrinos produce muons, which leave long (1 km for a 500 GeV muon), tracks in the detector, while electron neutrinos produce compact electromagnetic showers. At energies above about 1 PeV, tau neutrinos can produce a spectacular “double-bang” topology -- one energy cluster where the neutrino interacts in the detector, a minimum ionizing tau track, and a second energy cluster when the tau decays, several hundred meters from the first light. For high-energy muon tracks, an angular resolution of about 1 degree is possible. Because neutrino interactions are so rare (10,000 atmospheric neutrinos/year in the complete detector), background rejection is a major challenge. The down-going cosmic-ray muon rate is about 500,000 times higher than the neutrino rate; selecting signal events requires complex background rejection techniques. Neutrino reconstruction also requires robust calibrations. Much effort has gone into understanding the optical properties of the ice that makes up IceCube. The absorption and scattering lengths have been measured as a function of depth and photon wavelength. The DOM timing calibration system maintains relative timing to better than 3 nsec, across the entire array. IceTop, a 160-tank surface array detects cosmic-ray air showers with energies above 300 TeV. It is used to study the cosmic-ray energy spectrum and nuclear composition, for IceCube directional calibration, and as a veto for events originating in the atmosphere. Each tank contains two DOMs frozen into a block of clear ice. After reviewing the physics goals of IceCube, I will discuss the detector in detail, with emphasis on how it can detect and reconstruct neutrino interactions. I will also present some initial results on atmospheric neutrinos, searches for extra-terrestrial neutrinos, and cosmic-ray physics.

Thursday AM I: Stanley 105-2

Multi-Frame High Resolution Imaging System for Time-Resolved Fast-Neutron Radiography

Volker Dangendorf, Physikalisch-Technische Bundesanstalt

In recent years, significant progress in fast-neutron based interrogation techniques for air luggage and palletized cargo has been achieved by introducing a new method of multi-frame high speed imaging, that incorporates ultra-fast exposure timing on the nanosecond time scale. The method utilizes pulsed broad-energy (1 - 10 MeV) neutron beams and energy selective fast-neutron imaging techniques. One of the detection methods which we investigated in recent years will be presented here. It is based on a modified (but, in principle, commercially available) high-speed camera systems with segmented, independently gateable image intensifiers and a very fast optical booster. The booster provides sufficient light even from very faint light sources such as ultra-fast plastic and liquid scintillators for the high-speed camera system. Utilizing the Time-of-Flight (TOF-) method, the detector is able to simultaneously take images of up to 8 images, each at a different neutron energy. Additionally also the gamma flash, preceding the neutrons in the TOF spectrum, can be included in the image series. Thus, also combined neutron / gamma interrogation of objects becomes feasible which allows to combine the low-Z element sensitivity of the neutron resonance method with the high-Z materials detection capability of gamma radiography. PS: The subcategories in the selection box above are not properly aligned to the main categories. The preferred subc are: neutron radiography and/or fast neutron detection and spectroscopy

Thursday AM I: Stanley 105-3

Development of a Fast-Neutron Detector with Silicon Photomultiplier Readout

Raffaele Bencardino, CSIRO Minerals
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CSIRO has developed a fast-neutron/gamma-ray radiography (FNGR) technique for the rapid imaging (including composition) of air freight. Whilst the output of the Co-60 gamma-ray source used in the scanner is constant, the output of the 14 MeV DT neutron generator varies and needs to be monitored if high quality images are to be obtained. A full-scale system operated at Brisbane Airport, Australia used a Thermo A-711 generator (producing up to 1.0e10 n/s) and a neutron monitor comprising a fast scintillator read out using a photodiode. To avoid radiation damage to the photodiode, the monitor could not be operated close to the generator, which limited the statistical precision of the flux measurements. A new monitor detector was developed comprising an Eljen EJ-204 plastic fast scintillator block coupled to a Hamamatsu S10362-11-100C 1 mm2 silicon photomultiplier (SiPM) via a 1.5 m length of Kuraray Y11 wavelength shifting (WLS) plastic fibre. The paper discusses the optimisation of the optical design and the implementation of a gain-stabilisation thermally-controlled bias circuit. Count rates and pulse height spectra are compared for the old and the new neutron monitor detectors. The new arrangement allows the scintillator block to be operated close to the source, significantly improving neutron count rates. Using a Thermo A-325 generator (producing up to 6.0e7 n/s), count-rates over 20,000 cps were measured with a small scintillator

placed close to the neutron emission point. The new detector design is ideal for measuring rapid variations in flux in a high radiation environment.

Thursday AM I: Stanley 105-4

Advanced Compact HPC System with Switched Architectures for Large High-Performance Detectors

V.I. Vinogradov, Institute for Nuclear Research, Russian Academy of Sciences

New Electronics, Compact Computer Systems and Communication are moving to Integrated Switched System-Network Architecture and giga-speed component interconnects. A tradition parallel bus based system architectures (VME/VXI bus, cPCI/PXI) are not perspective for new generation high-speed low-power Processors. Advanced high-speed interconnect and HPC systems for high-speed data sources are required. Fundamentals in new generation system architecture development are to decide of gigabit limit speed between system components at low-level signals, low power multi-core processors with new serial switched high-speed interface chips and high-modular structure on all levels of both system and network interconnects. Advanced modular system components and development approaches based on advanced international standards are described and discussed, including new high-speed serial interconnects, module structures, new connectors, interactions of processor cores in distributed compact nodes and general network architecture and topology. Perspective switched tendencies are especially effective for high-performance large detectors, future data acquisition and image processing systems.

Thursday AM I: Stanley 105-5

Analysis of the signal and Noise Characteristics Induced By Unattenuated X-Rays from a Scintillator in Indirect-Detection CMOS Photodiode Array Detectors

Ho Kyung Kim, School of Mechanical Engineering, Pusan National University
Seung Man Yun (presenting), Chang Hwy Lim, Min Kook Cho (School of Mechanical Engineering, Pusan National University); Thorsten Graeve (Rad-icon Imaging Corp.)

