SORMA WEST 2008

2008 Symposium on Radiation Measurements and Applications

June 2-5, 2008 Berkeley, California, USA

Poster Program, May 12, 2008

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

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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.

These poster presentations will be given in two sessions, 2-3:15 and 3:45-5, on Monday afternoon. (Setup is expected to begin at 1:30.) Odd-numbered posters will be presented in the first session, even-numbered posters in the second session. All posters should stay up all afternoon and into the evening, when we will have a reception.

Be sure to stop by the tables of the private-sector supporters who helped make SORMA West 2008 possible.

Semiconductor Detectors
1-36

1

Performance and Longevity Studies of the Silicon Detectors of the CDF Experiment

Alexander Sukhanov, University of Florida

The CDF Silicon Detector is a system devoted to make precision tracking and vertex measurements. The silicon detector is used in regular data taking, having collected more than 3.0 1/fb of data during the Run II of the Tevatron Collider at Fermilab. This detector has been exposed to extreme conditions of irradiation so providing an exceptional opportunity to study the effects of the radiation on the sensor in a real-time scale. In this talk we describe the study of the evolution of the silicon detector performance as radiation damage becomes more severe, specifically after the innermost layers of the detector have crossed the so-called inversion point.

2

The Effect of the Dielectric Layer Thickness and Permittivity on Spectral Performance of CdZnTe Gamma Ray Spectrometers

Alireza Kargar, S.M.A.R.T. Laboratory, Kansas State University
Adam C. Brooks, Mark J. Harrison, Douglas S. McGregor (Mechanical and Nuclear Eng. Dept., Kansas State University); Henry Chen, Glenn Bindley (Redlen Technologies)

CdZnTe Frisch collar devices have shown a promising potential for inexpensive room temperature operated gamma ray spectrometer applications. The dielectric layer between the bare CdZnTe crystal and the Frisch ring has been reported to have a great impact on device performance. In this study, the optimum thickness of the dielectric layer for a few specific Frisch collar device geometries has been determined experimentally. The results were confirmed through modeling of the weighting potential and electric field of the desired device. Teflon tape and Parylene-N have been used as the dielectric layer to fabricate CdZnTe Frisch collar devices. The effect of the device geometry on spectral performance of Frisch collar detectors has been previously reported, and the limitations on the aspect ratio of the bar shape Frisch collar detectors has been determined. As the dielectric layer thickness increases, the aspect ratio of the Frisch collar device decreases, which results in a more linear weighting potential. This effect degrades the device performance, especially if the aspect ratio of the device is significantly altered. Alternatively, the voltage profile also becomes more linear, increasing the electric field near the cathode region, which potentially improves the device performance. Hence, increasing the dielectric thickness, has two different effects on device performance in which one effect improves device performance (voltage or electric field), and the other deteriorates device performance (weighting potential). Therefore, there is an optimum dielectric layer thickness, given the device geometry, CdZnTe charge transport properties and the dielectric constant (permittivity) of the dielectric layer. The starting material was acquired from Redlen Technologies and the devices were fabricated at the SMART laboratory at Kansas State University.

3

Silicon on Insulator Radiation Detectors for Microdosimetry and Other Applications

Anatoly B. Rosenfeld, University of Wollongong
Peter D. Bradley (Univ. of Wollongong and Zarlink Semiconductor); Iwan M. Cornelius (Univ. of Wollongong); Andrew Wroe (Univ. of Wollongong and Zarlink Semiconductor); Andrew Dzurak, Wee Han Lim, Nai Shian (Univ. of New South Wales); Amy Ziebell (Univ. of Wollongong); M. Reinhard, Dale Prokopovich (Univ. of Wollongong and Australian Nuclear Science and Technology Organisation), Susanna Guatelli (Australian Nuclear Science and Technology Organisation)

Accurate measurement of Linear Energy Transfer (LET) is an important aspect of research performed in the field of radiation physics, for example, in particle identification, separation of mixed field components and microdosimetry. One of the challenges associated with this task is the production of thin silicon radiation detectors with a thickness of 1-5 microns, or bulk detectors with well defined charge collection volume (CCV) of micron-scale dimensions. Silicon on Insulator (SOI) is a promising choice for such detectors due to a well defined CCV determined by the thickness of bonded or epitaxially grown high resitivity silicon wafer on top of an insulating layer. We have developed three generations of SOI microdosimeters and investigated their electrical characteristics, charge collection properties and radiation damage properties with micron spatial resolution for charged particles with LET range of 10-1000 keV/um using an ion microbeam. The first is based on an array of closely attached orthogonal planar CCVs with an n+ core and p+ lateral contact fabricated on p-type SOI with a thickness of 2-10 um. The second generation utilised 3D cylindrical mesa CCV, providing close to 100% charge collection in a small volume. The third generation is still under development and will utilise controllable charge amplification in the CCV to measure LETs of up to 0.01 keV/um and will be produced on SiGe SOI with integrated readout electronics. These results have been used in the development of a variety of applications including hadron therapy, radiation protection, avionics and space applications. The developed SOI detectors are ideal for future homeland security applications due to high selectivity of low rate, high LET radiation and neutrons in a strong gamma background.

4

Characterization of CZT Interconnects Using Scanning Acoustic Microscopy

Charles G. Woychik, GE Global Research
Tan Zhang, Kristen Wangerin, David Shaddock, Brian D. Yanoff (GE Global Research)

Scanning acoustic microscopy (SAM) is commonly used for interconnect inspection in the semiconductor packaging industry. It is frequently used to characterize the integrity and reliability of flip chip interconnects between a bare silicon die and a substrate. We have adapted this technique to non-destructively characterize the conductive epoxy interconnects that join the anode pads of a CZT detector to a substrate. The ultrasonic signals were found to effectively penetrate a 10 mm thick CZT crystal, and the resulting images clearly show the integrity of the all interconnects as well as the contacts, surfaces and interfaces. Mechanical defects, such as grain boundaries are also highly visible in the images. The technique was validated using destructive methods to correlate the characteristics of the SAM image with the physical characteristics of the interconnect. We present data showing the value of this technique in evaluating the quality of the initial assembly of CZT detectors, and their reliability under accelerated stress testing.

5

Studies of the Silicon Neutron Sensor Characteristics

Igor E. Anokhin, Institute for Nuclear Research, Kiev, Ukraine
O. Zinets (Institute for Nuclear Research); A. Rosenfeld, M. Lerch (Centre for Medical Radiation Physics, University of Wollongong); V. Perevertaylo (SPO BIT, Kiev, Ukraine); M. Yudelev (Ted B. Wahby Cancer Center, Mount Clemens, MI, US); M. Reinhard (Australian Nuclear Science and Technology Organisation (ANSTO) and Centre for Medical Radiation Physics (CMRP), University of Wollongong, AU)

The using of the silicon planar structures as neutron integral sensors is based on the effect of the non-ionizing energy losses when radiation damages are introduced into the silicon bulk and influence on current-voltage (I-V) and capacitance-voltage (C-V) characteristics. Both I-V and C-V characteristics of silicon planar p-i-n diode sensors of cylindrical geometry have been calculated and measured. Dependencies of the shift of the forward and reverse bias characteristics of the sensors versus neutron doses were obtained. It was shown that for forward I-V characteristic the sensitivity for neutron irradiation of the p-i-n diodes is proportional to the current in the case of the low injection level or to the square root of the current in the case of the high injection level. The C-V characteristics and voltage of full depletion of the diodes were calculated and it was found good agreement with experimental data. The sensors were fabricated by planar technology on high resistivity silicon wafers and irradiated by fast neutrons from Be(d,n) 48.5MeV reaction on superconducting cyclotron of the fast neutron therapy facility in Detroit. The using of the planar cylindrical structures as neutron sensors allows optimizes the sensor's sensitivity by choosing different geometry and measuring currents. Proposed sensors are small and can be used for beam monitoring and medical application.

6

Characterization of the X-Ray Spectroscopic Performance of a Very Large Area Silicon Drift Detector

Gianluigi Zampa, INFN Sezione di Trieste
Alexander Rashevsky, Andrea Vacchi (INFN Sezione di Trieste)

Silicon drift detectors (SDD), due to their collection electrode geometry, have excellent noise performance and are well suited for low-energy X-ray spectroscopy applications. On the other hand these detectors, when dedicated to low energy x-ray spectroscopy, have a small sensitive area (few square centimeters) to reduce the leakage current and its impact on the energy resolution. Because of this limitation they are rarely used in applications where large sensitive surfaces are required. We present the characterization of the spectroscopic performance of a very large area SDD (about 53 square centimeters) that has been realized in the frames of the LHC-ALICE experiment. We studied the energy resolution of the detector analyzing its dependence on both biasing conditions and temperature, and we evaluated the contribution of the different noise sources exploiting their relation with the shaping time. The experimental results obtained with 241Am and 55Fe sources show that the goal of a high energy resolution combined with large sensitive areas can be achieved.

7

Performance of 3-D CdZnTe Detectors using BNL-H3D ASIC Readout System

Cedric Herman, University of Michigan, Nuclear Engineering and Radiological Sciences
Zhong He, Feng Zhang (Nuclear Engineering and Radiological Sciences, University of Michigan); Gianluigi De Geronimo, Emerson Vernon, Jack Fried (Instrumentation Division, Brookhaven National Laboratory)

A new Application Specific Integrated Circuitry (ASIC) readout system was developed by the Instrumentation Division at the Brookhaven National Laboratory for high-resolution 3-dimensional position sensitive CdZnTe gamma-ray spectrometers. This new ASIC is capable of reading out energy and timing signals from all 121 pixel anodes and the planar cathode electrode simultaneously. The combinations of very low electronic noise, high-order pulse shaping, multiple options of peak detection and timing measurement provide high performance and new capabilities. The measured system noise using a 5-mm thick pixellated CdZnTe detector is about 2 - 2.5 keV FWHM, while the dynamic range of the detector system is 2.7 MeV. The first result obtained by researchers at BNL showed an energy resolution of 0.72% FWHM at 662 keV for a single pixel after applying the cathode to anode signal ratio depth correction method on a 20*20*5mm3 Redlen CdZnTe detector. After observing similar performance on a few pixel anodes, the single pixel event energy spectrum from all 11x11 pixels has been obtained for the first time and a resolution of 0.83% FWHM at 662keV is achieved on a similar 5mm thick Redlen CdZnTe detector. The spectroscopic and timing performance of several 5mm, 10mm and 15mm thick CdZnTe detectors will be reported.

8

Energy Resolution of Canberra HPGe Detectors above 3 MeV for Active Interrogation Applications

Ionel Dragos Hau, Canberra Industries, Inc.
William Russ, Gregor Geurkov (Canberra Industries, Inc.)

Techniques for rapid and efficient non-intrusive active interrogation of special nuclear materials (SNM) in cargo containers, such as delayed high-energy gamma rays and nuclear resonance fluorescence rely on the detection of gamma-rays emitted with energies above 3 MeV. This energy region is characterized by very low natural background, thus providing a high signal-to-noise ratio for the detection of gamma-rays obtained by exciting the target nuclei. Typically, due to activation and fluorescent excitation, the emission lines of SNMs are mixed with those coming from benign materials in the cargo container. Good separation of these energy lines is thus required for identifying SNMs. High-energy resolution spectroscopy with HPGe detectors above 3 MeV is crucial in discriminating the benign from threat materials. For active interrogation applications, the FWHM energy resolution of a set of Canberra HPGe detectors has been measured as a function of gamma-ray energy up to 8 MeV using prompt gamma neutron activation lines. High-energy gamma-rays were obtained by thermal neutron activation of NaCl samples with a Cf-252 neutron source. Preliminary results show an energy resolution better than 5 keV FWHM in the energy range from 3 to 8 MeV. In this paper, we will discuss the experimental setup, the dependence of energy resolution as a function of energy on the detector parameters and count rate, and we will focus on the implications for efficient detection of SNMs through gamma-ray spectroscopy above 3 MeV.

9

Neutron Responses of 6H-SiC and 4H-SiC Semiconductor Detectors for Fast Neutrons

Jang Ho Ha, Korea Atomic Energy Research Institute
Sang Mook Kang, Han Su Kim, Se Hwan Park

Surface barrier neutron detectors for a high temperature application were fabricated. Two types of different SiC wafers were used for a neutron detector fabrication and 6LiF was used as a neutron converting material. One is a partially depleted detector based on a semi-insulating substrate with over a 106 ohm-cm resistivity, and a 380 um thickness, and the other is a Schottky diode type with an n-type 4H-SiC substrate with a 0.018 ohm-cm resistivity, and a 350 um thickness. 4H-SiC detector structure was an n-layer(5.12um, 1E15) and an n+ layer(0.5um, 1E18) doped onto an n-type substrate. Au/Ni was evaporated as form electrical contacts under a neutron converter. Each Au and Ni thickness was 30nm to enhanced the charge particle transmission into the SiC active region. 4H-SiC Schottky diode detector was able to operate at a zero bias voltage. Neutron responses were measured by using $2E^{7}$ n/s neutrons from a 241Am/Be source. Absolute neutron detection responses were measured 1.7E-4 for the 4H-SiC detector and 2.5E-5 for the 6H-SiC at an average energy of 5.0 MeV.

10

Fluence Dependent Recombination Characteristics in Heavily Irradiated by Neutrons and Protons Si for Ionizing Radiation Detectors

Juozas Vaitkus, Vilnius University
Eugenijus Gaubas, presenting
A.Kadys, A.Uleckas (Vilnius University)

Carrier capture processes determined by radiation defects are the most important factor which limits radiation hardness of Si particle detectors. Deep understanding of the generation and evolution of these recombination centers ascribed to point and extended radiation defects by primary damage and further reactions of defects can pave advanced technologies of defect engineering and improvement of radiation hardiness of Si based particle detectors. In this work, a comparative analysis of carrier lifetime variations under introduction of radiation defects by high energy proton and neutron irradiation is presented. High purity, Czochralski grown under magnetic field (MCZ), float zone (FZ), diffusion oxygenated FZ (DOFZ) as well as moderately doped FZ and epi- Si wafers and

detector structures have been investigated. These samples were irradiated by reactor neutrons and 2 MeV - 24 GeV protons using different fluences in the range from 10^12 to 3x10^16 cm^-2. Recombination characteristics have been examined in the as-irradiated and annealed samples. Carrier lifetime has been directly measured by exploiting excess carrier decay transients measured combining the microwave probed photoconductivity (MW-PC), dynamic grating (TG) and C-DLTS techniques. The measured carrier decay rate with fluence in the as-irradiated samples has shown a nearly linear decrease of lifetime with fluence, from few microseconds to about of 200 ps within the examined range of neutron and proton irradiation fluences. This dependence persists under relatively low (80 deg. C) temperature heat treatments. Close absolute values of recombination lifetimes for fixed fluence, irrespective of initial material, particle species and energy of the penetrative protons accelerated to more than 10 MeV for Si samples of 300 um thickness, imply dominance of cluster type recombination defects those density increases with fluence. Cross-sectional scans of lifetime depth-profiles within detector base region have been examined. These lifetime depth-profiles show rather high homogeneity of recombination defects within bulk of detectors irradiated by penetrative particles. However, clearly sharp lifetime depth-profiles have been found under irradiations of the relatively low energy (~2 MeV) protons. These lifetime depth-distributions correlate rather well with TRIM simulated profiles of Si damages within stopping range of ~2 MeV protons. Additionally, recombination lifetime values are obtained to be significantly less than those measured in samples irradiated with penetrative hadrons. Fluence dependent decrease of recombination lifetime correlates rather well with changes in the C-DLTS spectra examined in the same diodes, where an enhancement of 170 K DLTS peak with irradiation fluence has been obtained relatively to well-known vacancy attributed traps. Possible scenarios of defect evolution and competition deduced from carrier lifetime variations are discussed.
Acknowledgements: This work was performed in the frame of CERN collaborations RD50 and RD39. Authors acknowledge the CERN PS facility and M. Moll, Helsinki University proto accelerator facility and J.Raisanen, and Ljubljana neutron reactor at Jozef Stefan Institute and M. Mikuz for the samples irradiation, and Lithuanian Science and Studies foundation for the support.

11

High-Resolution Electron-Track Measurements for Advanced Compton Imaging

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B. Plimley, presenting
S.E. Holland, A. Karcher, W.F. Kolbe (LBNL); D. Chivers UCB)

Compton imaging was recently demonstrated to provide new and improved capabilities in the detection and characterization of nuclear materials. One of the drawbacks of the current approaches is the inability to measure the track of the Compton electron resulting in a cone of possible incident directions for each gamma ray. This limits the achievable sensitivity and contrast that can be ultimately achieved in Compton imaging significantly. To circumvent this limitation, we are developing and evaluating Compton imaging instruments able to measure the electron track with high accuracy and efficiency. Our current approach is based on Si-detectors that can provide excellent energy and spatial

resolution. We have performed measurements with a scientific CCD instrument that provides a spatial resolution of 10 um and an energy resolution of 130 eV at 5.9 keV. These measurements allow us to evaluate the electron track properties in these devices - e.g., as function of gamma-ray energy and scattering angle - under controlled conditions. It further enables the benchmarking of our electron track and charge transport models and finally, it allows us to evaluate the impact of the electron tracking capability for Compton imaging. We will report on our initial measurements and their evaluation for Compton imaging.
This work is supported by the joint NSF/DNDO Academic Research Initiative.

12
Characterization of Amorphous Selenium for Medical Imaging and Nuclear Detectors
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Michael Choi, Anton Smirnov, Sung Hoon Kang, Alket Mertiri (EIC Laboratories, Inc.)