For an indirect-detection CMOS photodiode array detector, the signal due to direct x-ray absorption and the related quantum noise have been analyzed. The direct x-rays are those that are unattenuated from a scintillator and that directly interact with a photodiode array. In order to isolate the signal response induced by direct x-ray absorption, we inserted a sheet of light absorbing blackout paper between the scintillator and the photodiode array. The characteristics have been analyzed in terms of MTF (modulation-transfer function) and NPS (noise-power spectrum). The detailed results will be addressed. This study will provide a good accounting of the contribution of the unattenuated x-rays in the image quality.

This work was supported by the Korea Science and Engineering Foundation (KOSEF) grant funded by the Korea government (MOST) (Grant No. R01-2006-000-10233-0).

Novel Radiation Sources for Security and Research

Thursday AM I: Bechtel

Chair: Arlyn Antolak, Sandia National Laboratory

Thursday AM I: Bechtel-1

Laser-based, Ultrabright Gamma-Ray Sources: Nuclear Photo-Science and Applications

C. P. J. Barty, Lawrence Livermore National Laboratory
S. Anderson, A. Bayramian, B Berry, S. Betts, J. Dawson, C. Ebbers, G. Anderson, D. Gibson, C. Hagmann, J. Hall, J. Heebner, M. Johnson, H. Phan, J. Pruet, V. Seminov, M. Shverdin, A. Sridharan, A. Tremaine, J. Hernandez, M. Messerly, P. Pax, F.V. Hartemann, D. McNabb, C. Siders (LLNL, P.O Box 808, Livermore, CA 94551)

We review the construction of LLNL's novel, laser-based, tunable, monochromatic gamma-ray source. Beam-like gamma-ray (>1 MeV) output with peak pulse brightness more than 15 orders beyond the current synchrotron state of the art are possible. Mono-energetic gamma-rays may be used to efficiently excite nuclear resonance fluorescence and in the process enable new methods for isotope-specific detection and imaging well shielded materials. Application of these sources and techniques to homeland security and nuclear non-proliferation will be reviewed.

Thursday AM I: Bechtel-2

Pulsed White Neutron Generator for Explosives Detection

Michael King, Lawrence Berkeley National Laboratory
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Successful explosive material detection in luggage and similar sized containers is a critical issue in securing the safety of all airlines passengers. Tensor Technology Inc. has recently developed a methodology that will detect explosive compounds with pulsed fast neutron transmission spectroscopy. In this scheme, tritium beams will be used to generate neutrons with a broad energy spectrum as governed by the T(T,2n)4He fission reaction that produces 4-9 MeV neutrons. Lawrence Berkeley National Laboratory (LBNL), in collaboration with Tensor Technology Inc., has designed and fabricated a pulsed white spectrum neutron source for this application. The specifications of the neutron source are demanding and stringent due to the requirements of high yield, fast pulsing, and hard vacuum seal. In a unique co-axial geometry, the ion source uses ten parallel rf induction antenna to externally couple power into the toroidal discharge chamber. There are 20 extraction slits and 3 concentric electrodes to shape and accelerate the ions into a titanium target. Fast neutron pulses are created by using a set of parallel-plate deflectors switching between plus and minus 1500 volts. It is expected to achieve 5 ns neutron pulses at tritium beam energies between 80 - 120 kV. First experimental results will be presented. This work is being supported by Tensor Technology Inc. under contract number LB05-001379.

Thursday AM I: Bechtel-3

Intensity Modulated Advanced X-Ray Source (IMAXS) for Homeland Security Applications

Willem G.J. Langeveld, Rapiscan Laboratories, Inc.
William A. Johnson (HESCO/PTSE Inc., 2501 Monarch St., Alameda, CA 94501), Roger D. Owen (HESCO/PTSE Inc., 2501 Monarch St., Alameda, CA 94501), Russell G. Schonberg (Schonberg Research Corporation, P.O. Box S, Los Altos, CA 94023)

X-ray cargo inspection systems for the detection and verification of threats and contraband must address competing performance requirements. High X-ray intensity is needed to penetrate dense cargo, while low intensity is desirable to minimize the radiation footprint, i.e. the size of the controlled area, required shielding and the dose to personnel. We report here on a collaborative effort between HESCO/PTSE Inc., Schonberg Research Corporation and Rapiscan Laboratories, Inc. to build an Intensity Modulated Advanced X-ray Source (IMAXS) that allows such cargo inspection systems to achieve up to 2 inches greater penetration capability, while on average producing the same or smaller radiation footprint as present fixed-intensity sources. Alternatively, the new design can be used to obtain the same penetration capability as with conventional sources, but reducing the radiation footprint by about a factor of three. The key idea is to anticipate the needed intensity for each x-ray pulse by evaluating signal strength in the cargo inspection system detector array for the previous pulse. IMAXS requirements therefore include a linac-based x-ray source capable of changing intensity from one pulse to the next by electronic signal, as well as electronics inside the cargo inspection system detector array determining the required source intensity for the next pulse. The project also aims to significantly reduce the overall size and weight of the IMAXS linear accelerator system and its shielding, as compared to comparable conventional sources. We will investigate the comparative feasibility and technical merits of S-band (2998 MHz) and X-band (9303 MHz) linac designs for the IMAXS.
This project is funded under an SBIR award from DHS/DNDO.