We have developed and characterized large volume amorphous (a-) selenium (Se) stabilized alloys for room temperature medical imaging devices and high energy nuclear detectors. The synthesis and preparation of well-defined and high quality a-Se (B, As, Cl) alloy materials have been conducted using a specially designed alloying reactor in an argon controlled glove box. The alloy composition has been precisely controlled and optimized to ensure good device performance. The synthesis of large volume a-Se (B, As, Cl) alloys has been carried out by thoroughly mixing vacuum distilled and ultra-purified zone-refined (ZR) Se with previously synthesized Se-As master alloys, Se-Cl master alloys and ultra pure enriched boron (B-10) powder. The synthesized a-Se (B, As, Cl) alloys have been characterized by x-ray diffraction (XRD), differential scanning calorimetry (DSC), Raman, Fourier transform infra-red spectroscopy (FTIR), x-ray photoelectron spectroscopy (XPS), glow discharge mass spectroscopy (GDMS), transmission electron microscopy (TEM), atomic force microscopy (AFM) and detector testing by modulated energy beam sources. The grown a-Se alloys have shown high promise for x-ray, charged particles, and high-energy physics detectors with their high dark resistivity (>10^13 Ohm.cm), good charge transport properties, and cost-effective large area scalability. Details of various steps involved in detector fabrication and testing of these devices will be presented.
One of the authors (K.C.M.) acknowledges financial support provided by the NIST (SB 1341-03-C-0019), U.S. Department of Energy (DE-FG02-03ER83640 & DE-FG02-07ER84736) and the NIH (1R43RR018651-01A1).

13
MOVPE Growth of CdTe on Si Substrates for Gamma Ray Detector Fabrication
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Single crystal thick epitaxial films of CdTe were grown on (211) Si substrates using the metalorganic vapor phase epitaxy (MOVPE) technique for gamma ray detectors fabrication. Crystal growth was carried out using dimethylcadmium and diethyltellurium precursors at a substrate temperature of 560-600 deg. C. 100 to 260 micrometer thick high quality single crystal CdTe films with the growth orientation parallel to the substrate were obtained. A high growth rate, varying from 30 to 70 micrometer/h, was achieved by adjusting the precursor's flow rate and ratio, and the substrate temperature. The gamma ray detector was fabricated in a heterojunction diode structure comprising p-CdTe/n-CdTe/n+-Si. Finally, gold contacts were deposited on the p-CdTe side and the n+-Si side of the detectors by vacuum evaporation. The heterojunction diode showed good rectification property, where the room-temperature reverse bias leakage current was typically 0.2 microamp/cm2 at 100V. Radiation detection measurements were performed using 241Am gamma source. The diode-type detector clearly resolved 59.5 keV gamma peak and other low-energy peaks at room-temperature, however, the peak shape was affected due to the leak current noise. Dramatic improvement in the detector performance was observed while cooling the detector down to -30 oC. In the latter case, the detector was fully capable of recording the entire energy peaks from the 241Am gamma source with good energy resolution (6 % at 59.5 keV peak). Details on the properties of the grown crystals and gamma detection performance of the heterojunction diode detector will be presented.

14

The Long Term Stability of the TlBr Detector Using Guard Ring and Without Surface Etching Treatment

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The long term stability of the TlBr detector was found over 40 days for the measurement carried out without removing the bias voltage. TlBr crystals were grown by the vertical Brigdman technique, using a quartz crucible in vacuum atmosphere. Better results were obtained for the detectors prepared using crystals with surface submitted only to a mechanical treatment, cutting and polishing without chemical etching. Following the process, the samples were polished with toothpaste, cleaned with alcohol and immediately received the carbon colloidal painting to produce the electrical contacts. The samples did not receive any heat treatment. The final thickness of the crystals was around 0.4mm. Contacts were applied on each side, plus a ring contact surrounding the anode contact. The bias voltage was applied directly between the cathode and ring contacts. The signal was removed from anode contact by AC coupled It was observed that the contacts should be painted immediately after polishing in order to reduce the polarization phenomenon. It was necessary around 20 days to reach the maximum channel height, after that a constant value was found. On the other hand, the same crystal without the guard ring did not present this phenomenon; however, the detector showed a fast signal deterioration. The enhancement of the TlBr detector stability for months allowed observing the resolution degradation with the temperature increase, identifying noise from R and C in the configuration used. For practical application, the detector has been used for about ten hours per day in the last six months, in a surgical gamma probe, without presenting the polarization phenomenon.

15

An Investigation of Nanocrystalline Semiconductor Assemblies as a Material Basis for Ionizing-Radiation Detectors

Mark Hammig, University of Michigan
Kihyun Kim, presenting, James Huang (University of Michigan)

Nanocrystalline (NC) semiconductor materials have previously been studied as a means of increasing the exciton multiplicity upon the impingement of visible light, for applications such as solar cells. If the multi-exciton states have highly uniform multiplicities across macroscopic NC samples, then one can also potentially quench the statistical counting noise associated with charge-carrier creation in the bulk. We thus assess the viability of using NC semiconductor materials for the detection of ionizing radiation. Using CdTe NC films, we report on the colloidal synthesis and deposition procedures for 10 nm NC particles. In particular, using a thioglycolic-acid (TGA)-stabilized CdTe NC solution adsorbed to polycations, CdTe nanocrystal films were deposited on glass, metallic, and semiconductor substrates using the layer-by-layer (LBL) method. The formation of the organic interstitial layer was also varied, and the electronic response of the material was observed. A scanning electron microscope was used to study the morphology and impurity concentrations of the CdTe-films, and by sandwiching the films between evaporated aluminum and tungsten electrodes, the junction properties of the material were studied, and rectifying characteristics were observed. The resulting depletion region and the material's response to alpha particle impingement were studied as the organic capping group was varied. Thus, the variation in the degree of charge trapping is shown to depend on the electronic character at the interface. Although the CdTe system was effective for characterizing the dispersion generation and deposition procedures, the lead chalcogenides are expected to prove more suitable for uniform multi-exciton generation when impinged by ionizing radiation. We thus also discuss our efforts to prepare PbSe colloidal dispersions suitable for detector development.

16

Neutron Detectors Based Upon Artificial Single Crystal Diamond

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The Fusion department of ENEA Frascati and the Department of Mechanical Engineering of Rome "Tor Vergata" University since many years are cooperating to develop radiation detectors based upon artificial single crystal diamond films (SCD). These SCD detectors show excellent reproducible properties: stability, no polarization, 100% collection efficiency and high energy resolution (< 1%). These detectors are based upon a layered structure in which a high doped boron layer acting as conducting region is deposited by CVD technique on top of a commercial High Pressure High Temperature (HPHT) diamond substrate. The high purity SCD film is then grown on top of the borated layer in a subsequent step by CVD. Neutron detectors with layered structure and covered with a thin film (up to 4 microns) of LiF enriched in Li-6 were used at JET tokamak contemporary detecting slow and fast neutrons thanks to the n-alpha reactions in Li-6 and in C-12 respectively. Last, but not least, these detectors can work both in pulsed or current mode and can withstand high temperature as well as high neutron and gamma fluence. This paper reports about state-of-the-art artificial SCD neutron detectors and discusses their properties and their responses under neutrons irradiation. Some applications, such us that presently in progress at JET tokamak, are addressed too. Recently a boron layer up to 750 nm) was deposited on top of the diamond film. The properties of this new detector were investigated and compared with that of LiF covered detector. Last, but not least, some problems related to the processing of the very fast electrical pulse produced by diamond are addresses and the studied developments of the processing electronics are reported as well.

17

Composite Polycrystalline Boron Nitride, Boron Carbide and Lithium Fluoride Based Alpha and Neutron Detectors

Michael Roth, The Hebrew University of Jerusalem
Michael Schieber, presenting, Evgeny Mojaev, Michael Roth, Asaf Zuck, Oleg Khakhan, Alon Fleider (The Hebrew University of Jerusalem); Michael Fiederle (Freiburger Materialforschungszentrum, Albert-Ludwigs-Universitat Freiburg)

Single phase polycrystalline hexagonal Boron Nitride (BN) or mixed with Boron Carbide (BC) and/or polycrystalline cubic Lithium Fluoride (LiF), embedded in an insulating polymeric matrix were tested as alpha particles and neutron detectors. The detectors show rather good spectral responses for alpha particles from an 241Am (5.5 MeV) isotope source (~10^5 cm^-2 s^-1). 1 mm thick detectors also show a minute gamma response which ranges from ~10^-5 for 1173 keV to 10^-5 for 661 keV and to 10^-4 for 60 keV. A thinner, only 0.3 mm thick composite BN detector, exposed to a 133Ba source (with strongest gamma emission at 81 keV) has shown a lower gamma rejection of only 6.84x 10^-9. For detection of thermal neutrons from a low flux source, the neutron counting is possible by subtracting the integrated noise from the integrated total signal counted above some threshold. The signal-to-noise ratios (S/N) of the composite neutron detectors were ~6 for 6LiF enriched isotope, ~7 for mixed BN and BC and ~19 for pure BN. The main advantages of composite semiconductor neutron detectors are: a low production cost (lower temperatures), use of natural boron (not enriched in 10B) and the ability to produce detectors in any shape and size. In comparison with the widely used 3He gas detectors, BN composite detectors provide higher thermal neutron detection efficiencies (assuming the same detector dimensions). Another advantage of BN is its low sensitivity to the gamma background. Thermal neutrons are detected through (neutron, alpha) reactions on 10B (or 6Li), and the signals from such reactions are much higher than from gamma reactions. Moreover, the BN material has low Z-numbers, and thus the probability of a gamma interaction within the detector is low. The present paper summarizes the improved responses of composite BN detectors as well as the results obtained with BN mixed with BC. Results obtained with composite LiF detectors are also reported. The latter samples were fabricated using enriched and non-enriched 6Li. These samples were tested using 5.5 MeV alpha particles emitted from a 241Am source and also with neutrons emitted from an AmBe source of thermal neutrons. In all cases the

detectors exhibited good S/N ratios. Our measurements prove that the boron nitride, boron nitride mixed with boron carbide and lithium fluoride composite materials are quite efficient detectors of thermal neutrons. Currently, work focusing on further improvement of the detector fabrication technology is underway, with the specific aim of reducing the noise that is mostly c aused by discharges.

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X-ray Beam Intensity Monitor Using CVD Single Crystal Diamond Detector

Nicola Tartoni, Diamond Light Source ltd.

Mario Pillon (ENEA Frascati); Gianluca Verona-Rinati, Marco Marinelli (Universita' di Roma "Tor Vergata"); Maurizio Angelone (ENEA Frascati); Mark A. Roberts (SRS Daresbury Laboratory); Claudio Verona Salvatore Almaviva (Universita' di Roma "Tor Vergata")

The very intense X-ray beams produced by the insertion devices in the third generation synchrotron radiation machines needs compact radiation monitors that can whithstand such intense beam. This work describes the construction and test of a monocrystalline diamond detector as X-ray beam monitor. The detector has been built as a multilayered structure obtained by a two-step growing procedure by CVD technique. The different layers of CVD diamond are grown on a commercial high pressure, high temperature (HPHT) Ib single crystal diamond. The first diamond layer is about 15 um thick and heavily doped by boron. A second layer of intrinsic high purity and high quality CVD diamond is thus grown on top of the doped diamond. A metal contact (gold or aluminium of about 1000 u) is deposited on top of the intrinsic diamond. The resulting structure is in practice a p-i junction. This device has been placed in the beam of the station 9.1 of SRS (Daresbury laboratory - UK) and several tests have been performed to assess the linearity of responsivity as a function of the photon flux, the long term stability, and the response to the sudden onset of radiation. The tests have been performed at two photon energies, 10.6 keV and 12.5 keV, and with the detector operated in photovoltaic and reverse biased mode. The device shows an excellent linearity and long term stability, while the response to the onset of radiation have still to be understood. The responsivity is greater when the radiation is switched on than during the steady state phase, this might be due to polarization effects and have to be further investigated. The results obtained can open up the path to the construction of extremely radiation hard devices to be exploited as X-ray beam monitors.

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Irradiation Studies with the CMS Forward Pixel Detector and Upgrade Proposal for SLHC

Ping Tan, Fermilab

<u>*Simon Kwan (Fermilab), presenting*</u>

At the designed LHC luminosity, 10^34 cm^-2 s^-1, the inner-most layer of the CMS pixel detector is expected to sustain a total radiation dose of 3x10^14 1 MeV neutron equivalent cm^-2 per year. After the first few years of running of the CMS experiment, due to radiation damage the performance of the pixel detector will be degraded. For the upgrade of the LHC (SLHC), the designed luminosity will be 10^35 cm^-2 s^-1. Simulation indicates that the current design of the readout chip is not able to handle the high occupancy rate and significant reduction in efficiency is expected for the inner-most layer. The implementation of a pixel-based track trigger in the low-level CMS trigger system is very necessary to keep and extend the physics reach at the SLHC era. Research and design (R&D) efforts towards the SLHC upgrade of the CMS pixel system has started in pursuing more radiation-hardness sensor and readout chip, improved readout-chip design to incorporate trigger requirement, reduced material, etc. The current design of the CMS Forward pixel sensor is n+-in-n sensors with p-stop isolation, and they are bump-bonded to the PSI V46 readout chip to read out. The USCMS collaboration took major responsibilities in designing and constructing the CMS forward pixel detector. Extensive beam test activities have been performed to study the radiation impacts on the detector efficiency, the charge collection efficiency, etc. The impact on the detector operation due to the LHC beam losses are also studied in simulation, laser tests, and beam tests. In working towards the SLHC upgrade of the CMS pixel detector, a 3-dimensional sensor approach is being proposed to achieve higher radiation-hardness. Initial R&D activities has started already. We are working with our industrial partners and expecting the first patch of sensor wafers in the middle of this year. These sensors will be bump-bonded to PSI V46 readout chips. Further characterization of the sensors with laser system and beam tests are under way. In this talk, the irradiation studies with the current CMS forward pixel detector are reviewed, and the R&D plans towards a 3D sensor for the upgrade of the CMS pixel system are outlined.

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Fast Neutron Detection With Silicon Carbide Semiconductor Radiation Detectors

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Ranbir Singh (GeneSiC Semiconductor Inc.); John G. Seidel, Frank H. Ruddy (Westinghouse Science & Technology Department)

Silicon carbide (SiC) radiation detectors have been developed for high-temperature applications in harsh radiation environments. Among these applications are characterization of nuclear reactor fuel and detection of concealed fissionable materials, which both require the optimization of SiC fast neutron detectors for detection and quantification of fission neutrons. These detectors have consisted of a depleted n-epitaxial layer of 50-100 micron thickness on a SiC conducting substrate. In order to enhance fast-neutron sensitivity, new detectors are being developed which consist of a 360 micron thick semi-insulating wafer of SiC without an epitaxial layer. A proton recoil converter layer is placed in front of the wafer. Measurements are being made with 14 MeV and 2.5 MeV neutrons. Measurements of 14 MeV neutrons show improved sensitivity and excellent gamma ray discrimination, yielding a very good signal to background ratio.

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Ion Impact Detection and Micromapping with a SDRAM for IEEM Diagnostic and Applications

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Ion Electron Emission Microscopy (IEEM) can provide an alternative approach to microbeams for micrometric characterization of the sensitivity map to Single Event Effects (SEE) of an electronic device. In IEEM technique, a broad (not focused) ion beam is sent onto the Device Under Test (DUT). Secondary electrons emitted by the target surface during each ion impact are collected and focused by a system of electrostatic lenses and finally imaged by a high-rate and high-resolution position detector. We will report on the IEEM working at the SIRAD irradiation facility located at the 15MV Tandem of INFN Laboratori Nazionali di Legnaro. To ensure a copious and uniform emission of secondary electrons from a DUT a very thin (100 nm) self-standing Silicon Nitride (Si_3N_4) membrane with a Au deposition (40 nm) is mounted directly on the top of the DUT. To study the deformations of the membrane due to the electrostatic field of the IEEM, a 256Mbit SDRAM has been used as a reference DUT. The micrometric feature size of the array of memory cells and the precise knowledge of their physical locations makes this device a good candidate for IEEM calibration. The Au/Si_3N_4 membrane and the underlying SDRAM is irradiated with a heavy ion beam. The physical map of ion impacts detected by the memory array is compared with the one reconstructed by the IEEM and the obtained information is used to introduce the proper corrections. In the contribution we also describe how the very same SDRAM can be used for target alignment purposes.

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Characterization of Pixellated TlBr Radiation Detectors for Gamma-Ray Spectroscopy

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TlBr is an attractive material for radiation detectors due to its high density (7.56g/cm3) and high atomic number (Tl:81, Br:35). In the present work, a 3mm thick TlBr crystal has been investigated. We observed a resolution of 10%, 11.4% and 8% FWHM at 60, 122 and 662 keV at room temperature, respectively. The depth sensing method using the cathode to anode (C/A) signal ratio has demonstrated that the detector is fully active from the cathode to the anode surface. Electron transport properties in TlBr are being investigating using the depth sensing technology and will be reported at the conference.

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Correlation of Proton and Photon Induced Conductivity of a Poly(p-phenylene vinylene) Derivative

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Semiconducting polymers offer potentially attractive and tunable material and electrical properties for solid-state particle counting detectors. The high ratio of hydrogen to carbon provides neutron sensitivity, while the low Z material offers natural gamma discrimination. Compared to existing detectors, these materials could potentially offer large-scale, direct radiation detection with increased sensitivity for fission energy neutrons, and at a substantially reduced cost. The present work focuses on derivatives of poly(p-phenylene vinylene), or PPV. Neutron detection in this material is based on the proton recoil reaction, so we initially tested the materials in a proton beam. Using a 3MeV proton accelerator, we demonstrated a distinct ion-induced conductivity transient response. Additionally, the material showed device turn-on at a bias voltage of only 50 V, and did not show signal degradation until a total dose of 1 Mrad. After proving sensitivity to protons, we compared this to excitation with a laser energy source and show a direct relationship. This allows further testing to be done with a simple laser excitation source to investigate material improvements for eventual neutron detection.
Sandia National Lab. is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL8500.