Thursday AM I: Bechtel-4

Pulsed Neutron Facility for Research in Illicit Trafficking and Nuclear Safeguards

Bent Pedersen, Institute for the Protection and Security of the Citizen (IPSC)
J-M. Crochemore (IPSC), A. Favalli (IPSC), H-C. Mehner (IPSC)

The Joint Research Centre has taken into operation a new experimental device designed for research in the fields of nuclear safeguards and illicit trafficking. The research projects currently undertaken include detection of shielded contraband materials, and mass determination of small fissile materials in shielded containers. The device, called the Pulsed Neutron Interrogation Test Assembly (PUNITA), incorporates a pulsed 14-MeV neutron generator and a large graphite mantle surrounding a sample cavity. The sealed (D, T) neutron generator emits neutrons in 5-microsecond bursts. After a slowing-down time of about 300 microseconds, an average thermal neutron lifetime of about one millisecond is achieved in the graphite moderator and the sample cavity. By pulsing the neutron generator with a frequency in the range of 10 to 150 Hz, a sample may be

interrogated first by fast neutrons only and a few hundred micro-seconds later by a pure thermal neutron flux. For the detection of materials such as explosives the device employs gamma detectors for characteristic prompt gamma rays from inelastic scattering, by fast neutrons, and from thermal neutron capture. The gamma detectors include HPGe detectors and scintillation detectors based on the Lanthanum Bromide crystal. This new scintillation detector is particularly suited for the detection of activation gamma rays in the MeV range. For the purpose of fissile material assay (nuclear safeguards) the PUNITA device employs about hundred 3-He proportional counters located on the outside of the graphite mantle and embedded in cadmium covered polyethylene modules. The paper reports about the design and characterization of the new research facility as well as the different experimental configurations employed for the research activities in the fields of illicit trafficking and nuclear safeguards. The paper also presents and discusses the results obtained so far.

Thursday AM I: Bechtel-5

Development of New X-ray Source based on Carbon Nanotube Field Emission and Application to the Non Destructive Imaging Technology

Jong Uk Kim, Korea Electrotechnology Research Institute (KERI)
Hae Young Choi, KERI

In the present work, a new concept for an x-ray source was developed. The conventional thermionic tungsten filament tube is commonly available in various fields of application, such as, medical diagnostic and therapy system, microwave amplifier, and non-destructive testing (NDT) technology and so on. However, it has intrinsic inevitable problems such as high power consumption, very low x-ray efficiency and out-gassing problems and so on. Therefore, in the present study a new carbon nanotube (CNT) based x-ray source was developed as a substitute for the conventional one. The new x-ray source is consisted of three major parts (i.e., triode structures), for example, the CNT electron field emitter was employed as a cathode, a very thin metal mesh as a grid to extract electrons from the CNTs and finally molybdenum embedded copper target as an anode to accelerate electrons. A supplementary electrostatic double focusing lens was employed in the tube to focus electron beam on the anode target. Detailed description of the tube structure as well as electron beam characteristics were presented in the study. In addition, preliminary x-ray images obtained by using the CNT x-ray tube were also presented in the study.

Imaging Technology and Special Applications

Thursday AM II: Stanley 105

Chair: Alan Owens, European Space Agency

Thursday AM II: Stanley 105-1

Overview of the Nuclear Compton Telescope

Eric Bellm, UC Berkeley
Steven Boggs, presenter
Eric C. Bellm, Jason D. Bowen, Daniel Perez-Becker, Cornelia B. Wunderer, Andreas Zoglauer (University of California Space Sciences Laboratory, Berkeley, CA); Mark Amman (Lawrence Berkeley National Laboratory, Berkeley, CA); Chih-Hsun Lin (National Space Organization (NSPO), Taiwan), Mark E. Bandstra (University of California Space Sciences Laboratory, Berkeley, CA);Yuan-Hann Chang (National Central University, Taiwan); Paul N. Luke (Lawrence Berkeley National Laboratory, Berkeley, CA), Hsiang-Kuang Chang, Jeng-Lun Chiu, Jau-Shian Liang (National Tsing Hua University, Taiwan); Zong-Kai Liu (National Central University, Taiwan); Alfred Huang (National United University, Taiwan); Pierre Jean (Centre d'Etude Spatiale des Rayonnements (CESR), Toulouse, France)

The Nuclear Compton Telescope (NCT) is a balloon-borne soft gamma ray (0.2 MeV-10 MeV) telescope designed to study astrophysical sources of nuclear line emission and polarization. A prototype instrument was successfully launched from Fort Sumner, New Mexico on June 1, 2005. The NCT prototype consisted of two 3D position sensitive high-purity germanium strip detectors (GeDs) fabricated with amorphous Ge contacts. We are currently working toward two balloon flights: another conventional balloon flight from Fort Sumner, New Mexico in September 2008, and a long-duration balloon flight (LDBF) from Alice Springs, Australia in December 2009. The NCT instrument is being upgraded to include all twelve planned GeDs. The electronics for all twelve detectors have been redesigned for smaller size, lower power consumption, and lower noise, and are now being fabricated and tested. Here we present our current progress in preparing for the flights and discuss sensitivity and performance of the instrument.

The NCT project is funded by NASA under Grant #NNG04WC38G for the NCT-US team and by the National Space Organization (NSPO) in Taiwan under Grant 96-NSPO(B)-SP-FA04-01 for the NCT-Taiwan team.

Thursday AM II: Stanley 105-2

The Gamma-Ray Imaging Mission GRI

Cornelia Wunderer, Space Sciences Laboratory, UC Berkeley

Observations of the gamma-ray sky reveal the most powerful sources and the most violent events in the Universe. While at lower wavebands the observed emission is generally dominated by thermal processes, the gamma-ray sky provides us with a view on the non-thermal Universe. Here particles are accelerated to extreme relativistic energies by mechanisms which are still poorly understood, and nuclear reactions are synthesizing the basic constituents of our world. Cosmic accelerators and cosmic explosions are major science themes that are addressed in the gamma-ray regime. ESA's INTEGRAL

observatory currently provides the astronomical community with a unique tool to investigate the sky up to MeV energies and hundreds of sources, new classes of objects, extraordinary views of antimatter annihilation in our Galaxy, and fingerprints of recent nucleosynthesis processes have been discovered. NASA's GLAST mission will similarly take the next step in surveying the high-energy (~GeV) sky, and NuSTAR will pioneer focusing observations at hard X-ray energies (to ~80 keV). There will be clearly a growing need to perform deeper, more focused investigations of gamma-ray sources in the 100-keV to MeV regime. Recent technological advances in the domain of gamma-ray focusing using Laue diffraction and multilayer-coated mirror techniques have paved the way towards a gamma-ray mission, providing major improvements compared to past missions regarding sensitivity and angular resolution. Such a future Gamma-Ray Imager will allow the study of particle acceleration processes and explosion physics in unprecedented detail, providing essential clues on the innermost nature of the most violent and most energetic processes in the Universe.

Thursday AM II: Stanley 105-3

Modelling an Energy-Dispersive X-ray Diffraction System for Drug Detection

Silvia Pani, School of Medicine and Dentistry-Queen Mary Univ of London/Barts and The London NHS Trust, London,UK

Emily Cook (Department of Medical Physics and Bioengineering, University College London, UK), presenting; Julie Horrocks (School of Medicine and Dentistry-Queen Mary Univ. of London/Barts and The London NHS Trust,UK); Leah George, Sheila Hardwick (Counter Drug Technologies Team, Home Office Scientific Development Branch, Sandridge, UK); Robert Speller (Department of Medical Physics and Bioengineering, University College London, UK)

Purpose: Preliminary studies have shown the effectiveness of energy-dispersive X-ray diffraction in illicit drug detection. Following these results, the possibility of an X-ray diffraction system for concealed drug detection is currently being researched. A simulation program has been developed to evaluate the optimum combination of geometrical parameters, beam spectrum and detector. Method: A modelling code has been written in IDL. The model is based on a system consisting of a polychromatic X-ray source, a primary beam collimator, a diffraction collimator at a fixed angle and a spectroscopic detector. The program calculates the angular resolution of the system from the geometrical parameters: the collimator angle, the distances between the elements, the apertures of the collimators, the source size and intensity profile and the sample thickness. Several layers of different materials can be included in the model. The input data are diffraction patterns produced with a commercial, high-resolution diffractometer. The data are convolved with the energy resolution of the detector (typical values for HPGe and CZT have been applied) and by the calculated angular resolution of the system. The broadening of the angular resolution with increasing momentum transfer is taken into account, as well as sample self-attenuation. Finally, the diffraction pattern is weighted by the X-ray tube spectrum. Poisson statistical fluctuations are introduced for developing and validating the material identification protocol. Results: The influence of different parameters on diffraction patterns has been assessed. Comparison with

experimental data for reference materials shows a good agreement for both peak width and peak height.

Thursday AM II: Stanley 105-4

Observation of the n(3He,t)p Reaction by Detection of Far-Ultraviolet Radiation

Charles W. Clark, National Institute of Standards and Technology
Alan K. Thompson (National Institute of Standards and Technology); John W. Cooper, Michael A. Coplan, Patrick Hughes (University of Maryland); Robert E. Vest (National Institute of Standards and Technology)

We have detected Lyman alpha radiation as a product of the n(3He,t)p nuclear reaction occurring in a cell of 3He gas. The predominant source of this radiation appears to be decay of the 2p state of tritium produced by charge transfer and excitation collisions with the background 3He gas. Since the speed of the tritons and protons produced in the nuclear reaction is comparable to the speeds of the electrons in the helium atom, the cross sections for such collisions are relatively large. Our experiments use a gas cell and a filtered photomultipler package, mounted on a cold neutron beamline at the NIST Center for Neutron Research. Under the experimental conditions reported here we find yields of tens of Lyman alpha photons for every neutron reaction. These results suggest a method of cold neutron detection that is complementary to existing technologies that use proportional counters. In particular, this approach may provide single neutron sensitivity with wide dynamic range capability, and a class of neutron detectors that are compact and operate at relatively low voltages.

Thursday AM II: Stanley 105-5

Withdrawn

Electronics

Thursday AM II: Bechtel

Chair: Stuart Kleinfelder, Univ. of California, Irvine

Thursday AM II: Bechtel-1

Fast Self Triggered Multi Channel Readout ASIC for Time- and Energy Measurement

Michael Ritzert, University of Heidelberg
Peter Fischer (University of Heidelberg), Ivan Peric (University of Heidelberg), Martin Koniczek (University of Michigan)

We present a 16 channel self triggered readout chip for simultaneous time and energy measurement, suitable for a wide range of applications. All circuit elements required for detector readout are integrated on the chip. A fast, low-noise discriminator detects hits at the differential inputs. The events are time stamped with an electronic resolution of 15ps (single channel rms). The timing range is virtually infinite by means of a coarse counter and an overflow indicator. In parallel to the time stamping of the discriminated input signal, the analog input is integrated during a programmable time window and digitized with 8 bit integral resolution. Readout is achieved through a simple serial protocol. Several chips can be synchronized by means of a built in PLL circuit locking to a common reference clock. The 3x3mm2 chip has been fabricated in 0.18um technology, employing a differential logic for all crucial parts. Possible applications of this ASIC are in high energy physics experiments, medical imaging, range finding, georadar and other fields.