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New Two-Dimensional Solid State Pixel Detectors with Dedicated Front-End Integrated Circuits for X-ray and Gamma-Ray Imaging

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New two-dimensional position sensitive solid state pixel detectors with dedicated mixed-signal front-end integrated circuits (ICs) have been developed for x-ray and gamma ray imaging. The ICs were designed to be versatile and accommodate many types of position-sensitive solid-state detectors. These versatile ICs aim to serve both conventional and flip chip detector applications. These two-dimensional solid state pixel detectors are designed to address the needs of a wide range of photon counting applications with high energy resolution imaging, high spatial resolution and for fast photon counting with simultaneous multiple energy binning capability. Two of these ICs, called the RENA-3 (Readout Electronics for Nuclear Applications) and DANA-2 IC (Detector Array for Nuclear Applications) are intended to have practical flexibility for use with detectors such as Si, Ge, GaAs, HgI2, PbI2, Se, CdTe and CdZnTe in a variety of configurations, such as multichannel strip or pixel geometries, to detect and image x-rays and gamma-rays of energy up to 1.3MeV. The fast photon counting ICs with simultaneous energy binning are called XENA-2 and HILDA-2. They can be used with the similar solid state detectors. The high spatial resolution imaging pixel detector ICs are called MARY-N50/100. These pixel detectors can produce x-ray images with >= 50x50 micron resolution. These are primarily developed for digital mammography but can be used for numerous other applications.

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Effects of Point Defects on the Electrical Properties of Aluminum Antimonide -- a First Principles Investigation

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A first principles computational study is conducted of the effects of point defects on the electrical properties of bulk AlSb, a material of interest for room temperature gamma radiation detection. Detailed calculations were performed for all native defects, including vacancies, antisites, interstitials, and split interstitials, and also for a variety of impurities (H, C, Si, Ge, Sn, P, O, S, Se, Te). Formation energies of each defect in different charge states were calculated to determine the equilibrium defect density and net carrier density for a range of temperatures. The pure material is found to be naturally n-type. Carrier scattering rates for each defect were calculated using perturbation theory to determine the effects on electron and hole transport. The most detrimental, as well as innocuous, defects were identified. The dominant native defects tend to be weak carrier scatterers, while carbon and oxygen impurities are the strongest scatterers. Relative solubilities of the impurities were examined along with their scattering rates to find efficient dopants that minimize mobility degradation. Te, Se, and Sn are identified as the most interesting compensating dopants with the least effect on carrier mobility. Finally, deep trap energy levels were studied and compared to DLTS data to understand the role of point defects and impurities on carrier trapping and carrier lifetimes.
Prepared by LLNL under Contract DE-AC52-07NA27344.

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Effects of Depth Resolution on Spectroscopic Performance of Pixellated CdZnTe Detectors

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CdZnTe detectors using pixellated anodes and the VAS_UM/TAT ASIC readout system can achieve excellent energy resolution better than 1% FWHM at 662 keV, on good quality crystals. However, the energy resolution of multiple-pixel events is significantly worse than expected when considering the noise contributions from the triggered pixels. Multiple-pixel events are important for Compton imaging and spectroscopy. It is expected and experimentally demonstrated that the depth resolution is worse at lower energies. For cathode side events in a 15mm thick CdZnTe detector manufactured by eV Products, the depth resolution from drift-time measurement degraded from 0.7 mm at 662 keV to 1.7 mm at 60 keV. Our depth correction technique relies on drift time measurement for multiple-pixel events, and each energy deposition is smaller than the initial incident energy of the gamma ray. Therefore the depth resolution is poorer for multiple-pixel events than for single-pixel events. This suggests that the depth correction for multiple-pixel events cannot be performed as accurately as that of single-pixel evenets, resulting in poorer energy resolution. This effect has been studied by measuring the overall energy resolution for single pixel events as a function of the depth bin width used for detector calibration, and applying this analysis technique to multiple-interaction events. The degradation in energy resolution due to poorer depth resolution was found to be less than 0.1% FWHM at 662 keV for depth bins less than 1 mm in size, for single-pixel events.

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Characterization of Massive Silicon Detectors for Low Energy Events at Liquid Helium Temperature

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We demonstrate that it is possible to develop detectors for the measurement of very small energy depositions in X and gamma ray, provided that the detecting material is high purity silicon kept at liquid helium temperature. The detectors we have characterized are 1 cm thick and have diameters ranging from 3 to 10 cm, thus these devices can be considered suitable also for the detection of low rate particle energy release events. Depletion in the active volume is obtained via carriers freeze-out, and the probability to find impurity levels in an excited state due to thermal energy is nearly zero; in fact the typical energy of shallow levels is of a few tens of eV, an energy that is available by a liquid nitrogen bath yet. These shallow levels are associated to residual impurities, which in the materials we have studied have a concentration of 10^{11}-10^{12} cm^{-3}. Besides, the suppression of all the free carriers allows relatively low polarization voltages, and we have observed that fields of the order 100 V/cm are sufficient to prevent charge trapping effects. Total depletion due to freeze out has been verified in 1 cm thick pin diode detectors, starting from three types of material (silicon with three different residual concentration of impurities, i. e. room temperature resistivity of 10-40 kOhm cm) and due to the low applied voltages, the electrical contacts have been fabricated without passivation of the surface. This last property is also important for the development of a massive detector at affordable prices, less expensive than the standard detectors operating at liquid nitrogen. To demonstrate that the requirements to detect low rate and low energy events are met, we will show the measured current-voltage and capacitance-voltage curves at 5 K and the acquired gamma spectra from radioactive sources in the energy range 60 - 600 keV. The complete charge collection at liquid helium temperature even at low applied fields was verified collecting a few hundreds of cosmic rays events. Moreover, to further enhance the sensitivity of this kind of detector, we would like to utilize the phenomenon of avalanche multiplication. At liquid helium temperature in fact the mean free walk of electrons is longer than at room temperature due to the high value of mobility, and so the multiplication of carriers should take place for low applied electric fields. We will show preliminary tests to obtain the avalanche effect in silicon at liquid helium temperature, using microstrip contacts of the order of 50 micrometers.

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Neutron Damage Effects in SSB and CZT Radiation Detectors for Spent Fuel Facility Monitoring

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SSB (Silicon Surface Barrier) and CZT radiation detectors were fabricated in KAERI by using a planar process to detect charged particles and gamma-rays in high dose fields such as a spent fuel facility. In this study, neutron induced radiation damage effects were investigated by comparison of resulting I-V curves and energy spectra. SSB radiation detectors, which have various electrode configurations such as a guard electrode structure and plain planar structures with various active area sizes, were exposed in neutron flux of 8X10E7 n/sec for 6 hours. After irradiation, I-V curves and alpha energy spectra were compared. An Ohmic-Ohmic contacted CZT radiation detector (10 X 10 X 4 mm) was also exposed in the same neutron flux and I-V curves and 59.6 keV gamma energy spectra were also compared. Energy resolution recoveries after annealing at room temperature were also investigated at 1 week intervals.
This work has been carried out under the nuclear R&D program of the Ministry of Science and Technology (MOST) of Korea. And we are also supported by the iTRS Science Research Center / Engineering Research Center program of MOST / Korea Science and Engineering Foundation (grant # R11-2000-067-02001-0) and partially supported by the BK21 program of Korea Research Foundation(KRF).

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TlBr Stack Detectors for Gamma-ray Spectroscopy

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Thallium bromide (TlBr) is a compound semiconductor promising for room temperature gamma-ray spectrometers. The most attractive physical property of TlBr is its high photon stopping power greater than other semiconductor materials due to its high atomic numbers (Tl: 81, Br: 35) and high density (7.56 g/cm3). TlBr has wide band-gap energy of 2.68 eV, which enables room temperature operation. Since TlBr exhibits a low melting point (460 deg. C) and no phase transition below the melting point, simple melt-based processes can be employed to purify and grow TlBr crystals in quartz ampoules. Although thin TlBr detectors have exhibited good energy resolutions, the detection efficiencies were insufficient due to the thin thickness. In order to improve the detection efficiencies, TlBr stack detectors were fabricated from two planer detectors in this work. Commercially available TlBr powder with nominal purity of 99.999% was used as the starting material for the crystal growth process. Since high purity material is required for radiation detector fabrication, the starting material was purified by the zone refining method. After the zone purification, the furnace movement speed was reduced and single

zone pass was performed in order to grow a single TlBr crystal. Planar TlBr detectors were fabricated from the grown crystal. The TlBr crystal was cut into several wafers with a diamond wire saw. The two surfaces of the wafers polished mechanically. The electrodes of the devices were constructed on the polished surfaces by vacuum evaporation of Tl (coated with Al). The resultant planar detectors have electrodes of 3 mm in diameter. Two planer detectors (0.36 mm and 0.46 mm thick) were stacked and the facing electrodes were connected electrically. A positive bias of 100 V was applied to the inter-detector electrodes. The electrodes of both ends of the detector were connected electrically and maintained at ground potential. For comparison a single planar TlBr detector with 0.81 mm thick and electrodes of 3 mm in diameter was also fabricated. The TlBr detectors were connected to a charge sensitive preamplifier (Clear Pulse 580K) and a gated integrator (Ortec 673). Since TlBr crystals exhibit low electron and hole motilities, gated integration is effective to realize full charge correction and high energy resolutions. The TlBr stack detector exhibited an energy resolution of 5.2% FWHM for 662 keV gamma-rays from 137Cs. Although both detectors have almost the same detector volume (the stack detector had the total thickness of 0.82 mm and the simple planar detector had the thickness of 0.81 mm), the planar detector 0.81 mm thick operated with a bias voltage of 100 V exhibited poor energy resolutions with no full-energy peaks in the 137Cs spectrum.

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Gamma-ray Response of Cl-doped Semi-Insulating CdMnTe Crystal

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The properties of CdMnTe such as segregation coefficient of Mn in CdTe and iconicity of bonds make good candidate material to compete with CdZnTe in the solid state detector. Indium and aluminum forms localized states in the deep level of CdMnTe crystals which deteriorate energy resolution by multiple trapping. The Cl-doped CdMnTe (Mn=10%, Cl=10^18 cm-3) crystal was grown by vertical Bridgman method. As-grown ingots are sliced parallel to the twin in 2mm and then mechanically and chemically polished to 1mm. Material uniformity throughout ingot was estimated near-IR transmittance measurement. After surface etching with BLE (Br + lactic acid + ethylene glycol) etchants, Au and In electrode was deposited using thermal evaporation method and surface passivation processes were applied using sulfur. To evaluate material properties as a gamma-ray detector, electrical resistivity and mobility-lifetime products was measured. Finally, the energy resolution of CdMnTe:Cl detectors were measured with a multi-channel analyzer using 241 Am gamma-ray source at room temperature.

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Characterization of a Large Volume CdZnTe Coplanar Detector

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Currently portable nuclear instruments are being developed that utilize compact high sensitivity detectors operated at room temperature. It is desirable that these detectors have large absolute efficiency and reasonably good energy resolution in the 50 to 3,000 keV energy range. In order to provide high efficiency, large volumes are needed. For semiconductor detectors able to operate at room temperature, the largest effective volumes with acceptable resolution are achieved with CdZnTe coplanar-grid detectors. In this work we report the performance of a large volume coplanar-grid CdZnTe detector with dimensions 2 cm X 2 cm X 1.5 cm. The CdZnTe crystal was made by Yinnel Tech (USA) and Arnold Burger (Fisk University) fabricated the detector. We will present the measured radiation, timing and material performance characteristics. We will also compare the performance of this coplanar-grid CdZnTe to a 2.54 cm X 2.54 cm LaBr3(Ce) cylindrical crystal purchased from Saint Gobain. In addition, the experimental spectrum measured from CdZnTe will be compared with Monte-Carlo simulations performed with Geant4. The implications of the results of comparison between LaBr3 and CdZnTe will be discussed with regards to the practical use of these units in portable spectrometers.

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Investigation of the Importance of the Contact in Performance of CZT Radiation Detectors at Various Temperatures

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CZT is a proven material for good gamma-ray stopping efficiency and high energy resolution in room-temperature applications. Metal contact could determine to a large degree the performance of such a detector. We investigate the dependency of detector performance upon the contact at various temperatures. A CZT resistive detector (Au/CZT/Au structure) and a CZT Schottky detector (In/CZT/Au structure) were made. To fabricate the Schottky diode, the crystals were mechanically polished and chemically etched. The indium was vacuum evaporated on a face of the crystal, and gold was deposited with electroless deposition method on the opposite face of the crystal. The CZT detector with Au/CZT/Au structure was made with similar procedures. I-V curves and energy spectra for the two detectors were measured and compared, showing similar performance. Detector temperature was varied from -10 C to 50 deg. C and the leakage current and the energy resolution were measured at each temperature. The CZT resistive detector showed more stable performance over various temperatures. Acknowledgment : This work was performed under the long-term nuclear research and development program sponsored by Ministry of Science and Technology of Korea, and supported by the Innovative Technology Center for Radiation Safety (iTRS).

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New Silicon Quantum Photon Detector Structures and Performance

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Low light detection applications in life sciences, nuclear medicine, high energy physics, radiation detection and general instrumentation have for many decades been based on photomultiplier tubes (PMT), reminiscent of older vacuum tube technologies. In recent years efforts have been expanded to develop APD structures operating in Geiger Mode, to replace PMT technology with solid state devices of equal or better performances. Based on micro-pixel structures a new type of Silicon Photon Quantum Detector (Si-QPD) has been developed and promises to provide an alternative to vacuum PMTs. This new single photon counting technology brings significant advantages in terms of lower bias operation, lower power consumption, insensitivity to magnetic fields and ambient light, miniaturization and integration of micro-pixels on a single chip, potential future integration of read-out electronics on the same material platform and finally leverages low cost CMOS compatible volume manufacturing processes. In this paper, the operation and performance of Silicon Photon Quantum Detector (Si-QPD) are reported. Different form factors and micro-pixel geometries have been manufactured and are being compared. Measurements of the basic Si-QPD characteristics are presented: photon detection efficiency, gain, inter-pixel crosstalk, dynamic range, recovery time and dark count rate. Keywords: Geiger-mode avalanche photodiodes, photon counting, Silicon photomultiplier, PMT

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Development of Amorphous Semiconductors for Radiation Detection Applications

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The effects of ionizing radiation on amorphous semiconductors were examined by characterizing changes in DC ionization current as a function of exposure to alpha radiation. Two different glass systems were studied: a chalcopyrite glass (CdGexAs2; where $0.45 < x < 1.0$), with a tetrahedrally coordinated structure, and a chalcogenide glass (As40Se(60-x)Tex; where $0 < x < 12$), with a layered or three-dimensionally networked structure, depending upon tellurium content. These compounds were chosen for their similarity in density, electrical resistivity, and bandgap to CdZnTe (CZT), a commonly used crystal for gamma detection. Changes in DC ionization current were measured as a function of radiation exposure, temperature, and applied bias. A sharp increase in current ranging from 30% to 475% was consistently observed in the presence of a sealed alpha source. Additionally, the development of Schottky barrier contacts on these materials to reduce leakage currents and increase photo-sensitivity will also be discussed. These results demonstrate the promising potential of these materials for applications in a variety of radiation detection applications.

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Effects of the Extended Defects in CZT using a Synchrotron X-ray Beam

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There are several types of the extended defects in CZT (such as dislocations, microtwins and subgrain boundaries) that are present in the crystals and are not readily visible with IR imaging techniques. Some of them can be revealed by etch pit distributions obtained with Nakagawa etching. With nondestructive techniques employing synchrotron radiation, we can observe defects that are often overseen in commercial CZT material. Studies to understand their role on charge trapping and possible distortion of the internal electric field were completed. These techniques and the latest experimental results will be presented.

Gas, Liquid, and Cryogenic Detectors
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Cryogenics for the LUX Detector

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The LUX is a new dark matter search experiment to be carried out in the renewed underground laboratory SUSEL at the Homestake (SD) old gold mine. The LUX detector is designed as the biggest two-phase emission liquid xenon (LXe) detector in the family of LXe detectors searching for WIMPs. The detector consists of a cylindrical vessel with a 24 inch diameter and 47 inch depth containing 300 kg of LXe and enclosed in a copper thermal screen and vacuum jacket. The large size of the detector supports effective internal shielding from natural radioactivity of surrounding materials. The detector will be immersed in 125-ton water shielding bath suppressing neutron and gamma ray background coming from rocks of the cavern. The detector will be built from low background materials, oxygen-free copper and possibly titanium. In this paper we describe results on R&D of economical and efficient cryogenic system for the LUX. In the detector, LXe will be supported at ~175-177K. The cooling agent is free-boiling liquid nitrogen at a temperature of about 78K in conditions of the underground site. The cryogenic system should provide effective and economical heat exchange between the detector and liquid nitrogen and allow storing LXe at stable conditions for weeks with minimal mechanical vibrations and temperature gradients over the LXe volume. The last requirements are important to provide effective light collection from bulk LXe samples and through the free liquid surface. The experimental cooling system consists of a cold head attached to the thermal screen, two thermosyphons attached to the cold head and one thermosyphon attached to the bottom of the thermal screen. One of the thermosyphons uses a 1.5 inch diameter tube mounted directly to the cold head, and has demonstrated about 1 kW cooling power for initial cooling of the detector and xenon condensation; another one, with ~0.2kW cooling power, is attached with a Teflon thermal impedance of thickness selected to support the detector operation when the temperature of the detector has been stabilized. The third thermosyphon of cold-plate type is connected to the bottom of the thermal screen with the impedance in order to reduce the temperature gradient along the thermal screen. The cooling system has been used for operation of a prototype of the LUX detector. We will discuss the results for this work.

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Next Generation TRD for the CREAM: Construction and the TRD Prototype Beam Test Results

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The Cosmic Ray Energetics And Mass (CREAM) experiment is designed to investigate the source, propagation and acceleration mechanism of high energy cosmic-ray nuclei, by directly measuring their energy and charge. Incorporating a transition radiation detector (TRD) provides an energy measurement complementary to the calorimeter, as well as additional track reconstruction capability. Plastic foam provides a weight-efficient radiator that doubles as a mechanical support for the straw layers. This design provides a compact, robust, reliable, low density detector to measure incident nucleus energy for $3 < Z < 26$ nuclei in the Lorentz gamma factor range of 10**2 - 10**5. This paper discusses the new TRD design and the low power front end electronics used to achieve the large dynamic range required. Beam test results of a prototype TRD are reported.

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Comparison of the Characteristics of He-3 and He-4 Proportional Chambers

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The helium-filled proportional chambers are widely used in the field of neutron detection. The He-3 chamber is used mainly for the detection of thermal neutron by using (n, p) nuclear reaction and He-4 detector is used for fast neutron by using recoil interaction. The major aim of this paper is to establish the optimum operating conditions and to compare detector response characteristics of He-3 and He-4 chambers when they are used for fast neutron detection. We used two commercially available cylindrical proportional chambers with a size of 5 cm diameter and 30 cm effective length for the present study. And we designed and manufactured polyethylene moderator for He-3 tube. The neutron sources used for this study are Cf-252, Am(241)-Be, and mono-energy fast neutrons by using the 1.7-MV Tandem accelerator in Korea Institute of Geoscience and Mineral Resources (KIGAM). The leakage and signal currents of these detectors according to the bias voltage change were measured using high precision electrometer. To determine the appropriate shaping time for neutron-gamma discrimination, gamma-ray response was measured by using Co-60, Cs-137, and Co-57 (about 10 micro Curie) sources. Pulse height distributions were obtained for different energy neutrons, and standard electronics which consists of a preamplifier, a shaping amplifier, and a multi-channel analyzer were used. We obtained and compared the pulse height spectra and energy resolution according to the shaping time as a function of neutron energy.

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The Transparent MSGC
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Gaseous radiation detectors are used in various applications, however, recent progress in the micro-pattern gaseous detectors can expand the application area of these relatively old radiation detectors. Optical observation is often very important since it provides tremendous information on the object (like a biological sample) to be detected. In particular, radiation imaging itself provides just a part of information on the application target. Therefore, we have decided to start up a new autoradiography method which combines the optical image and the radiation image by using see-through gaseous radiation detectors. MicroStrip Gas Counters (MSGCs) are still useful micropattern gas detectors because of its uniform response, high counting rate capability, fine resolution, etc. Normal metals such as Cr, Au are used in Conventional MSGCs, which inhibits the use of optical image since the metal pattern absorbs the light. Indium Tin Oxide (ITO) is widely used transparent electrode material. If the MSGC is transparent, it is also possible to observe light from gas proportional scintillation counters . Thus, we have decided to develop a transparent MSGC by using ITO electrodes. Here, we introduce this new category of micropattern gas detectors. We have selected our multi-grid-type MSGC configuration in our ITO-MSGC since it enables the use of a variety of substrate glasses. In the multi-grid-type MSGC, grid electrodes are inserted between narrow anode strips and wide cathode strips. The role of grid electrodes is to virtually reduce the surface resistance and to stabilize the electric field. We have used Corning #1737 glass and OA10 glass (used for Liquid Crystal Display) for the substrate and the Indium Tin Oxide layer of 170 nm thick is used for electrical patterning. ITO pattern is only slightly visible but difficult to be resolved by naked eyes. In order to test charge amplification properties of this plate, we have operated the plate in a PR gas (1 atm, Ar (70%)+CH4(30%)). The detector has been irradiated by X-rays from an Fe-55 source. The anode and cathode signals are successfully obtained. A gas gain of ~2000 is successfully achieved at the anode voltage of 700 V. A measured pulse height spectrum is shown. Then we have examined gas scintillation properties of the plate. We have operated the ITO-MSGC in 1 atm CF4 gas, which is known as a good scintillation gas medium. The plate is operated in a clear chamber and a photomultiplier tube (Hamamatsu R928) is placed outside the chamber behind the plate. Optical photons are transmitted through the glass substrate plus the chamber wall. Observed optical signal taken with a PMT is very promising. We have successfully demonstrated the optical signal readout with ITO-MSGC.

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Electrostatic Detection of Radioactive Materials
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For the past six years, staff at PNNL have been investigating the feasibility of detecting and quantifying radioactive sources using the methods of research in atmospheric electricity. Of particular interest are: 1) detection and quantification of distributed radioactive materials outdoors (e.g., due to a spill) and; 2) the detection of undeclared radioactive materials in shipping containers. For the outdoor studies, we utilized a Gerdien condenser for measurements of air conductivity and ion concentration. Changes in air conductivity due to the presence of radiation-induced ions also impact the earth's fair weather electric field (100 V/m at the surface). Electric field perturbation measurements were made using an electric field mill and an electric field-change antenna. Long-term experimental field data show that time-dependent variability in the terrestrial electrical signature limits sensitivity for real-time radioactive materials detection and monitoring. However, for sufficient source activity, we have demonstrated the viability of this means of radioactive materials detection. Time-dependent air conductivity measurements were also performed in sealed laboratories and shipping containers containing radioactive sources of known activities. Of particular interest were the air conductivity equilibration times and ion lifetime. The experimental data suggest the possibility of radioactive materials detection using a simple air conductivity sensor which draws air from the container volume.

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High Pressure Operation of the Photon-Assisted Cascaded Electron Multiplier

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We present the Photon-Assisted Cascaded Electron Multiplier (PACEM) operating in high pressure xenon atmosphere. The PACEM concept uses the scintillation light produced during the avalanche processes for signal propagation: the avalanche from a first multiplication stage propagates to the successive one via its photons, which in turn induce photoelectron emission from a photocathode deposited on the second multiplier stage; the multiplication process may further continue via electron-avalanche propagation. A high optical transmission grid is placed between the first and the second element allowing for light transmission and, by a proper choice of geometry and fields, complete blocking of the ion back-flow into the first element; thus, only ions from the latter will flow back to the drift region. In this work, the PACEM concept was validated by operating a cascade of electron multipliers with a Micro-Hole & Strip Plate (MHSP) as the first element, followed by a Gas Electron Multiplier (GEM) with a CsI photocathode deposited on its top. Varying the xenon pressure from 0.6 to 3.3 bar, the intermediate scintillation stage provides optical gains varying from 1000 to 25. With this concept ion backflow lower than 10 ions/primary electron was achieved. Systematic studies of this detector concept for both optical gain and ion back-flow as a function of gas pressure and voltages applied to the different electrodes will be presented.

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Frequency-Domain Multiplexed Superconducting Gamma-Ray Spectrometer

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Kam Arnold, Adrian T. Lee, Helmuth G. Spieler (University of California, Berkeley); Owen Drury, Miguel Velazquez, Stephan Friedrich (LLNL)

We have built ultra-high energy resolution gamma detectors based on superconducting transition edge sensors (TESs) for fundamental science and nuclear non-proliferation applications. They are operated at 0.1K at the end of a cold finger of an adiabatic demagnetization refrigerator, and have achieved an energy resolution between 50 and 90 eV FWHM for gamma-ray energies below 100 keV. For increased sensitivity, we are currently developing large arrays of TES detectors and the associated frequency-multiplexed electronics to read out large arrays with few wires. We use a frequency-domain multiplexed scheme in which each TES forms the resistive element in an LCR resonant circuit and is biased at a unique frequency. Gamma ray absorption modulates the amplitude of the carrier signal, which can be demodulated at room temperature to retrieve the original signal. We have built 16-pixel multiplexing modules whose noise performance is well within the design specifications. Here we discuss the performance of TESs multiplexer, progress towards reading out a full 112-pixel array of superconducting TES Gamma-ray detectors, and scaling to larger array sizes.

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Examination of Matsushita High Density Aerogel

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Don Summers, Peter Sonnek (Univ. of Mississippi); Jim Reidy Jr. (Oxford High School); David Sanders (Univ. of Mississippi), Ghislain Gregoire (Universite Catholique de Louvain)

We have designed a threshold Cherenkov particle i.d. detector for the MICE experiment at the Rutherford Appleton Laboratory. The detector identifies muons in the (230-350) MeV/c momentum range. The cherenkov media are high density aerogels from Matsushita Electric Works. We investigated properties of three densities of Matsushita aerogel for the design. The nominal indexes of refraction were n = 1.03 , 1.08, 1.12 respectively. Two of the samples are of high density and not commonly used for cherenkov light detection. We present results of an examination of some optical properties of the aerogel samples.

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Evaluation Of Lithium Gadolinium Borate Capture-Gated Spectrometer Neutron Efficiencies

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Accurate determination of neutron dose equivalent requires knowledge of the neutron energy distribution. Existing neutron spectrometers, such as Bonner sphere sets, are typically bulky and require long acquisition times. Hence, a handheld or portable system that could perform area monitoring with acceptable accuracy would be of interest. Such a device will require a detector that is efficient, and possesses gamma- neutron discrimination capabilities. An organic scintillator that contains lithium, gadolinium, and boron, all three of which possess isotopes with large neutron capture cross-sections for highly exothermic reactions, has been recently developed by MSI/Photogenics. This combination of materials provides for the detection of fast neutrons by proton recoil which when used in conjunction with a slow neutron capture gate allows total energy information to be obtained. The system also responds to gamma-rays but n-gamma discrimination techniques allows it to be applied in mixed fields. Photogenics recently completed the full demonstration of a Lithium Gadolinium Borate (LGB) neutron spectrometer's performance under a Department of Homeland Security Domestic Nuclear Detection Office (DNDO) grant. A potential application suggested for this technology is in the identification of shielded fissile materials. A 2x2 inch sample of composite scintillator, consisting of lithium gadolinium borate crystals in a plastic scintillator matrix, produced by Photogenics has been tested for this purpose. The Tests consists of verifying the n-gamma discrimination and measurements of both captures and capture gated efficiencies using Cf-252 and Am-Li neutron sources of various activities under a variety of gamma shielding and neutron attenuation geometries. The results, for this small test sample, showed that in addition to its rudimentary spectroscopic capability, the Photogenics LGB detector has a overall neutron detection efficiency that is attractive for hand held applications.

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Gas Mixture Studies for Streamer Operation of RPCs

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RPCs, Resistive Plate Chambers, are gaseous ionization detectors with resistive and parallel plate electrodes, typically made of bakelite or glass. Because of their excellent time resolution, ~1 ns for 2 mm gas gaps, and good space resolution, ~1 cm, RPCs are widely employed in High Energy Physics as trigger detectors (ATLAS, CMS and ALICE at LHC), as muon trackers inside (magnetized) iron bulk systems (BABAR, BELLE, OPERA and INO), and also in cosmic ray physics (ARGO). With thinner gas gaps (~100 micron), they can be used also for timing applications (ALICE and HARP Tof). Though the avalanche working regime is mandatory for high rate environments (LHC experiments), the streamer is otherwise preferred because of the large signal amplitudes (~ 100 mV), reducing the read-out electronics cost (no amplifiers needed). Typical gas mixtures for streamer operation of RPCs are composed by Argon, Tetrafluoroethane (R134a) and isobutane. Small quantities of SF6 (~1%) can also be added. We have studied the properties of several gas mixtures using cosmic rays with a telescope made of small RPC prototypes with bakelite electrodes and 2 mm gas gap. The efficiency, the counting rate, the charge/count released in the gas, the charge induced on the read-out electrodes (prompt charge) and the time resolution have been measured. By analysing the prompt charge spectrum and the single signal waveforms, the multi-streamer probabilities have also been estimated. Comparing the results obtained by changing one mixture component at a time, a complete knowledge of the properties of each gas is obtained. The final aim is to find a suitable gas mixture with the lowest possible R134a concentration, in order to reduce the gas cost. From the point of view of the charge/count released in the gas, it seems that the R134a concentration cannot be lowered below 20%, with 4% isobutane and 1% SF6. An analysis based instead on the multi-streamer probability is the main topic of this presentation.

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Development of the DT-GEM: a Gas Electron Multiplier Detector for Neutron Diagnostics in Controlled Thermonuclear Fusion

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In controlled thermonuclear fusion reactors the fusion power is assessed by the measurement of the neutrons emitted from the plasma through D-T reactions. The development of detection systems for 14 MeV neutrons suitable to be applied in the future fusion reactors, i.e. ITER, is still an open challenge. In fusion reactors applications the neutron detectors should meet the following requirements: compact dimensions, high counting rate capability, high detection efficiency, stability against electromagnetic field, radiation resistance, insensitivity to gamma rays and suppression of unwanted signals. In such context, the features of the gas electron multipliers (GEM) are attractive: systems based on GEM technology have been extensively applied as fast monitors in other radiation fields and, in particular due to their high counting rate capabilities, can play an important role as neutron diagnostics in fusion machines. A new neutron flux monitor by means of a triple-GEM and a proton recoil converter has been developed. The design and the optimization for the detection of 14 MeV neutrons have been performed using MCNPX and FLUKA Monte Carlo Codes and the detector has been tested at the Frascati Neutron Generator (FNG). Polyethylene is used as converter and a thin aluminum sheet covers a triple 10x10 cm2 GEM filled with an Ar/CO2/CF4 gas mixture. The detector's readout system consists of 64 pads 3x3 mm2 in an 8x8 matrix. The DT-GEM design and the results of the test performed at FNG are presented and discussed in this paper.

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Design of a New Microdosimetry Detector Based On Thick Gas Electron Multiplier

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We present design of a new microdosimetry detector based on thick gas electron multiplier. A prototype detector was designed for a cylindrical sensitive volume with 5 mm diameter and 5 mm height. To optimize the thick GEM design, the gas multiplication gain was calculated using the Garfield program by varying hole diameter and GEM thickness. The detector response for photon is modeled using the EGS5 Monte Carlo code. The influence of the GEM material on the detector response is carefully investigated. The prototype detector was manufactured and filled with the tissue-equivalent propane gas. A benchmark test was carried out using a mixed neutron-gamma ray field at the McMaster Accelerator Laboratory. The initial test results proved that the multiplication gain of the prototype detector is high enough when compared with a standard tissue-equivalent proportional counter (TEPC). The pattern of the

microdosimetric spectrum also looks consistent with the spectral pattern from the standard TEPC. To further investigate the thick GEM performance in detail, thick GEMs with various thicknesses were additionally manufactured. References [1] A.J. Waker, Radiat. Prot. Dosim. 61 (1995) 297. [2] J. Burmeister et al., Med. Phys. 28 (2001) 1911. [3] F. Sauli, Nucl. Instr. Meth. A 386 (1997) 531. [4] M. Farahmand et al., Nucl. Instr. Meth. A 509 (2003) 262. [5] C.K. Shalem et al., Nucl. Instr. Meth. A 558 (2006) 468.

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Cryogenic Rare Earth Manganite Bolometers for Total Energy Measurements of the Linac Coherent Light Source Free Electron Laser

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Owen B. Drury, presenting
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Over the next decade, several free-electron X-ray lasers will come on line whose brightness will exceed that of third generation synchrotrons by ten orders of magnitude. Among them, the Linac Coherent Light Source (LCLS) will be the first to extend the range of operation into the X-ray range. LCLS will produce monochromatic 200 fs pulses of 10^12 X-rays in the energy range from 0.8 to 8 keV at a rate up to 120 Hz. To measure the total energy of each pulse, we have developed a detector scheme based on epitaxial Nd2/3Sr1/3MnO3 sensor thin films grown by pulsed laser deposition on buffered silicon substrates. The bolometers are designed to meet the conflicting requirements of radiation hardness, sensitivity and linearity over a dynamic range of three orders of magnitude, and readout speed compatible with the LCLS pulse rate. They are operated in a pulse-tube refrigerator at ~150 K and read out with a low-noise bridge circuit. We will present the bolometer design, their noise characteristics, and the photoresponse of prototype devices to pulsed optical lasers over the energy range of interest for LCLS.

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On-Chip Fast Data Sparsification for a Monolithic 4096-Pixel Device

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The paper describes a prototype of a mixed-mode ASIC built up of a fast readout architecture that interfaces with a matrix of 4096 Monolithic Active Pixel Sensor (MAPS). The matrix is arranged in 128 columns by 32 rows, is divided into 256 regions of 4 x 4 single pixels (of 16 elements, 50 by 50 um each), named macro-pixels (MPs). Even though 16 pixels compose one MP, one single hit is sufficient to force the MP to a frozen condition and to a time-stamp association. This information is stored outside the matrix of sensors within the digital readout logic. This is fast, optimized, parallel readout architecture to overcome the speed limit of sparsification logic of large matrixes of pixel devices. The architecture can read up to 32 hits at a time if they belong to the same column and it can send the formatted space-time data to the output. As the output port can only accept one-hit information at a time, an internal queuing system has been provided. The ASIC can work in two different operating modes: custom-mode and digital-mode. In fact, it can be connected to an actual full-custom matrix of MAPS or to a digital matrix emulator composed of standard cells. In the first case the pixels may only be switched on via striking particles while in the second case the digital matrix must be loaded during an initial slow-control phase. This latter mode was designed to provide testing facilities. The two different modes can be selected and activated only one at a time. For both modes a slow-control phase is required to load the chip configuration via 256 mask bits to select which MPs are to be read and which are not, for example in case they are too noisy or burned up. The readout circuit operates in the same manner for the two modes. The chip is an extension of a smaller version composed of 256 pixels that was designed and is currently under test. Both chips were designed via STM 130nm CMOS technology. The fabrication process for the 4096 pixels version is ongoing. The work is aimed at improving the design of MAPS detector with an on-chip fast sparsification system, for particle tracking, to match the requirements of future high-energy physics experiments. The readout architecture implemented is data driven extending the flexibility of the system to be also used in first level triggers on tracks in vertex detectors. Preliminary simulations prove that the readout system can cope with an average hit rate up to 100 MHz/cm2 if a master clock of 80 MHz is used, while maintaining an overall efficiency over 99%.

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The Data Readout System of Nuclear Compton Telescope (NCT)

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The Nuclear Compton Telescope (NCT) is a balloon-borne telescope based on the 3D-positioning germanium detectors. It is designed to study astrophysical sources of gamma-ray emission in the energy range of 0.2MeV to 10MeV. The data readout system of NCT is designed to amplify, digitize and collect signals from a germanium detector according to a certain trigger scheme. It also has an interface to the flight computer to receive commands and transfer data. In this paper, we brief the system design and the development status of the data readout system of NCT.