Thursday AM II: Bechtel-2

High Speed Multichannel Charge Sensitive Data Acquisition System with Self Triggered Event Timing

Anton S. Tremsin, Space Sciences Laboratory, UC Berkeley
Oswald H.W. Siegmund, John V. Vallerga (Space Sciences Laboratory, UC Berkeley)

A number of modern experiments require simultaneous measurement of charges on multiple channels. The event rates exceeding MHz levels and requirement of charge detection with accuracy of 100-1000 electrons rms require adequate data processing electronics. One of the widely used data processing scheme relies on application specific integrated circuits enabling multichannel analog peak detection asserted by an external trigger followed by a serial/sparsified readout. Although that configuration minimizes the back end electronics, its counting rate capability is limited by the speed of the serial readout. The recent advances in analog to digital converters and FPGA devices enable fully parallel high speed multichannel data processing with digital peak detection enhanced by the finite impulse response filtering. Not only can the accurate charge values be obtained at high event rates, but the timing of the event on each channel can also be determined with high accuracy. We present the concept and first experimental tests of fully parallel 128-channel charge sensitive data processing electronics capable of measuring charges with accuracy of 1000 e- rms. Our system does not require an external trigger and, in addition to charge values, it provides the event timing with an accuracy of

~1.2 ns. One of the possible applications of this system is high resolution position sensitive event counting detectors with microchannel plates combined with cross strip readout. Implementation of fast data acquisition electronics increases the dynamic range of those detectors to multi-MHz level, preserving their unique capability of virtually noiseless detection of both position (with accuracy of 10 um FWHM) and timing (~1.2 ns FWHM) of individual particles, including photons, electrons, ions, neutrals, and neutrons.

Thursday AM II: Bechtel-3

Electronics Development for Fast-Timing PET detectors: The Multi-Threshold Discriminator Time of Flight PET system

Jialie Lin, University of Chicago and Enrico Fermi Institute, University of Chicago Octavia Biris (University of Chicago), Chin-Tu Chen (Department of Radiology, University of Chicago), Woon-Seng Choong (Lawrence Berkeley National Laboratory), Henry Frisch (University of Chicago and Enrico Fermi Institute, University of Chicago), Chien-Min Kao Chen (Department of Radiology, University of Chicago), William W. Moses (Lawrence Berkeley National Laboratory), Fukun Tang (Univ. of Chicago), Qingguo Xie (Department of Radiology, Univ.of Chicago), Lin Zhou (Univ. of Chicago)

We present the status of development of an all-digital Positron Emission Tomography system designed to have time-of-flight resolution of less than or equal to 100 picoseconds. The timing resolution we strive for will much improve the quality of imaging obtained in radiology and medical physics fields [1]. The test setup is composed of a 1-cm diameter Fluorine-18 source giving two back-to-back gamma rays, which impinge on a pair of detector modules, each consisting of a 6.25 x 6.25 x 3 mm^3 LSO scintillator that is covered by Teflon on five sides and coupled to a Hamamatsu R9800 PMT. The outputs of each detector were read into a 40-GHz sampling Tektronix oscilloscope to form a library of pulses. Using a constant fraction discriminator, these pulses have a measured coincidence timing resolution of ~300 ps fwhm and a 2~3 ns rise time [2]; studies are underway to understand the underlying physical effects contributing to the timing resolution. By having a digitized pulse train available, we can test different algorithms to extract timing estimators, but the event rate provided by oscilloscopes is too low to be practical for what we encounter in PET. We are therefore developing electronics that are compatible with PET requirements. The architecture of the electronics system consists first of a multi-threshold discriminator, using Analog Devices' Ultrafast SiGe Voltage Comparators ADCMP582 [3]. The output from the comparators will then feed into a board with the CERN High Performance Time to Digital Converter [4], which further feeds into a Xilinx Spartan FPGA, then a Digital IO board to allow input into a

PC. In order to optimize the number and setting of the thresholds the pulses collected were fed into a simulation of the electronics and analysis [2]. In light of the preliminary simulation results, our discriminator will have eight thresholds, to allow for a broad range of input PET pulse-types and to compare with the simulation. We will present results on the analysis of the timing characteristics of the pulse as well as the construction and performance of the multi-level timing discriminator.

[1] W. Moses. Time of Flight PET revisited, IEEE Trans. on Nucl. Sci. 50 (2003) 1325.
[2] Q. Xie, C. Kao, X. Wang, N. Guo, C. Zhu, H. Frisch, W. Moses, C. Chen. Potential advantages of digitally sampling scintillation pulses in timing determination in PET. IEEE NSS `07 CR. 6 (2007) 4271.
[3] http://www.analog.com/UploadedFiles/Data_Sheets/ADCMP580_581_582.pdf [4] M. Mota, J. Christiansen, S. Debieux, V. Ryjov, P. Moreira, A. Marchioro. A flexible multi-channel high-resolution time-to-digital converter ASIC. IEEE NSS `00 CR. 2 (2000) 9/155.

Thursday AM II: Bechtel-4

High Sensitivity Readout and Data Processing for Environmental Spectral Radiation Measurements

Vladimir Popov, Jefferson Laboratory

We have developed a new version of high sensitivity electronics front end and analog signal processing for use with high pressure ionization chambers in environmental radiation measurements. The readout circuit provides low noise signal readout from individual events of gas ionization. Readout electronics is connected to the analog-to-digital converter providing continuous high rate data sampling. The data processing algorithm allows noise rejection and extraction of pulse shape and amplitude information related to the ionization loss in the gas for each ionization event. The output of the detector could be presented in a traditional way as the accumulated ionization charge per unit time, and as a signal amplitude spectroscopic distribution. Results of the initial evaluation are presented. These results were obtained using the designed electronics connected to the RSS-1013 Reuter-Stokes high pressure ionization chamber filled with Ar at 25 atm. The HPIC detector was tested using cosmic radiation and several external radiation sources. Combined measurements of total ionization and ionization spectrum in the detector provide a new type of powerful instrument capable of better separation between the natural background radiation and the radiation form external sources, as well as the improved low energy gamma radiation detection.