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Architecture of a Slow-Control ASIC for Future High-Energy Physics Experiments at S-LHC

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This work is aimed at defining the architecture of a new digital ASIC, namely Slow Control Adapter (SCA), which will be designed and fabricated in a commercial 130 nm CMOS technology. This chip will be embedded within a high-speed data acquisition optical link (GBT) to control and monitor the front-end electronics in future high-energy physics experiments at super-Linear Hadron Collider (S-LHC) in Geneva. The GBT link provides a transparent transport layer between the SCA and control electronics in the counting room. The proposed SCA supports a variety of common bus protocols to interface with end-user general-purpose electronics. Between the GBT and the SCA a standard 100 Mb/s IEEE-802.3 compatible protocol will be implemented. The project is justified because embedded applications in modern large high-energy physics experiments require particular care to assure the lowest possible power consumption and the radiation tolerance, still offering the highest reliability demanded by very large particle detectors. In fact, as the SCA will be located in a radiation environment, it will have to include a robust design to face Single Event Effects (SEE). It will be provided with rad-tolerance redundant circuitry on critical logic. By contrast, the measures of leakage current of commercial 130 nm standard-cells, designed via linear transistors rather than enclosed-gate-transistors, under a hard-radiation environment as foreseen for SLHC, have proved that there is no need to re-design a dedicated library of cells to face total dose tolerance. Thus, we are investigating only different redundant architectures to protect logic from Single Event Upset and Single Event Transient, and we are exploiting different designs to compare robustness, power consumption, dimensions and circuit implementation complexity. All in all, via the SEE facilities the proposed GBT-SCA will work in a radiation environment and will interface, from one side, with front-end boards designed for the experiments and, from the other side, with an Ethernet port of a common PC for data acquisition. This will also allow testing general-purpose electronics equipments by replacing the real optical link with a user-designed emulator through the Ethernet port. The test could be also carried out in a user laboratory and, eventually, once the system will require a more in-depth and real test, the GBT-SCA chip along with its optical fiber will replace the emulator. This facility is independently of the experiment. The project of rad-tolerant ASICs for a new optical link for high-energy physics experiments at S-LHC is a continuation of a set of designs that were developed over the latest years via a 250 nm CMOS technology for LHC experiments. As today this latter technology is no longer available as it was in the past, the request of a technology upgrade for future experiments is to be fulfilled in any case.

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An All-Digital Coincidence Detection System for a Large RPC-PET Camera

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<u>*Filomena M. C. Clemêncio, presenting*</u>

An all-digital coincidence detection system for a large RPC-PET camera Abstract Current work [1] aiming at studying the feasibility of a resistive plate chamber (RPC)-PET camera for human whole-body screening indicates that a very cost-effective and high-sensitivity camera can be built. Such a camera will use the high intrinsic time resolution (better than 300 ps) of the RPC technology to implement a time of flight (TOF)-PET camera that, along with its very large field of view, can reach a sensitivity exceeding the present crystal-based PET technology by a factor up to 20 with a spatial resolution near 1 mm. Due to the large number of RPC plates forming such a system (in the order of 100 RPC plates, or even more) and to the large amount of data generated it is essential to have an effective on-line trigger that helps reducing the pressure on the data saving and processing system. In this work we present simulation results of an all-digital coincidence-detection system implemented in a FPGA that can cope with the task of generating the high speed trigger of such a camera. Each RPC plate in the camera generates a fast hit signal when a photon is detected. This signal is sent to the FPGA and used to check for coincidences. The coincidence detection window, due to the geometry of the camera and the large field of view, is within 3 ns. The fast hit signal coming from each RPC plate is sampled by the FPGA using a 550 MHz DDR clock. Each stream of data produced is optionally filtered for noise removal and an edge detection algorithm is run. The edges found are then checked for coincidence detection. The coincidence window width can be selected in increments of 0.9 ns up to 3.6 ns. Coincidences are detected in parallel in all channels resulting in a 50x50 matrix of coincidences (for a system with 100 independent channels). An algorithm to validate globally the coincidences can then be applied. The method implemented for coincidence detection is

virtually dead-time free and very fast. In the actual implementation the input data streams produced by sampling the fast hit signals are scanned at approximately every 4 ns and the coincidence matrix is refreshed at this rate. A trigger signal can be sent to the RPC plates originating the coincidences in less than 25 ns after the fast hit signals were received, allowing collecting the slow data (containing the information on the position of the event in the RPC plate) just in the plates involved in the coincidence event.
Acknowledgements: This work was financed by Fundacio para a Ciencia e Tecnologia and FEDER under Contracts POCI/FP/63411/2005, POCI/SAU-OBS/61642/2004 and by Instituto de Investigaco Interdisciplinar da Universidade de Coimbra.
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High Count Rate Neutron Spectrometry with Liquid Scintillation Detectors

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Liquid scintillation detectors are widely used in nuclear/high-energy physics and nuclear fusion for spectral measurements in mixed radiation fields due to their compactness, fast response and neutron/gamma discrimination capability. The use of response functions evaluated for the specific system and of appropriate methods of data analysis allows such systems to be used as broadband spectrometers for photons and neutrons [1]. System stability and ability to reach high count rates are key challenges for several applications (e.g.: neutron spectrometry for nuclear fusion devices), but standard analogue electronics limits the operation of liquid scintillator neutron spectrometers to low count rates (~30 kHz). The count rate capabilities of a liquid scintillator neutron spectrometer (NE213 detector) from the Physikalisch-Technische Bundesanstalt (PTB) was extended to ~450 kHz, by coupling it to a digital acquisition system developed at ENEA-Frascati [2]. The PTB detector is provided with a Light Emitting Diode (LED) coupled directly to the light collection system to monitor the stability of the pulse height spectra (PHS) with respect to gain variations of the photomultiplier-tube (PMT). The digital system consists of an FPGA-based, 14 bit, 200 MSamples/s acquisition board storing data on a PC through the PCI bus; data analysis is performed off line by a specially developed LabVIEW software. Measurements have been carried out at PTB using gamma sources and accelerator-produced 2.5 MeV and 14 MeV neutrons. Digital PHS obtained at high count rates (14 MeV neutrons) have been compared with low count rate PHS recorded with standard analogue electronics; PMT gain variations have been quantified and corrected off-line by analysis of LED pulses. The results show that stable PHS (within 1%) can be obtained at high count rate despite the high sensitivity of PMT gain to count rate variations and the influence of PMT high voltage on the PHS stability.

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A Mammography Imaging Hybrid Pixel Sensor Test Chip with Low Noise CMOS Readout IC on Fully Depleted Silicon-on-Insulator Design Trade Off Study

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This paper reports the design trade off study of the design of an innovative CMOS active pixel sensor (CAPS) based on Silicon-on-Insulator (SOI) technology. The CAPS designs approach provides the flexibility and high-density features of hybrid pixel sensors with photon counting architecture. This sensor is the key component for optimized X-ray Tomosynthesis. A proof-of-principle test chip, paying particular attention to the noise performance of the pixel, front-end electronics (FEE) and readout speed, is available for testing in 2008. We present the design trade off study of the test chip in this paper.

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A Low Energy Neutron Detector Array at NSCL

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A neutron detector array for the detection of low energy neutrons, is being developed at the NSCL. The Low Energy Neutron Detection Array (LENDA), will permit the study of p,n charge exchange reactions, in inverse kinematics. The study of charge exchange reactions is of great importance for nuclear structure and nuclear astrophysics. To date most of the studies of charge exchange reactions performed have utilized stable beams and targets. In the experimental program pursued by the charge exchange group at NSCL, the high intensity radioactive beams available from the coupled cyclotron facility will be utilized to study isovector excitations of nuclei away from the valley of stability. During these experiments, the produced neutrons will have energies ranging from 100 keV up to about 4MeV. The LENDA array is designed to enable the detection of neutrons at these energies, with high efficiency and energy resolution, while at the same time providing information on the position of interaction with the detector. The final array will consist of 24 300mmx45mmx25mm plastic scintillators, each one having a photomultiplier at each of the long ends. The neutron energy will be determined by the time of flight technique, while the position of interaction will be deduced using the timing and energy information from the photomultipliers. A prototype of the final array has been constructed and characterized at the NSCL. In the present work, results on the detector response obtained via experimental measurements and simulations are being presented. These results are discussed in terms of the detector characteristics required for the use of radioactive beams in studies of charge exchange reactions away from stability.

This work has been supported by the US NSF (PHY-0606007).

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A Novel CMOS Monolithic Active Pixel Sensor with Analog Signal Processing and 100% Fill Factor

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A novel CMOS Monolithic Active Pixel Sensor (MAPS) in a 0.18 um image-sensor technology (INMAPS) which has a 100% fill factor for charged particle detection and full CMOS electronics in the pixel has been designed and fabricated. The key component of the INMAPS process is the implementation of a deep P-well beneath the active circuits. A conventional MAPS design for charged-particle imaging will experience charge sharing between the collection diodes and any PMOS active devices in the pixel. This can dramatically reduce the charge collection efficiency, and thus the signal, when complex readout electronics is implemented in the pixel. By implementing a deep P-well, which effectively shields the readout PMOS active devices, the charge deposited in the epitaxial layer is more efficiently collected by the collecting diodes. Two variants on two different pixel architectures for charged particle detection, expected to have similar characteristics in terms of noise and power consumption, have been implemented in the sensor which has been produced. All pixel architectures include four N-well diodes for charge-collection, analog front-end circuits for signal pulse shaping, a comparator for threshold discrimination, digital logic for threshold trim adjustment and pixel masking. Pixels are served by shared row-logic which stores the location and time-stamp of pixel hits in local SRAM throughout the period when the sensor is operating with no dead time. The sparse hit data are read out from the columns of logic after this data acquisition period. The power consumption of the pixel is approximately 10 uW. The target application for these pixels is for the sensitive layers of an electromagnetic calorimeter (ECAL) in an International Linear Collider (ILC) detector. However, owing to the improved characteristics in charge collection and complexity of readout, these sensors could be developed in the context of more generic future colliders. The first test sensor using this technology was received from manufacture in July 2007. Design details and experimental results, obtained using laser illumination, radiation sources and beam tests, will be presented.

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Nuclear Pulse Height Measurement Using Vernier TDC

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<u>P. H. Hsueh, presenting</u> (National Tsing Hua University)

A Vernier type time to digital converter (TDC) is developed to measure nuclear pulse hight by measuring the time interval of a fast discharging analog to digital converter. The Vernier TDC contains two different propagation velocity delay lines to measure the discharge time interval and result in high resolution. A clock counter is incorporated to speed up the conversion speed. The proposed work is realized with a CMOS integrated

circuit technology. Results indicated that the conversion time is smaller than 5 clock periods with a 200 MHz clock, the maximum time can be measured is 75ns with a resolution of about 30 ps, the differential nonlinearity is between -0.3LSB and +0.7LSB, and the integral nonlinearity is between +0.5LSB and +1.0LSB..

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The Role of Offset and Gain Corrections in Digital Radiography Detectors over the Working Lifetime

Ho Kyung Kim, Pusan National University
Thorsten Graeve (Rad-icon Imaging Corp.)

For the combination of phosphor screens having various thicknesses and a photodiode array manufactured by complementary metal-oxide-semiconductor (CMOS) process, we report the observation of image-quality degradation under the irradiation of 45-kVp spectrum x rays. The image quality was assessed in terms of dark pixel signal, dynamic range, modulation-transfer function (MTF), noise-power spectrum (NPS), and detective quantum efficiency (DQE). For the accumulation of the absorbed dose, the radiation-induced increase both in dark signal and noise resulted in the gradual reduction in dynamic range. Unlike the MTF measurements, severe degradation in NPS was observed in the case of thin screen. This is caused by incomplete correction of the dark current fixed-pattern noise. The change in NPS with respect to the total dose degrades the DQE. However, with carefully updated and applied correction, we can overcome the detrimental effects of increased dark current on NPS and DQE. This study gives an initial motivation that the periodic monitoring of the image-quality degradation is an important issue for the long-term and healthy use of digital x-ray imaging detectors.
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).

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Development of Multifunctional Pulse Processing Device in Nuclear Spectroscopy

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Eun-Joo Kim (Chonbuk National University), S. Y. Kim (NOTICE Co. Ltd.)

We will present the development of a standalone multifunctional device based on 20 MHz and 10 bit Flash Analog-to-Digital Converter (FADC). This module has a function of peak sensing ADC, time to digital conversion (TDC) by constant fraction discrimination method (CFD) and pulse counter. Moreover, it can be used for FADC with 25 us waveform length for the monitoring purpose. It consists of 4 analog inputs, 1 trigger input and 1 trigger output connector. The external trigger and internal trigger function are implemented and internally triggered signal can be send out by the trigger output connector. All of these functions are implemented with Field Programmable Gate Array (FPGA) programming. It operates with single 5V DC supply and digitized data can be directly transferred to the computer by 100 Mbps Ethernet port. We will report performance test results with conventional crystal scintillator as well as liquid scintillator. The module can be used for the signal processing of the various radiation detectors for small nuclear and high energy laboratory experiments, nuclear spectroscopy and particle and radiation detection.

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A Multi-Frame, Megahertz CCD Imager

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Scott A. Watson, Daniel O'Mara, Robert K. Reich, Steve J. Balzer (LANL)

The Los Alamos National Laboratory's Dual Axis Radiographic Hydrotest Facility (DARHT) generates flash radiographs of explosive experiments using two linear induction electron accelerators situated at right angles . The DARHT second axis accelerator generates an 18-MeV, 2kA, 2usec electron beam which is converted or "chopped" into four individual pulses ranging from 20 to 100nsec in length at 2 MHz frequency . The individual electron beam pulses are down-converted to create four radiation flashes to image explosively driven events. To record these events, a high efficiency, high speed, imager has been fabricated which is capable of framing rates of 2 MHz. This device utilizes a 512 x 512 pixel charge coupled device (CCD) with a 25cm2 active area , and incorporates an electronic shutter technology designed for back-illuminated CCD's, making this the largest and fastest back-illuminated CCD in the world . Characterizing an imager capable of this frame rate presents unique challenges. High speed LED drivers and intense radioactive sources are needed to perform the most basic measurements. We investigate properties normally associated with single-frame CCD's such as read noise, full-well capacity, sensitivity, signal to noise ratio, linearity and dynamic range. In addition, we investigate several properties associated with the imager's multi-frame operation such as transient frame response and frame-to-frame isolation while contrasting our measurement techniques and results with more conventional devices.

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Front-end Electronics and Preamplifiers for Compact Arrays of Germanium Gamma-ray Spectrometers

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Craig E. Aalseth, James E. Fast (PNNL), Michael Momayezi (Bridgeport Instruments, LLC), John L. Orrell (PNNL)

Germanium gamma-ray spectrometers are customarily sold as single channel systems intended for laboratory use. In such circumstances the size of the front end electronics and preamplifier is not a crucial element for the utility of the detector system. A fourteen crystal array of germanium detectors intended for field applications must economize on the size of all components included in the system, most notably including the vacuum cryostat, liquid nitrogen tank, and electronic instrumentation. For the latter, the PXI electronics platform readily provides a compact solution for data acquisition using commercial products. However, the attendant high density front-end electronics, preamplifiers, and high voltage supplies peculiar to germanium gamma-ray spectrometers are currently not available commercially. A contract with Bridgeport Instruments has produced a set of components that reduce the size by approximately a factor of 4 in

comparison to what is available commercially. The multi-crystal germanium array is presented with a focus on the performance of these small form-factor germanium gamma-ray spectroscopy components.

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Research and Development of the Humanitarian Landmine Detection System by a Compact Fusion Neutron Source

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Teruhisa Takamatsu, Yasushi Yamamoto, Kiyoshi Yoshikawa, presenting, Kai Masuda, Hisayuki Toku, Takeshi Fujimoto (Institute of Advanced Energy, Kyoto University); Eiki Hotta, Kunihito Yamauchi (Tokyo Institute of Technology); Masami Ohnishi, Hodaka Osawa (Kansai University); Seiji Shiroya, Tsuyoshi Misawa, Yoshiyuki Takahashi (Research Reactor Institute, Kyoto University); Ken Takiyama (Hiroshima University); Yoshikazu Kubo, Toshiro Doi (JGC Corporation)

Research and development of the advanced anti-personnel landmine detection system have started by using a compact discharge-type fusion neutron source called IECF (Inertial-Electrostatic Confinement fusion), and the technique for BNCT (Boron Neutron Capture Therapy) for cancer treatment in Japan as one of the viable detection methods through Afghanistan reconstruction program. A new ion production scheme, i.e., magnetron discharge, for drastic improvement of neutron yields including robust power source were studied as well as analyses of envisaged detection system with multi-sensors, showing both promising features for landmine detection in Afghanistan. Tests were conducted for two kinds of wax-diluted explosives; TNT 240 g, TNT 100 g, RDX 100 g, RDX 29 g each buried in the depths of 5 cm, 10 cm, 15 cm, and soil moisture of 2 wt%, 10 wt%, 18.5 wt%, respectively with the D-D neutron yield of ~10 million neutrons/sec. Explosives were buried in a soil box and then it was inserted under the detection system. Tests were performed in 7 trials each under several mixed conditions for 20 minutes measurement. The thermal neutron capture gamma-rays of 10.8 MeV emitted from nitrogen in the explosives buried in the soli can be clearly detected above the background. We judged the possible existence of explosives by using the statistical criteria, i.e., we judged tentatively in this study that there is a landmine when the enhancement of the gamma-rays exceeds 0.67 times the statistical error. 231 tests were done, and the reliabilities of the landmine detection by measuring only 10.8 MeV gamma-ray from nitrogen atoms are found to be 0.77 for less than 18.5 wt% soil moisture, and 0.83, for arid soil (

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Low Energy Measurements using the CsI(Tl) Crystal Coupled to photodiodes in Coincidence-Sum Circuitry

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Carlos Henrique de Mesquita, presenting (IPEN/CNEN)

The detector of CsI(Tl) coupled with PIN photodiode constitutes one of the most promising technologies to measure gamma and X-Ray radiations. Compared with PM

tubes, photodiodes offer the advantages of higher quantum efficiency, lower power consumption, compact size, improved ruggedness and they are practically insensitive to magnetic fields. However, electronic noise of the photodiode-CsI system is very influenced by the size of the photodiode surface, on other words: its intrinsic capacitance, and consequently it commonly has been used with small crystal size like 1x1x1 cm3. This kind of assembling is suitable for low energy radiation. Unfortunately, in such case, especially for low energy radiation, like 125I (approximately 27keV), the electronic noise is responsible for the loss of the measurement performance. One way to overcome this limitation consists in using small photodiode and small crystal, but this approach generates low geometrical efficiency. The proposal of this work is to use two photodiodes (Hamamatsu S3590-04) connected to charge sensitive preamplifiers (Hamamatsu H4083) coupled to the same CsI(Tl) crystal (1x1x2 cm3) and applied to a circuit of coincidence and sum of signs. This detector system is capable to reduce the electronic noise severely. In this manner it is possible to measure efficiently low level of 125I radiation presenting low signal/noise ratio. The authors make considerations on the geometric aspects of the coupling between the photodiodes and the crystal and that could serve as suggestions for the photodiodes manufacturers to produce new integrated arrangements of photodiodes.