Thursday AM II: Bechtel-5

Radiation Tolerance of an Analog LSI Developed for X-ray CCD Camera Readout System Onboard an Astronomical Satellite

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We present the results of radiation damage experiment of an analog Application Specific Integrated Circuit (ASIC) developed aiming at the use in a readout system of X-ray CCD camera. Conventional X-ray CCD cameras onboard X-ray astronomical satellites have achieved fano-limited energy resolution and superior spatial resolution with X-ray mirrors. The only weakness of the X-ray CCDs is relatively inferior readout time, which causes pile-up of X-ray events and subsequent wrong measurement of the X-ray photon energy. The most reliable and direct method to improve timing resolution without declining other performances is to increase the number of readout nodes of X-ray CCDs. However, this requires the larger size and higher power consumption of the data acquisition systems. Then we are developing an ASIC and subsequent electronics, with which we are able to achieve very high readout rate of approximately 1Mpixels/sec, much faster than conventional frame-transfer type CCD systems in orbit. Our ASIC consists of four identical sub-circuits that simultaneously process X-ray events. Each sub-circuit is composed of pre-amplifier, 5-bit DAC, and delta-sigma type AD converter. It has been fabricated with Taiwan Semiconductor Manufacturing Company (TSMC) 0.35-micron CMOS process and then 3mm square bare chip is Quad Flat Pack (QFP) packaged. We introduced delta-sigma converter into the readout system of X-ray CCD for the first time. It is characterized with high-resolution using relatively simple circuit and its noise-shaping architecture drives white noise away to higher frequency than that of the signal band. The output digitized signals are decimation-filtered in a subsequent FPGA. Our ASIC has realized rather low power consumption down to the order of 100mW per chip, we are able to load many chips to a satellite and hence high timing performance could be possible even using X-ray CCDs with many readout nodes. We have also succeeded to readout with high speed of 625kpixels/sec and with low noise of less than six electrons, which is comparable with existing X-ray CCDs in orbit. The effective energy range reaches up to approximately 40 keV, which is sufficiently high for use in X-ray astronomy. Radiation tolerance of the ASIC is one of the critical issues to put it in orbit. In the low-earth orbit, the ASICs suffer low-energy solar protons when the satellite goes through South Atlantic Anomaly (SAA). Hence we conducted the radiation damage test with 200MeV proton beam utilizing HIMAC (Heavy Ion Magnetic Accelerator in Chiba) in Japan. There was no significant degradation the noise performance and linearity until the absorbed dose amounts more than 14krad, which corresponds to approximately 14 years endurance in the low-earth orbit. When the absorbed dose exceeded 14krad, the noise performance and linearity suddenly degraded for every channel but there was no significant increase of the current. Typical mission time of X-ray astronomical satellite is less than 10 years, hence we proved that our ASIC has sufficient radiation tolerance for use in the low-earth orbit.

Radiation Measurements in Physics

Thursday PM I: Stanley 105

Chair: Yuen-Dat Chan, LBNL

Thursday PM I: Stanley 105-1

MAJORANA: An Ultra-Low Background Enriched-Germanium Detector Array for Fundamental Physics Measurements

Jason Detwiler, Lawrence Berkeley National Laboratory

For decades, germanium detectors have played a central role in fundamental physics measurements, for example searches for neutrinoless double-beta decay (0nbb). Detecting this phenomenon would establish the Majorana nature of the neutrino and simultaneously give a measure of the absolute neutrino mass scale. The MAJORANA collaboration aims to perform such a search by fielding arrays of HPGe detectors mounted in ultra-clean electroformed-copper cryostats located deep underground. Recent advances in HPGe detector technology, in particular highly-segmented detectors and point-contact detectors, show great promise for identifying and reducing backgrounds to the 0nbb signal, which should result in improved sensitivity over previous generation experiments. The MAJORANA Demonstrator R&D program will field three ~20 kg modules of segmented and point-contact detectors, of which 30 kg will be enriched to 86% in 76Ge. I will present recent progress in this R&D effort, and discuss its physics reach. I will also contrast MAJORANA's "clean cryostat" approach with the "active cryogen" approach currently being pursued by the GERDA collaboration in Europe, and discuss the future of 0nbb experiments in 76Ge.

Thursday PM I: Stanley 105-2

NA62 RICH: Test Beam Results

Antonino Sergi, INFN - Perugia, Italy

NA62 experiment at CERN, aimed to measure K -> pi nu nubar branching fraction (O(10^-11)), relies on a gas based RICH detector for pion/muon separation and L0 trigger. The experimental requirements on this detector are mainly a time resolution of 100ps and a muon rejection better than 10^-3 in the momentum range 15-35GeV. A first prototype of such a detector has been built and tested in October 2007: it is a full lenght (18m) Ne filled vessel equipped with a spherical mirror and 96 PMs on its focal plane, 17m upstream. The test has been performed at the CERN SPS on a 200GeV pion beam, mainly as a first check of its time resolution and of the light collection technique; the time resolution has been found to be about 65ps, and the light collection, i.e. the number of hit PMs, fairly as expected. Other parameters, like cerenkov angle resolution and track angle resolution, even if biased by the low number of PMs, have been tested and found within expectation.

Thursday PM I: Stanley 105-3

Performance of the CREAM-III Calorimeter

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Cosmic Ray Energetics And Mass (CREAM) is a balloon-borne experiment to directly measure the elemental spectra of protons to iron nuclei with energies up to ~ 10^15 eV. Energies of these cosmic ray particles are measured by an ionization calorimeter comprised of 20 layers of 1 radiation length thick tungsten plates and 20 layers of 0.5 mm diameter scintillating fibers. Each tungsten plate is 500 x 500 x 3.5 mm^3 and the fibers are grouped into fifty 1 cm wide ribbons. The CREAM-III calorimeter was constructed and tested at CERN, the European high energy physics lab, in the H2 beam line of the SPS. Following the CERN test, the calorimeter was integrated into the CREAM-III instrument, and flown successfully in the 3rd flight during the 2007/8 Antarctic campaign. We present performance of the CREAM-III calorimeter in lab and beam tests.