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High Spatial and Temporal Resolution Neutron Imaging with Microchannel Plate Detectors

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Special microchannel plates (MCPs) developed by Nova Scientific Inc. incorporate high efficiency neutron conversion materials into the MCP to provide a high neutron stopping power. B and Gd have high interaction cross sections for low energy neutrons and their incorporation into MCP glass is a convenient way to make MCPs efficient for neutron counting with high spatial resolution. We have evaluated neutron event counting 2D imaging detectors using these MCPs with a cross delay line readout, cross strip readout, and a MEDIPIX readout. Tests at NIST and MNRC with the cross delay line and cross strip readouts have established spatial resolution with neutrons as good as 15 microns over 27mm, with event rates approaching 1 MHz, low fixed pattern noise, event time tagging of 25ns and intrinsic background rates of 100 MHz level) at a spatial resolution limited by the 55 micron pixel size of the Medipix 2 readout. We have also performed measurements in Timepix "time over threshold" mode where individual events are centroided to subpixel resolution to obtain the best spatial resolution for neutron images at the expense of lowering the event rate limit. We will describe the detector systems and tests and compare the benefits of each and their potential applications.
This work was supported in part by the U.S. Department of Commerce, the NIST Ionizing Radiation Division, the Director's office of NIST, the NIST Center for Neutron Research, and the Department of Energy through interagency agreement no. DE-AI01-01EE50660. Nova Scientific acknowledges US government support for original development of neutron- sensitive MCPs through Contract DASG60-98-C-004.

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A Novel Independent Channel, Smart Triggering Readout Electronics for Single Photon Imaging Applications
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A. Argentieri, E. Cisbani, S. Colilli, F. Cusanno, R. Deleo, R. Fratoni, F. Garibaldi, F. Giuliani, M. Gricia, L. Lucentini, M.L. Magliozzi, Paolo Musico, F. Santavenere, S. Torrioli (INFN)

A new readout electronics for Multi Anode Photomoltipliers (MAPMT) or equivalent devices has been developed and tested; the system will be used in single photon gamma and optical imaging (e.g. SPECT and Cherenkov Ring Imaging respectively) applications. The system is based on the 64 channel compact - front-end VLSI chip (called MAROC) and provides high configurable, independent channels readout together with self triggering capability. Each MAROC chip is controlled by a FPGA and both are hosted on a small front-end (FE) card. Up to 16 FEs (1024 channels) are connected by a parallel bus that is laid out on a backplane. Up to 4 backplanes can be connected to a Control Board (CB), where another FPGA acts as master on the 4 busses and manages the USB 2.0 interface to the DAQ computer. The digital signals (fast) of each MAROC are combined to strobe the corresponding detector channels at FE stage and, while the analog data (relatively slow) are converted, a second level trigger can be generated by the CB FPGA based on the over-threshold MAPMTs channels information. The sustained trigger rate can be up to 30 kHz and the collected charge is converted with a 12 bit resolution. A complete prototype has been built: extensive testing show the effectiveness of the adopted solutions. The new system will be exploited for the readout of a MAPMT-scintillator based single photon system for in vivo stem cells and atherosclerotic plaques functional studies on small animals and early diagnosis of breast-cancer in human. This system can also be used as imager in RICH detectors. The modularity and flexibility of the architecture and the extensive run plan of the MAROC designer team should permit an easy adaptation to the readout of other detector such as the promising SiPM or the Micro Pattern Gas Devices.

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Optimal Digital Pulse Processing for Radiation Detection Systems
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Traditional approaches to digital pulse processing rely on linear filtering methodologies. However, with increasing count rate, the high-pass filters required to shorten pulse length and increase throughput also degrade signal-to-noise ratio (SNR), and ultimately, energy resolution. This paper presents a digital pulse processing technology based on the Maximum Likelihood Estimation of events within the pulse train output of radiation detectors. The output from the radiation detection system is modeled as the sum of an unknown number of signals, of predetermined form, with unknown energy and unknown arrival time. Based on this model, a Maximum Likelihood Estimator is used to determine the number, energy, and timing of radiation events in the detector output. This technique enables accurate characterization of individual radiation events, even in the presence of very severe, multi-pulse pileup. The performance of this pulse pileup recovery

technology has been evaluated at high count-rates using a digital nuclear pulse generator. The results indicate that over a 250-fold increase in input count-rate (from 10 kc/s to 2500 kc/s) system throughput and energy resolution degrades by less than 10%. Further performance evaluation was conducted using a standard 76 x 76 mm NaI(Tl) crystal coupled to a PMT. At a count-rate of 9 kc/s the FWHM energy resolution of the NaI(Tl) crystal was 6.7% at 662 keV, this degraded to 7.3% at 230 kc/s. By decoding radiation events corrupted by pulse pileup, this Maximum Likelihood approach to pulse pileup recovery dramatically improves the throughput and resolution of radiation detection systems.

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Prototype Large-Angle Photon Veto Detectors for the NA62 Experiment at CERN

Riccardo Fantechi, INFN - Sezione di Pisa

The NA62 experiment at the CERN SPS has been proposed to measure the BR for the decay K+-> pi+ nu nubar to within ~10%. The photon-veto system must provide 108 rejection for pi0 decays and it is composed of the existing Lkr calorimeter, large-angle veto detectors and small-angle calorimeters. We have explored three technologies for the large-angle veto detectors: one based on scintillating tiles, an other using scintillating fibers and a third using lead glass from the OPAL electromagnetic calorimeter barrel. We have constructed a prototype module based on the fiber solution and tested it using low-energy electron beams from the Frascati BTF. Onn the same beam we also have tested a tile prototype constructed at Fermilab for the CKM experiment and some lead glass blocks. We will present results on the linearity, energy resolution, time resolution and inefficiency.

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Characterizing and Correcting the Cross-Talk Effects on Depth Measurements in the NCT Detectors

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The Nuclear Compton Telescope (NCT) is a balloon-borne soft gamma-ray (0.2-10 MeV) telescope designed to study astrophysical sources of nuclear line emission and polarization. The heart of NCT is an array of 12 cross-strip germanium detectors, designed to provide 3D position for each photon interaction with full 3D position resolution

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Novel Approaches to Radiation Detection and Readout by Exploiting the Latchup Effect

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An innovative topology for solid-state pixel detectors is described. It is based on latchup effect, usually exploited in solid state electronic switches like thyristor and SCRs. In CMOS devices when caused by external radiation or SEU this effect is considered detrimental. However here it is proposed to use this effect in a building block for low power, low noise, fast and much simplified particle and radiation detection. The latchup effect relies on a positive feedback triggered in a loop of active devices by an injected charge. Following latchup, the circuit retains its final state until reset. This provides a digital and stable signal until the next cycle of readout is started. A detector prototype based upon commercial components was built and tested confirming the working principle. A sensitivity of approximately 1pC was achieved. The detector can operate at room temperature, does not require a high voltage power supply and is intrinsically tolerant to radiation as it uses standard, non-depleted, low-resistivity technologies. A new prototype with increased charge sensitivity is currently being designed in a commercial AMS 0.35um BiCMOS technology. A further improvement with the possibility of accurately selecting the threshold of ignition is also described here. It is based on floating gate MOS transistors, routinely used as building blocks for digital memory cells (i.e. EPROM or FLASH). Charge is electrically stored onto or erased from the floating gate of the MOS device, thus allowing tuning of its electrical characteristics. This effectively makes the device programmable with characteristics maintained for years, owing to the charge long retention time of floating gate. The proposed latchup based readout using floating gate MOSes is brought very near the ignition point, with the devices in the circuit biased near or below threshold. Thus very little current is drawn, making the readout inherently low power. Also, the input referred noise is low for the same reason. A small signal applied to the input ignites the positive feedback of the latchup circuitry, giving a fast transition and a clean digital output. The sensitivity of the circuitry is varied by changing the amount of charge stored onto the floating gate, i.e. changing the device threshold. This approach in principle could greatly simplify the readout, as most of the standard blocks, like charge amplifier, buffers or comparator, are implemented using few programmable devices. A prototype using commercial components is being built to validate the concept and to understand the limitations. The proposed solution might find applications in many fields of detection, particularly when large size systems of detectors are used, like in high energy physics applications, and power reduction is of crucial importance.

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Development of Embedded DAQ System for Beam Monitoring

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The embedded DAQ(Data Acquisition) system was developed for the proton beam position monitoring and beam flux monitoring. This embedded DAQ system was consist of ATMEGA128 microcontroller and current to digital converter with 20-bit resolution. This module has many advantages as a DAQ system, multifunctional capability such as ADC, timer, counter and low-level current measurement. The Proton beam flux was measured at the MC-50 cyclotron in the KIRAMS (Korea Institute of Radiological & Medical Sciences). We can monitor the proton beam flux by using a 16-bit timer/counter in ATMEGA128 embedded system with the scintillator. The result of data is recorded into the personal computer with a Linux operating system in real time through the serial connection. The data were analyzed with the C++-based data analysis program, ROOT package. This embedded DAQ system is portable and useful for beam flux, and position monitoring as well as radiation monitoring

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Energy and Spatial Resolution Study of Thick Sodium Iodide Gamma Cameras for Standoff Applications

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Standoff detection applications require position sensitive detectors with high sensitivity for gamma energies up to 3 MeV, sufficient energy resolution for isotope identification, and good spatial resolution for image reconstruction. Scintillator-based medical gamma cameras have satisfactory energy and spatial resolution (e.g., 10% energy resolution at 140 keV and 4 mm intrinsic spatial resolution) and can be assembled in a tiled mode to increase total detector area at much lower cost than semiconductor-based cameras. However, any type of commercial camera presents reduced gamma sensitivity above 0.511 MeV due to their specific design for low-energy clinical radioisotopes applications. We propose and study two modified versions of an existing medical camera (Infinia VC from GE Healthcare) with new 2- and 3- inch - thick NaI(Tl) scintillator crystals for improved gamma stopping power at high energies. Since increasing the thickness of a uniform scintillator plate leads to more scintillation light spread and deteriorates the position and energy resolution performance, we propose mitigating this effect by adopting the StarBrite(TM) (Saint-Gobain Crystals) patterning process for crystal plates. In this work, we investigate experimentally the detector energy and spatial resolution as a function of the depth and pitch of the StarBrite(TM) groove pattern. To explore this dependence, for each NaI(Tl) crystal thickness (2 and 3 inch) three regions with different depth/pitch pattern combinations are studied and benchmarked against a uniform region of the crystal. The trade-off study between the gain in sensitivity versus energy and position resolution effects will be presented in light of the intended camera use as a position sensitive detector for a standoff imaging system.
This material is based upon work supported by the Homeland Security Domestic Nuclear Detection Office under Contract No. HSHQDC-07-C-00092.

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Measurement of Fast Neutron/Gamma-Ray Cross-Correlation Functions with a Pu-Be Source

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We present an improved method for measuring time-correlated neutron and photon events from fission sources. These correlations are unique for a specific radioactive material and can be interpreted as a material signature. The goal of this work is to further explore the feasibility of using the cross-correlation functions to accurately identify radioactive materials such as special nuclear material (uranium, plutonium) and typical spontaneous fission sources (Pu-Be, Am-Li, Am-Be, etc.). In the measurements, a Pu-Be neutron source was used in conjunction with two 25 by 25 by 8 cm liquid scintillation detectors. The detectors are sensitive to both fast neutrons and gamma rays. The novelty of the approach is in the use of an offline digital pulse shape discrimination algorithm, which is used to correctly identify the particles detected while retaining time-correlation information with ns resolution. The neutrons and gamma rays from the radioactive sources have characteristic times of flight to the detectors. These arrival times depend on the type of particle (neutron or photon), and, in the case of neutrons, on their initial energy. Consequently, a characteristic cross-correlation distribution is obtained for a given source and geometry. Several source-detector distances were investigated in symmetric and asymmetric configurations, and with and without lead shielding. The measurements are compared to Monte Carlo simulations performed with the MCNP-PoliMi code. MCNP-PoliMi has the capability of simulating coincidences on an event-by-event basis and has been successfully used in the past. The results obtained are very encouraging, because they show unique features for the given source and geometries. In the full paper, we will show that the measurement and analysis of the cross-correlation functions results in accurate material identification. Also, the identification method will be described in detail. It should be noted that the number of pulses sufficient for the analysis can be measured in a few minutes (~3.8 uCi source). The method shows promise for applications in nuclear nonproliferation and safeguards. An acknowledgment goes to Jeff Peck of Impeccable Instruments for providing the prototype digitizer used in the measurements.

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Calculation of NRF Scattering Rate for Security Inspection

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H.D. Choi, presenting (Seoul National University)

NRF-based security inspection technique uses the difference of resonance scattering energies of the fluorescence photon among nuclides. It is performed by measuring the fluorescence photon and the transmitted photon spectrum while irradiating probe photon beam with continuous energy spectrum. So, the NRF-based technique is nondestructive and it can be applied to nonproliferation, clandestine material identification and homeland security, etc [1]. In this study, the NRF scattering rate from a cargo container was calculated to test the feasibility of NRF-based technique by using the conventional X-ray inspection system. The calculation was performed for the elements of C, N, O, Cl which are the major composition elements of the threat materials. The bremsstrahlung photon beam from a 9 MeV electron accelerator was chosen as the probe beam, since it covers the energy range of 1-10 MeV where the photons are resonantly scattered from the interesting nuclides and the contribution by background gamma-ray is weak. The energy differential flux of the probe beam was defined by using the MCNPX code [2]. The nuclear data required to calculate the resonance scattering cross sections were taken from ENSDF [3] and Table of Isotopes [4]. It was assumed that the emission of fluorescence were isotropic. And the Doppler effect was considered. The maximum NRF scattering cross sections and scattering rate for the listed nuclides are reported. And the feasibility of NRF-based security inspection technique is discussed.

This research was supported by National Nuclear R&D Program of Ministry of Science & Technology (MOST) and Korea Science and Engineering Foundation (KOSEF) of Korea.
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Adaptive Sampling with Rotationally Modulated Collimators for Efficient Source Detection

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Radiation imaging with rotationally modulated collimators (RMC) has traditionally focused on uniformly sampling over the entire period of rotation. The RMC is usually rotated at a constant velocity and when a photon is detected, the time of arrival, photon energy, and angular position of the RMC are recorded. It is clear by looking at the RMC detector response that the information necessary to locate a single point source is provided by both the frequency of the modulation peaks and the angular position of an extended dip or peak in the signal. Therefore, when uniformly searching for unknown sources, a large portion of the sampling effort is directed toward unimportant regions. Adaptive sampling techniques attempt to focus the sampling effort on the regions that provide the most information about the source location. Adaptive sampling techniques have been applied to a variety of search applications such as detecting the presence and position of a lost satellite in the sky or for locating small tumors in breast cancer patients. These techniques often incorporate a fast uniform scan of the source scene allowing a prior estimate of the source location to be computed. This information is then used to develop a cost function, which is used to weight the importance of the search regions. These regions are then sampled according to the respective weight and a posterior estimate is computed. This new estimate is used to modify the cost function, which then is used to update the weights on each sample region. The regions are sampled again with the new profile and the process is repeated. As more information is recorded, the search scheme becomes more efficient at estimating the pattern necessary to locate the source. This research focuses on an adaptive sampling scheme developed for a rotationally modulated collimator at the University of Michigan. The paper will detail the theoretical approach for sampling as well as the control structure used to command the RMC. Results are expected to show how implementing adaptive sampling can decrease the time it takes to positively locate hidden or weak radiation sources with this system.

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Passive Scanning of Occupied Passenger Vehicles
Chris Morris, Los Alamos National Laboratory (LANL)
Jeffrey Bacon, Konstantin Borozdin, Andrew Green, Gary Hogan, Mark Makela, William Priedhorsky, John Ramsay, Larry Schultz, Patrick McGaughey, Charles C. Alexander (LANL)

Over 120 million vehicles drive into the U.S every year. Many would be capable of transporting hidden nuclear weapons, and all are capable of carrying enough nuclear material to make a nuclear weapon. In most cases, the chances of intercepting such a threat depend largely on the observation powers of the immigration officers who briefly question hundreds of drivers/passengers every day. The chances of detection would be greatly improved if each officer had a scan available showing any dense objects in each vehicle as it reached the checkpoint. The DHS plans to use x-ray radiography at many locations, but the present capabilities of these systems are limited by the fact that they cannot be used on occupied vehicles and that the energy of the interrogating beam is too low to penetrate the vehicle and contents in many scenarios. We present a new technique that overcomes these limitations. Specifically, tomographic density scans can be developed passively and unobtrusively as the car stops at the checkpoint by observing the pathways taken by natural cosmic radiation as it enters and leaves each vehicle. This is not science fiction- it is merely an application of a technology currently under development at Los Alamos. The advantages of this technique are that it: is passive; does not require radiation above natural background and thus can be used for occupied vehicles; will not trigger salvage fuses; is transportable; and is selective to high-z dense materials. When coupled with passive radiation detection, muon interrogation can provide safe and robust border protection against nuclear devices or material in occupied vehicles and containers.

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Development of a Neutron Spectrometer using Spontaneous Fission Associated Particle (AP) and Double Neutron Scatter (DSNS) Techniques
Istvan Dioszegi, Brookhaven National Laboratory (BNL)
Peter Vanier (BNL), Leon Forman (Ion Focus Technology)

Spontaneous fission leads to the emission of many associated (correlated) particles including neutrons and gammas. The energy distribution of emitted neutrons can be measured by time of flight using a gamma ray to start an Associated Particle (AP) timing sequence. Neutron scattering in Double Scatter Neutron Spectrometry (DSNS) can also provide neutron spectral information based on the time of flight between two proton-recoil detectors. We have constructed a neutron spectrometer with a large plastic scintillator (31 cm x 31 cm x 5 cm) used with either a fast rise-time BaF2 AP gamma ray detector (10 cm diam. x 15 cm long) or with a DSNS plastic scintillator (12.5 cm diam. x 2 cm thick). We have determined that for this spectrometer, the AP configuration has higher energy resolution than the DSNS geometry for reasons that we will discuss. The AP results for a 1.15-meter source-to-paddle flight path is capable of neutron transmission spectroscopy that can differentiate between C6H12O6, CnH2n+2, and H2O attenuators. These results are reproduced by Monte Carlo calculations. We find that AP cosmic ray background counts are minimal because the cosmic ray shower process does not produce measurable correlated neutrons within the data-collection time window of 150 ns. In addition, the AP configuration simultaneously provides low-resolution gamma spectra capable of identifying radioisotopes such as Cf-252.

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Cs2LiYCl6:Ce Scintillator for Nuclear Monitoring Applications

Jarek Glodo, RMD
Edgar V. D. van Loef , William M. Higgins, Kanai S. Shah (RMD)

Cs2LiYCl6:Ce (CLYC) was originally proposed as a neutron scintillator. The fact, that it is capable of providing pulse shape discrimination between gamma and neutron events, makes it appealing for neutron detection. Yet recently, we have discovered another attractive feature that this material exhibits excellent energy resolution that closely follows the photoelectron statistics. This comes as a result of exceptionally high proportionality, which is essential in achieving energy resolution close to the value predicted from photoelectron statistics. Previously, we have shown results obtained on a 1-inch CLYC crystal. This crystal provided the energy resolution as good as 5.1% FWHM at 662 keV. In this presentation we are updating these results in two ways. First, we will present measurements for a 2-inch crystal. It is particularly important since many applications, including nuclear non-proliferation, require large crystals. It is not atypical to use crystals as large as 3-inch. Thus the scaling up process is an important part of the material development. Second, we will discuss energy resolution, and show that even better values can be obtained with this material.

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Compton Imaging for Safety and Security

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David Hanna (Physics Department, McGill University), Patrick Saull (Institute for National Measurement Standards, National Research Council)

We are designing an all-scintillator Compton gamma imager for use in pre-event criminal and national security investigations involving radioactive threat material. The instrument will also be useful post-event, in the consequence management of an accidental or malicious dispersion of radioactivity. It has applications as well in decommissioning of contaminated facilities. Using the BEAMnrc/EGSnrc Monte Carlo simulation package, we have constructed models of a number of different instrument designs, emphasizing portability while maintaining reasonable sensitivity and angular resolution. We have developed measures to quantify detector performance and have used these to evaluate the various modelled geometries and materials. Using a fitting algorithm, we have reconstructed images from the simulated data. Indications are that a reasonable design goal would be the localization of a 10 mCi 662 keV source 40 m distant to within a few square metres, in under a minute. The results of these design studies will be presented.

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Toward Practical Monitoring of Commercial Power Reactors with Antineutrinos

Lorraine Sadler, Sandia National Laboratories
Georg Aigeldinger, Adam Bernstein, Nathaniel Bowden, Steven Dazeley, James Lund, David Reyna (Sandia National Laboratories, Livermore)

Over the past several years, antineutrino detectors, based upon liquid scintillator, have be demonstrated to be a potential safeguards tool that provides a direct method for measuring the total fission rate as well as the change in fissile content at nuclear reactors [Bowden N.S., et.al. Nucl. Instr. and Meth. A 572, (2007) 985]. However, the flammability and toxicity of the liquid scintillator used to date poses significant concerns for both reactor operators and safeguards practitioners. Furthermore, transportation and handling of this material greatly complicates the deployment of such devices. In order to become a widely applicable technology, these detectors need to be more easily deployable, removing flammable materials and liquid from the design would be a large step in this direction. We present the next generation in reactor monitoring antineutrino detectors based upon a solid-state, plastic scintillator. This design removes all flammable materials, eliminates the risk of liquid leakage, and is able to be pre-assembled prior to deployment at the reactor site. In this talk, we present the design and deployment of this new plastic detector. We will discuss the results of our monitoring of the Unit 2 reactor at the San Onofre Nuclear Generating Stations (SONGS) during and after the reactor is refueled. Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

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Simulation and Testing of Radiation Survey Meters as Monitors of Internal Contamination Levels

Michael Shannon, Georgia Tech
Nolan Hertel, Michael Bellamy, Eric Burgett, Shahenn Dewji, Christina Lobracco, Ryan Manger, Sarah Scarboro (Georgia Tech)

The terrorist threat presents numerous challenges for public health professionals. One such challenge is the rapid and effective triage of victims of a Radiological Dispersal Device (RDD) event. In such an event, victims would potentially be both internally and externally contaminated. Methods for assessing external contamination are more well-defined than those for internal contamination. The preferred method to assess internal contamination would be the use of whole body counters, at least for low body burdens encountered in the typical activities at nuclear facilities. The challenge with this modality is that in a most parts of the United States, there are only a limited number of these instruments available and, in fact, they have much greater sensitivity than would be needed in an emergency situation. This fact was the catalyst for the present work, in which a study was undertaken to assess whether readily available handheld instruments, like those carried by many first responders, could be used to assess internal contamination. The goal of this work was to characterize the capabilities and limitations of these instruments in assaying internal contamination. The final characterization of the

instruments was performed by Monte Carlo simulation using anthropomorphic phantoms. To validate the detector models, MCNP5 simulations for point sources and PMMA slabs were compared to measurements. The detection efficiency for each isotope for a unit source level in each organ was then computed. The Oak Ridge National Laboratory code, DCAL was utilized to perform biokinetic modeling to determine the distribution of the inhaled isotopes in the body as a function of time. The DCAL computed compartmental organ activities were then folded with the organ counting efficiencies to determine the instrument reading as a function of time per Annual Limit on Intake (ALI) that would result in a 50 mSv committed effective dose. Six different anthropomorphic phantoms based on the MIRD phantoms were used in this work to determine the impact of body types. Two-page information sheets describing the procedure for using the detectors to triage RDD victims are being developed. Summary results will be presented for all detectors examined. Detailed results will be presented for a handheld GM probe, a handheld spectrometer, and a thyroid scanner.

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Neutron Background Measurements at Fission Energies

Nicholas Mascarenhas, Sandia National Laboratories, Livermore (SNL-L)
James Brennan, Kevin Krenz, Peter Marleau, Stanley Mrowka (SNL-L)

We have built a neutron scatter camera to aid in the search for hidden SNM. When searching for SNM cosmic rays are a dominant source of neutron background. It is therefore important to understand this background and the variation in S/N at different locations. Over the years much work has been done to study cosmic ray neutrons. However, there is a lack in knowledge of the angular dependence of cosmic neutrons. The angular dependence is important for two reasons; first many detectors have an efficiency that changes with the direction of the incident neutron. Second none of the measurements to date have determined how the flux changes with angle, their data must be modeled to estimate the full hemispherical flux. We present results on direct measurements of the cosmic neutron background using a neutron scatter camera in the energy range 0.2-10MeV. We report on neutron flux, energy spectra and angular distributions at different locations ranging from sea level, 174m, 1645m to 2743m. We have studied neutron backgrounds near an ocean tanker and measured differences in the neutron backgrounds over land and sea. These results could be of interest to those working on SNM searches in general, maritime and aviation applications.

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Ship-Effect Neutron Impacts on Screening at Borders

Richard Kouzes
Pacific Northwest National Laboratory (PNNL)
James Ely, Paul Keller, Ronald McConn, Allen Seifert, Edward Siciliano, Dennis Weier, Lindsay Windsor, Mitchell Woodring (PNNL); James Borgardt, Elise Buckley, Eric Flumerfelt, Anna Oliveri, Matt Salvitti (Juniata College)

Radiation portal monitor systems based upon polyvinyl toluene scintillators for gamma-ray detection and pressurized 3He tubes for neutron detection have been deployed to

screen for illicit trafficking of radioactive materials at international border crossings. Much has been published on these passive, gamma-ray detection systems and their results from border applications. This paper instead focuses on passive neutron detection requirements and their capabilities for use in such applications. Unlike the situation with gamma detection, the natural neutron background is relatively small. Nevertheless, its variation must be accounted for to realize the full sensitivity of the neutron detection system. The natural background of neutrons that is observed in monitoring instruments arises almost entirely from cosmic-ray-induced cascades in the atmosphere and the surrounding environment. One significant source of variation in that observed background is produced by the "ship effect," when large quantities of cargo pass by the detection instruments. Simulations have been used to show the effects of cargo materials on neutron spectra, different detector geometries, using a large-array of neutron detectors, and the effects of backgrounds including "ship effect" neutrons. This paper reports on results from measurements with typical monitoring equipment of ship effect neutrons in various materials and on the "neutron shadow shielding" effect seen with some low neutron density materials.
Acknowledgement : This work was supported by the US Department of Homeland Security. PNNL is operated for the US Department of Energy by Battelle under contract DE-AC05-76RLO 1830.

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Identification of Neutron Sources by Spectral Analysis of Pulse-Height Distributions

Senada Avdic, University of Tuzla
Predrag Marinkovic (University of Belgrade); Sara A. Pozzi, presenting, Marek Flaska (University of Michigan), Vladimir Protopopescu (Oak Ridge National Laboratory)

The uncontrolled proliferation of nuclear weapons and materials represents one of the most serious dangers the contemporary world is facing. Specifically, the development of fast, efficient, and robust identification methods of neutron sources remains a high priority in the field of nuclear nonproliferation and international safeguards applications. The neutron spectrum is a unique characteristic of each neutron source and could be used, at least in principle, for accurate source identification. However, small variations in the measured pulse-height distributions may lead to large variations in the unfolded neutron spectra. Therefore, it is important to look for new identification techniques, which do not rely on unfolding methods. The full paper will describe a new method for neutron source identification based on the analysis of spectral characteristics of neutron pulse-height distributions. These distributions are obtained with liquid scintillation detectors, which are used in nonproliferation and homeland security applications. The simulations of pulse-height distributions from various neutron sources were performed using the Monte Carlo MCNP-PoliMi code. This code is used to simulate in detail every neutron interaction within the detector. The simulated pulse-height distributions for californium-252 (Cf-252), americium-beryllium (Am-Be), and plutonium-240 (Pu-240) neutron sources were generated for various numbers of histories, to simulate varying counting statistics. We have investigated the frequency content of the amplitude distributions of simulated pulses and found that this analysis can be useful for accurate source identification. As a first step, the analog signal is sampled to the digital form. Secondly, a

Discrete Fourier Transform (DFT) is applied. The standard numerical algorithm for implementation of the DFT is the Fast Fourier Transform (FFT). The Power Spectral Density (PSD) has been calculated for each of the simulated pulse-height distributions. The inherent discretization and truncation processes result in some distortion of the frequency spectrum, such as loss in spectral resolution and/or spectral leakage. One approach to reduce these distortions is to use a weighting function or window function on the data. We have chosen three "moderate" window functions such as Kaiser, Hanning, and Chebyshev. Subsequently, a procedure was applied which consists of breaking the data into segments, computing the spectra for each of those segments, and averaging the periodograms from overlapping segments. The result of this procedure is a reduction of the noise-induced fluctuations in the power amplitudes at the expense of spectral resolution. We noticed that each of the investigated neutron sources (Cf-252, Am-Be and Pu-240) has characteristic spectral components with specific locations and intensities. The duration of the spectral analysis is quite short, which allows for fast and accurate neutron source identification. The results of the spectral analysis of the simulated pulse-height distributions indicate a new possibility for accurate identification of typical neutron sources such as Cf-252, Am-Be, and Pu-240. The full paper will include the spectral analysis of the experimental data obtained from several shielded neutron sources, which are important for nuclear nonproliferation and international safeguards applications. In addition, the influence of the mathematical tools used in the source identification procedure on the obtained spectra will be assessed.

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Determination of Source Shielding Using 3-D CZT Imaging Detectors

Weiyi Wang, University of Michigan
Zhong He, Feng Zhang (University of Michigan)

Energy-imaging integrated deconvolution (EIID) was developed and demonstrated in our previous work, to determine the most likely spatial and energy source distribution from measurements of radiation-interaction locations and energy depositions in a position-sensitive detector. If a gamma-ray source is shielded, some photons from the source will scatter in the shielding material before reaching the detector, while other photons will reach the detector without any interaction in the shield. The scattered photon will often carry lower energy than the initial photon from the source. Therefore, shielded sources should appear as a more diffuse point around the true source location with components extending to lower energy near this source location. This effect was first confirmed by our experiment using a single 2x2x1.5 cm^3 3-D position-sensitive CdZnTe detector to image gamma-ray sources behind shielding materials. Moreover, one can identify the shielding materials by identifying the characteristic x-rays produced in shielding materials.

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Improvement of SNM Detection Performance by Fusion of Data from Multiple Inspection Systems

Willem G. J. Langeveld, Rapiscan Systems, Inc.
Timothy J. Shaw, presenting
Dan A. Strellis, Doug Keeley), Tsahi Gozani (Rapiscan Laboratories, Inc.)

Differential Die Away Analysis (DDAA) is one of the most sensitive, if not the most sensitive, methods for the detection of Special Nuclear Material (SNM) due to three factors: a) the fission cross section of thermal neutrons is large, b) a large number (2.5-4.5) of fast neutrons are promptly emitted in each fission event, and c) 3He-based detectors can be made with a very high detection efficiency. However it is highly desirable to further enhance the DDAA performance. We show here that this can be achieved by the fusion of DDAA data with data from complementary systems. In DDAA, the cargo under inspection is irradiated with a pulse of neutrons, typically using a commercial electronic neutron generator (ENG) based on the D-D reaction, which produces ~2.5 MeV neutrons, or D-T reaction, which produces 14 MeV neutrons. Some of the source neutrons thermalize in the cargo. The thermal neutrons are then readily absorbed by SNM, producing fission and thereby prompt neutrons. The prompt neutrons, which escape the cargo are detected by, typically, 3He-based detectors covered by a thermal neutron absorbing layer, such as cadmium, to insure that only the epi-thermal and fast neutrons that originated in the fission process are detected. Because the thermal neutron population in the cargo remains long after the end of the neutron source pulse, any prompt fast neutrons detected after the source pulse are unequivocally due to presence of fissile material. While several techniques for interrogating cargo for the presence of SNM are quite promising, including DDAA, it is likely that no individual technique will succeed with all cargos. It is further likely that some cargos will be difficult to interrogate with any individual technique. An obvious way to improve performance is to combine detection techniques. The simplest combinations are Boolean. Data fusion involves combining the underlying features from various techniques in a systematic way, rather than just combining the final decisions. The systematic combination takes advantage of any complementarities between techniques, and has the potential to significantly improve performance compared to either individual techniques or simple Boolean combinations of techniques. We have collected data on a large number of different cargos, with and without the presence of SNM, using a prototype Special Nuclear Material Detection System (SNMDS) based on DDAA. We have also collected data on identical cargos and configurations using two systems complementary to DDAA, a high-energy x-ray system based on a 6 MV linac and a NaI-based gamma-ray detection system used for the detection of explosives. Detection algorithms were developed for each of the systems individually and combined in a Boolean decision, and at the same time algorithms were developed using data fusion of the DDAA-based system with each of the other two systems. The data fusion algorithms demonstrated a significant improvement in the detection performance, for the case of fusion of DDAA and gamma-ray systems, as well as a significant improvement in throughput, in the case of fusion of DDAA and x-ray systems, over Boolean combination algorithms.
Supported by DNDO Contract HSHQDC-07-00038

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Thermal Neutron Die-Away Studies in a 14-MeV Neutron-Based Active Interrogation System

Willem G.J. Langeveld, Rapiscan Laboratories, Inc.
<u>*Ryan Yee, presenting*</u>
Timothy J. Shaw, Tsahi Gozani (Rapiscan Laboratories, Inc.)