Thursday PM I: Stanley 105-4

New X-ray Detectors for Exotic Atom Research

Johann Marton, Stefan Meyer Institute

Exotic atoms of low Z systems in which the electron is substituted by a hadron like a negatively charged K meson are perfect probes for studying strong interaction at lowest energies using X-ray spectroscopy. New large area X-ray detectors (silicon drift detectors, SDDs) were developed to provide excellent energy resolution as well as timing capability. For the first time large area SDDs were employed to measure the L-lines of kaonic helium at high precision thus succeeding in clarifying a puzzle persisting 30 years since the 70s. An array of about 200 even more sophisticated SDDs (1cm2 SDDs with integrated FET) will be used to perform precision measurements (at the eV level) of kaonic hydrogen and kaonic deuterium (first measurement) at the DAFNE Phi-factory of LNF/Italy. The new X-ray detectors and the performance for precision experiments in the environment of an accelerator will be presented.

Thursday PM I: Stanley 105-5

Active, Beam-Defining Elements for Synchrotron Beamlines

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Jasmine Hasi, presenter
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Measuring the position of x-ray synchrotron beams is becoming more important as many experiments are using intense focused x-ray beams that are less than 100 by 100 square microns. In addition, many samples are heterogeneous so it is important to know that the beam is stable on a particular part of the sample. For example, protein crystallography experiments are now routinely studying crystals that are less than 30 by 30 by 30 microns cubed. If the beam moves relative to the crystal by more than 10 microns, the data quality is seriously degraded. Relatively inexpensive and simple beamline diagnostic apparatus has the potential to improve the delivery of beams to the samples. Passive beam elements, such as collimating slits made of tungsten, perform the function of blocking part of the beam, but provide no information about the beam. Active beam elements, such as collimating slits made of entirely or partly of silicon diodes, allow continuous recording of the blocked photon intensity, profile, and other parameters. Small real-time changes in beam position or intensity can be easily determined by measuring the current from these devices. They can also serve as a beam profile monitor, if the blade is scanned across the beam. Active edges are critical to most of these designs as the absence of insensitive edges greatly enhances the usefulness of such devices. Our group is developing a variety of diagnostic instruments for synchrotron beam lines. Results with collimating pinholes and slits made of silicon diodes will be presented.

Medical Applications

Thursday PM I: Bechtel

Chair: David Wehe, Univ. of Michigan

Thursday PM I: Bechtel-1

Recent Results from Axial 3-D PET Modules with Long LYSO Crystals, Wave Length Shifter Strips and SiPM Readout

Peter Weilhammer, University/INFN Perugia and CERN
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We describe a novel concept to extract the axial coordinate from a matrix of long axially oriented crystals, which is based on wavelength shifting (WLS) plastic strips. The method allows building compact 3-D axial gamma detector modules for PET scanners with excellent 3-dimensional spatial, timing and energy resolution while keeping the number of readout channels reasonably low. One module consists of a stack of 100 mm long LYSO scintillation crystals interleaved with arrays of WLS strips which allow the determination of the axial coordinate. To detect the light from the Crystals and the WLS strips Silicon Photomultipliers (SiPM) are employed. A voxel resolution of about 8 mm3 is expected. The performance of the concept has been demonstrated with a test set-up consisting of two long LYSO crystals and two WLS strips read out by SiPMs. Results obtained with the test set-up, demonstrating spatial, energy and timing resolution, will be summarized. Recent progress in building a demonstrator PET scanner prototype is reported.

Thursday PM I: Bechtel-2

Single crystal film scintillators for X-ray imaging applications with micrometer resolution

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X-ray detector systems are powerful tools which provide volumetric data of samples during a non-destructive examination for biology, medicine and material sciences. The detector able to provide sub-micrometer spatial resolution consists of a scintillator, light microscopy optics and a cooled charged-coupled device (CCD). The scintillator converts the X-ray into a visible light image which is projected onto the CCD by the light optics. Single Crystal Film (SCF) scintillator, grown by liquid phase epitaxy (LPE) from 1micron to 30micron thick, used for high resolution imaging suffers of low efficiency (2% at 50keV) owing to its few micron thickness. The detective quantum efficiency (DQE) is then mainly limited by the low absorption of X-rays and the light yield in the thin layer of scintillator. Performances, i.e absorption, light yield, afterglow, temperature effect and radiation hardness, of the operational system based on YAG:Ce, LAG:Eu and GGG:Eu scintillators[1] will be presented and compared to new LSO:Tb scintillators

developed in the European project, SCINTAX[2]. A new concept to improve the efficiency of detection in the 20-40keV energy range with 1micron spatial resolution will be presented. This concept based on multilayer scintillator can be produced by LPE process. An approach of this concept will be illustrated with X-ray images and will demonstrate the absorption efficiency improvement of the X-ray detector. The expected improvement is 8 times better than the current LAG scintillators. Keywords: X-ray imaging, scintillator, liquid phase epitaxy, microscopy, microtomography, synchrotron radiation.

The project SCINTAX is funded by the European Community (STRP 033 427, FP6)

[1] T. Martin and A. Koch, J. Synchrotron Rad. (2006) 13, 180-194
[2] K. Dupre, M. Couchaud, T. Martin, A. Rack, German Patent Application no. 10 2007 054 700.7 (2007).

Thursday PM I: Bechtel-3

Distributed Phantoms in Planar Coded Aperture Nuclear Medicine Imaging: Experimental Results

David M. Starfield, University of the Witwatersrand, Johannesburg
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Acquisition of images in nuclear medicine typically requires the use of a collimator. Coded apertures are an alternative to collimators, and under specific conditions can augment the signal-to-noise-ratio (SNR) of the system. However, the near-field geometry of nuclear medicine results in the presence of artifacts, and the SNR decreases further for distributed sources. The paper aims to provide a clear indication of the applicability of simple coded aperture acquisition for the near-field distributed sources of nuclear medicine. With respect to the low-energy-high-resolution (LEHR) parallel-hole collimator, septa size remains fixed. Resolution cannot be increased without a decrease in the open fraction of the collimator. Coded apertures have multiple holes that can be designed for optimal performance with a specific gamma camera, such that both the open fraction of the material and the field-of-view are maintained. Neither zero-order nor first-order artifact correction is implemented. Second-order artifact reduction is applied to all images. An anti-symmetric, self-supporting coded aperture is constructed by laser drilling a 1 mm tungsten sheet. A specialized aluminium frame attaches the coded aperture to the Philips Axis gamma camera. Printer cartridges are injected with Technetium-99m to obtain repeatable two-dimensional phantoms of distributed sources. Collimator and coded aperture images are acquired simultaneously. The results presented in the paper show that the coded aperture reconstructions suffer from significant noise. Simple multiplication of the collimator and coded aperture images decreases noise compared to the original coded aperture image, while the resolution advantage over the LEHR collimator image is retained. Use of the current state-of-the-art in coded aperture technology and an existing gamma camera, together with straightforward artifact correction and simple reconstruction techniques, gives coded aperture images that are at least comparable to collimator images. Unlike collimators, the potential exists for design of higher resolution coded aperture systems. The authors believe that the experimental results, which will be

presented in the paper, will provide a motivation for both further work on coded apertures and enhanced gamma camera design.

This work was supported by the University of the Witwatersrand, Johannesburg, and by the National Research Foundation of South Africa.

Thursday PM I: Bechtel-4

Characterisation of the Components of a Prototype Scanning Intelligent Imaging System for use in Digital Mammography: The I-ImaS System

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The physical performance characteristics of a scanning system for a prototype digital mammography (DM) unit has been investigated in terms of noise power spectrum (NPS), modulation transfer function (MTF) and detective quantum efficiency (DQE). The I-ImaS system was designed for use in DM implementing the use of CMOS MAPS promoting on-chip intelligence therefore enabling statistical analysis to be achieved in real time for the purpose of feedback during the image acquisition procedure. The focus of the intelligent system is to optimise the diagnostic content of an image implementing a statistical feedback loop where the x-ray beam intensity is modulated based on the nature of the region of tissue being scanned. The system consists of a dual array of CMOS MAPS that have been designed and developed specifically for this project. Twenty 520x40 32 micron pixel sensors are implemented within the system enabling a preliminary image (the scout image) and a diagnostic image to be obtained simultaneously. A 100 um thick thallium doped caesium iodide (CsI:TI) scintillator is used to provide x-ray sensitivity. A set of 10 x-ray attenuating filters are implemented where each one was specifically designed to provide various degrees of beam attenuation depending on the statistical information fed to the modulators. Prior to system characterisation care was first taken to directly determine the linearity of the system. The MTF was determined via the Fourier transform (FT) of an oversampled line spread function (LSF) obtained using the angled slit method according to the technique described by Fujita et al 1992. The MTF was found to be 0.1 at 6 cycles/mm. The 1-D noise power spectrum was estimated using the direct method where a thick slice consisting of 8 lines through the central region of the measured 2-D noise power spectrum was used. The presented noise power spectrum results illustrate the noise power decreases as exposure is increased. The 2-D spectra for all exposure levels investigated exhibit noise structures both on and off the primary frequency axis indicating the presences of periodic noise components; 1-D noise power spectrum estimates were made over a range of 5 exposures and 3 tube voltages where the results show the noise level to be inversely proportional to exposure and tube voltage having minimal effect. The DQE(0) has been measured to be approximately 0.5 at 17keV. These results show that the I-ImaS system noise, spatial resolution and detection efficiency characteristics are comparable to those obtained by current commercially available DM systems. Current work is on the acquisition of preliminary stitched images obtained conventionally and implementing off line intelligence in an attempt to compare the diagnostic content of the image. Simulations are being carried out in order to determine which statistical measure is best suited for implementation into the feedback mechanism. Once complete, the

results will show the potential benefits of implementing artificial intelligence within the data acquisition stage of digital mammography.

Thursday PM I: Bechtel-5

Synchrotron X-ray Fluorescence Computed Tomography Using an Emission Tomography System

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In this paper, we present a feasibility study of using an emission tomography (ET) system for 3-D mapping of trace elements based on x-ray fluorescence induced by synchrotron radiations. Synchrotron radiation based x-ray fluorescence computed tomography (XFCT) allows 3-D mapping of very low contents of trace metals (at the order of picograms) in volumetric samples. XFCT studies are typically performed using a collimated beam of synchrotron X-rays, scanning line-by-line through a volumetric sample in a first-generation tomographic geometry. Fluorescence X-rays that originate from the sub-volume irradiated by the beam are collected with a high-energy resolution, non-imaging spectrometer, yielding the line integrals through the various elemental distributions. After rotating the object through at least 180 degrees, the 3D distribution of trace elements inside the sample can be reconstructed based on the line integrals collected. Although excellent imaging performance has been demonstrated, the line-by-line mechanical scanning normally leads to a very long imaging time. In recent years, substantial efforts have been made to improve the speed of XFCT studies, which is particularly important for potential in vivo imaging applications. In this paper, we proposed an alternative imaging approach that involves a much reduced scanning steps and therefore offers an improved imaging speed. In this approach, we use an optimized single photon emission computed tomography (SPECT) system to detect the fluorescence x-rays. The proposed system consists of a ring of silicon pad detectors that offers both a high spatial resolution and an excellent energy resolution. In order to achieve an adequate detection efficiency for fluorescence x-rays, a specially designed truncated spherical collimator is used. This aperture consists of multiple pinhole or ring-hole openings surrounding the sample, which offers a detection efficiency of around 1% for X-rays originated in the sample. Although the aperture significantly cuts down the sensitivity, it makes up for this loss by (a) reducing the need for translational and rotational movements of the sample and (b) acquiring data that has much a reduced multiplexing. For the same imaging time, it is possible to achieve XFCT images with a substantially improved signal-to-noise ratio (SNR). In this paper, we will present the design of the dedicated XFCT system. Both experimental and Monte Carlo studies will be performed to evaluate the SNR that can be achieved with this system in comparison to those offered by other sampling techniques based on mechanical scanning.

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