The ability to classify cargo can be extremely useful in developing cargo-dependent algorithms as a method for improving threat detection. In a 14-MeV neutron based active interrogation system, fast neutrons are thermalized as they travel through a moderating cargo. Once they are thermalized, they can be absorbed by the surrounding cargo. The rate at which they are absorbed, the thermal neutron die-away, depends especially for large cargo (e.g. pallet size) on the composition of the moderating cargo. If practical measurements can be made to determine thermal neutron die-away in various cargos, improved threat identification via cargo dependent algorithms is possible, and higher sensitivity or faster SNM detection can be afforded. Using a single 3He detector is a simple means to measure the thermal neutron die-away. However, in actual inspection scenarios one generally cannot insert a neutron detector in the inspected object and measure cargo-characteristic die-away times. It has been shown previously, that some coarse assessment of the kinetic properties of the cargo can be made by a 3He detector external to the cargo. Here, we show how spectroscopic scintillator detectors such as NaI which are commonly used in explosive and other threat detection systems, can provide us with deep insight into the kinetic behavior of the cargo and its die away time. The study focused on comparing the die-away behavior of the thermal neutrons as measured directly by a 3He detector to the die-away time of the gamma-rays created through the thermal neutron absorption reactions. These measurements were performed with different cargos and different configurations of 3He and gamma-ray detectors. Representative gamma-ray energies produced from these capture reactions and used in the study were 2.22 MeV for hydrogen and 7.63 MeV for iron. Die-away times were then estimated based on the time-dependent behavior of the hydrogen and iron peak regions, using a unique two parameter (energy and time) data acquisition system. A strong correlation between both measurements was observed when highly hydrogenous, relatively dense cargos such as wax, water, and food were present. Estimates of thermal neutron decay times drawn from gamma-ray data for wax cargos was within 10% of those inferred from the 3He detectors. Similarly, 7% was achieved for mixed food-water cargos, and 3% for food only cargos. In all these cargos, the thermal neutron population reaches an equilibrium and an asymptotic decay mode is obtained. In other cargos, especially those with little or no neutron moderation, no asymptotic flux is reached and the effective die away time is continuously varying. In these cases, as expected, there was little agreement between these two methods since each method probes a different volume and material distribution. However, the decaying flux as shown by the capture gamma ray intensity versus time is quite distinct for these low-moderation cargos, and can be used in cargo identification. Examples of such cargo are steel, monitors, wires, vacuum cleaners, and cement bags. These measurements will be described and the analysis results will be shown.

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Intrinsic Limitations of Neutron Detectors in Radiation Portal Monitor Systems

Allen Seifert, Pacific Northwest National Laboratory (PNNL)
Sean M. Robinson, Mitchell L. Woodring (PNNL)

Radiation Portal Monitor (RPM) systems operate world-wide with the intent of detecting illicit radioisotopes in the stream of commerce. Presently deployed systems generally consist of large-area polyvinyl-toluene (PVT) scintillators for gamma-ray detection and He-3 tubes for neutron detection. These He-3 systems are, in principle, subject to many of the same limitations on performance as are the gamma-ray scintillators. This work examines the capabilities of He-3-based neutron detection tubes, and establishes their intrinsic limitations as employed in the field. Effects of high neutron count rates and strong gamma sources are evaluated using deployed RPM systems. Count-rate pileup, the effects of gamma rays on spurious neutron detection, and memory effects in the apparatus are all investigated using experimental and modeling techniques.

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Poisson Statistical Methods for the Analysis of Low-Count Gamma Spectra

John Kirkpatrick, Canberra Industries, Inc.
J.M. Kirkpatrick, B. M. Young (Canberra Industries, Inc.)

Although radioactive decay is well known to be a Poisson process, most of the gamma-ray spectral analysis and counting techniques in common use today have been developed in the Gaussian limit -- that is, under the explicit assumption that the Poisson distribution can be well approximated by the Gaussian distribution. However the Gaussian approximation is not good when the mean number of counts of the distribution is small, or when the behavior at the tails (i.e., many standard deviations away from the mean) of the distribution is of interest. We see increasing numbers of applications in disparate fields, from high energy astrophysics and particle physics to security screening and interdiction that fall into this regime. The blind application of Gaussian methods in these cases can yield erroneous and even non-physical results; in particular, reliance on the Gaussian notion of Critical Levels for detection decisions can have serious detrimental effects on detection probabilities and false alarm rates. In this paper, a set of rigorous Poisson-statistical tools have been developed, using a straightforward region-of-interest (ROI) approach, for the detection and quantification of signals in the analysis of low-count spectra. These tools provide improved accuracy over traditional Gaussian methods in both the quantitative evaluation and qualitative detection of small peaks. Formulae are derived for meaningfully estimating background and signal (net peak area) levels and their uncertainties, and for the evaluation of detection confidence. While these techniques are developed and presented here in the context of gamma spectroscopy, their applicability is quite general and can be extended to any radiation or particle detection scenario where Poisson statistics are expected to apply, including neutron, alpha and beta counting experiments.

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Time-interval Probability Analysis for Radiation Monitoring

Peng Luo, Clemson University
Timothy DeVol (L.G. Rich Environmental Research Lab)

Detection sensitivity using time-interval probability (TIP) analysis was compared with conventional counting statistical methods for radiation monitoring applications. TIP was determined using a DGF-4c (XIA, Inc) system in list mode to record the arrival time of individual pulses. The time between two pulses was recorded for fixed time intervals (~1-50 ms) to produce the time-interval probability distribution (histogram) that was subsequently analyzed. For purposes of illustration of TIP analysis, time interval probability distributions were recorded for a static and moving 90Sr source (~3700 Bq) and a static GM detector. For a stationary radioactive source, the experimental time-interval probability distribution correlates well with the theoretical distribution based on Poisson statistics. For a transient radiation signal above a relatively constant background TIP analysis was more sensitive than an a-priori analysis based on the "Currie Equation". TIP analysis is able to detect a small source from background quickly and effectively; TIP analysis has an ability to remove the negative effect due to the fluctuation of backgrounds; and thus holds promise as a more sensitive method for radiation monitoring. TIP analysis has potential applications in homeland security, environmental monitoring, and environmental process monitoring.

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Application of a Self-Multiplication Correction Method to a Neutron Coincidence Counter and Its Calibration for Spent Fuel

Tae-Hoo Lee, Korea Atomic Energy Research Institute

A neutron coincidence counter for the nuclear material measurement and control of the Advanced spent fuel Conditioning Process (ACP) has been developed by Korea Atomic Energy Research Institute (KAERI) since 2002. The most dominant neutron source among spontaneous fission nuclides contained in spent fuel is Cm-244 nuclide. To obtain the neutron counting rates of singles, doubles, and triples coincidence of the neutron counter with an increment of Cm-244 amount, active tests of the neutron counter were performed with several spent fuel rod-cuts in the ACP hot cell in July, 2007. The source term of spent fuel rod-cuts was obtained by using ORIGEN-ARP burnup simulation code and preliminary calibration curves of the neutron counter for the Cm-244 nuclide of spent fuel rod-cuts were generated. The calibration curves were also obtained from the results of MCNPX code simulation, but there is 10 to 20% difference in neutron count rates between measurements and MCNPX code simulation. This difference seems to originate from the uncertainty of source term analysis by using ORIGEN-ARP code. The overestimated Cm-244 mass obtained from ORIGEN-ARP simulation was corrected by a comparison with MCNPX simulation results. To correct the neutron multiplication of spent fuel rod-cuts, a self-multiplication correction method was applied to the neutron coincidence counter and corrected calibration curves were obtained. The calibration constants for a non-multiplying sample obtained by using the self-multiplication correction method are 2466 [Singles rate/mg of Cm-244] and 297 [Doubles rate/mg of

Cm-244] for singles and doubles rates, respectively. The differences between the calibration constant for a non-multiplying sample and the slope of calibration curve obtained by the MCNPX code simulation are 0.9% for singles rate and 3% for doubles rate. The differences between the calibration constant and the slope of calibration curve for self-multiplication correction are only 0.8% and 2% for singles and doubles rates, respectively. These results imply that the Cm-244 mass overestimated from ORIGEN-ARP code simulation can be rightly corrected with the self-multiplication correction method.

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Evaluation of Commercial Spectral Personal Radiation Detectors (SPRDs)

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M. Mayorov, M. Schrenk (IAEA); M. Swoboda (Atoiminstitute Vienna); K.D. Duftschmid (University Graz)

A new class of hand portable radiation detection devices is emerging on the market. They are not much larger than Personal Radiation Detectors (PRDs). According to the draft ANSI standard N42-48 and the requirements of users they combine features of a Personal Radiation Detector (PRD) -- automated operation with switching to radionuclide identification in case of a radiation alarm and the option to use them manually in a start/stop mode like an RID. They have several potential applications in homeland security, nuclear safeguards and emergency response: i.e., use by patrolling officers, border guards at the green border, combining both alarming with automated radionuclide identification or as a convenient small size, manual RID. Emergency responders and military may use them to assess dose rate and radionuclide in the field and security officers for covert estimation of dose rate and the radio nuclide that has caused it. Only a few devices are presently commercially available and some of them have been studied in this paper. One (the ICx/Thermo Interceptor) works with a large volume CZT detector for gross gamma search, combined with a much smaller spectrometric CZT detector for radionuclide identification. The second (MGP Instruments, Mirion technologies group, PDS 100GN/ID) device uses a CsI(Tl) detector, coupled to a small photomultiplier tube. A third device, RT-10, also with a CsI(Tl) crystal and a small photomultplier is produced by Georadis. All are relative small and compact and use internal processing for alarming and radionuclide identification. The evaluation started with a check of vendor provided specifications comparing them with measurement results and the ANSI N42-48 SPRD standard, based on radiometric studies in the Safeguards Instrumentation Laboratory (SIL) of the IAEA and in the JRC Ispra, using NORM, medical, industrial and nuclear radionuclide. Evaluation topics were:

* Static and dynamic gamma and neutron search capability at a given false alarm rate (FAR)
*Radionuclide identification including the capability of the devices to detect a threat isotope in presence of a masking medical radionuclide
*Graphical user Interface (GUI) and usability
* Data transfer to a notebook computer and post processing.

The results are being assessed and recommendations are given so support the further development of this new equipment type, which is due to its compactness and automated operation very attractive to users.
The purchase of Interceptor devices was supported by a German contribution to the IAEA Nuclear Securiry Fund. The Authors are grateful to Georadis and MGP Instruments - Mirion technologies group for the provision of evaluation units.

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Ottawa Valley Xe-133 Plume Modelling and Detection

Ed Korpach, Health Canada, Radiation Protection Bureau
Kurt Unger (Health Canada, Radiation Protection Bureau), Real d'Amours (Environment Canada, Canadian Meterological Centre)

Health Canada has set up a network of NaI detectors around Canadian nuclear power plants and facilities to monitor daily emissions of radionuclides and as in-situ monitors in the case of an emergency. Installed outdoors, these detectors monitor atmospheric radiation in real time and are especially sensitive to several of the noble gases, including Xe-133. One of the unique regions where these detectors are installed is in the area surrounding AECL's Chalk River Laboratories. This facility produces a large portion of the world's medical isotopes and regular operations include emissions of Xe-133. Although of negligible health impact, a combination of regular wind patterns and strategic placement of these sensitive NaI detectors allows multiple measurement of a plume of Xe-133 as it moves down the valley to Ottawa, approximately 180kms away. Environment Canada has developed Lagrangian dispersion models to predict the transport of plumes of particulate releases through the atmosphere. These modelling tools would be used in the case of a CBRN emergency and would assist emergency responders to determine the best course of action to ensure the safety of the public. Environment Canada has been using the NaI data as a tracer to validate the dispersion models. This ongoing comparison between actual measurement of emission and predictive modeling is done to improve the models and increase the confidence in them through these real world validations.

Radiation Sources
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Production of an Associated Particle Neutron Generator with ZnO:Ga Alpha-Detector

Steven Z. Kane, Purdue University
David S. Koltick, presenting
E. K. Mace (2K Corporation), M. Lvovsky (Lexel Imaging Systems, Inc), S. Z. Kane (Purdue University Physics Dept.)

An associated particle neutron generator (APNG) capable of 10^9 neutrons/second has been produced with an alpha particle detector made of ZnO:Ga phosphor with decay time of approximately 1 nanosecond. Fast 14 MeV neutrons and 3.5 MeV alpha particles are produced through a deuterium-tritium fusion reaction and travel in opposite directions to conserve linear momentum. The alpha particle transducer was found to yield a mean light output of 35 photoelectrons and a detection efficiency of 94%, using a bialkali photocathode. The neutron generator provides high rate capability, excellent nanosecond time resolution, and a large solid-angle with acceptance of 8%. Using a NaI detector to measure the return gamma ray spectrum, a significant reduction in the signal to noise ratio is found. The noise reduction is presented as a function of the generator's neutron production. The possibility of using the noise reduction capability of the APNG to search cargo for special nuclear materials (SNM) is discussed. The detection of the prompt fission gamma rays in coincidence with the segmented alpha detector signal from the APNG can greatly suppress backgrounds and help locate special nuclear materials within a container.

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Development of a RF-driven Neutron Generator for Associated Particle Imaging

Ying Wu, Lawrence Berkeley National Laboratory (LBNL)
Ka-Ngo Leung, Joe Kwan, Qing Ji (LBNL)

We present recent work in the development of a compact, D-T neutron generator for the application of associated particle imaging (API) used in explosive and contraband detection. The key in API is the use of the alpha particles produced in conjunction with the 14 MeV neutrons to locate the neutron interaction and reduce background noise. To achieve good API spatial resolution, a very small beam spot at the target (1-mm in diameter or less) is required. For portable neutron generators used in API, the ion source and target cannot be water-cooled, thus, the power deposited on the target must be low. By increasing the atomic ion fraction, the beam can be more efficiently used to generate neutrons, leading to an overall lower beam power requirement as well as having the effect of increasing the lifetime of the alpha detector inside the acceleration column. The rf ion source can produce very high atomic ion fractions (over 90%) as compared with traditional penning ion sources used in neutron generators, which produce less than 10%

atomic ions. The rf ion source presently being developed at Lawrence Berkeley National Laboratory (LBNL) for API differs from previous rf sources in that it requires much lower power (~100) to reach high atomic ion fraction. Using a quartz source chamber with a diameter to length ratio of 1:3 and a planar spiral antenna with 20 multicusp magnets surrounding the chamber, atomic fractions of over 80% can be achieved at powers as low as 100 watts. Experimental results in measuring the plasma parameters of the ion source such as the ion current density, atomic ion fraction, ignition and operating pressure, and electron temperature will be presented in the conference, as well as a discussion on lifetime issues of the alpha detector inside the acceleration column.

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Compact Portable Microwave-driven Neutron Generator

Qing Ji, Lawrence Berkeley National Laboratory (LBNL)
Ying Wu, Mark Regis, Joe W. Kwan (LBNL)

A portable, moderate yield D-D neutron generator is being developed at Lawrence Berkeley National Laboratory for applications such as short range SNM detection in suitcases and small parcels. For developing a field portable sealed D-D neutron generators, the key element is the ion source. Conventional RF driven ion sources that have been widely used in the neutron generators developed at LBNL so far, require fairly high pressure to start the plasma. This is not an ideal situation for applications in sealed tubes that lack vacuum pumping to keep the pressure low in the high voltage (ion beam acceleration) region. A compact permanent-magnet microwave plasma source currently under development is capable of providing modest ion beam current reliably for long time with low operating pressure and with low power consumption. Microwave power (2.45 GHz) can be coupled to a pyrex tube through a standard wave guide and generate plasma. In this source configuration, the wave guide serves as a secondary containment for sealed tube design. We have successfully ignited hydrogen plasma in the pyrex tube at a microwave power of 200 W and hydrogen pressure of 8 mTorr. We can also directly couple the 2.45GHz microwave signal to the wave guide through a standard coaxial cable with a N-type connections. In this case, plasma is generated in the wave guide. Preliminary results show that over 80% of molecular hydrogen ions were generated at a microwave power of 300W and hydrogen pressure of less than 2 mTorr. We expect to achieve higher atomic fractions upon further optimization. Experiments with different length of wave guides and with or without boron nitride liner will be carried out. The results of mass spectrum and current density measurements will be presented in the conference. This work is supported by NA-22 of NNSA under the Department of Energy contract No. DE-AC02-05CH11231.

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Measurement of the Neutron Yield of DD and DT Neutron Generators

David Chichester, Idaho National Laboratory (INL)
E. H. Seabury, A. J. Caffrey (INL)

Measurements have been performed to assess the yield of commercial deuterium-deuterium (DD) and deuterium-tritium (DT) electronic neutron generators, using indium foil activation to assess DD yields and copper foil activation to assess DT yields. A modified version of the "Texas Convention," using a high performance Ge spectrometer in place of a NaI scintillator, was the basis for the DT measurements. In addition, variations in the neutron yield of these devices have been determined in relation to the devices beam current and accelerating high voltage settings through the use of a ZnS doped plastic scintillator serving as a relative neutron flux monitor. These yield results are in agreement with previously published data on the subject and with the manufacturers quoted specifications to within the uncertainty of the measurements. An analysis of the devices pulse shape characteristics has also been carried out under several different timing sequences between 100 and 10,000 Hz.

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Ultra-compact Field Desorption Neutron Source

Ying Wu, Lawrence Berkeley National Laboratory (LBNL)
Lili Ji, Qing Ji (LBNL)

For the most common cancers occurring in men and women (prostate and breast cancer) definitive and/or post-operative radiotherapy are a mainstay of treatment. Unfortunately, the cost of building huge neutron machines and the inability to precisely control the delivery has hampered the widespread adoption of neutron based radiotherapy. Using a neutron generator which is small enough to be handheld and can be turned on and off would help to eliminate the use of radioactive sources. A proof-of-principle ultra-compact, field-desorption neutron generator is being investigated. This source utilizes microscale tungsten "needle-tips" and high electric fields applied to the sharp points to desorb and ionize surface atoms, e.g. gas atoms, which have adsorbed into the metal tip surface. The device can be preloaded with deuterium gas, tritium gas, or a mixture of both gases depending on the desired neutron energy and spectrum. For the case of the D-D reaction, the D+ atomic deuterium ions are produced via electrostatic field desorption of deuterium that is adsorbed from the gas onto the surface of the tungsten coated field emitter tips. When a voltage is applied between the tips and the gate electrode, an electric field is applied to the tips. When the field is high enough, the gas atom becomes ionized and ejected away from the metal surface. The field strength needed for field desorption is in the range of 10-40 V/nm. The neutrons can be produced on-demand by turning the high voltage on and off, thus eliminating excessive shielding needed when the source is not operational. The process flow for fabricating the field desorption tips has been developed. A testing device has been constructed for neutron yield measurement. The results will be presented in the conference.

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Development of a D-D Neutron Generator Using a Titanium Drive-in Target

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In spite of a smaller cross-section, the D-D reaction has some advantages over the D-T reaction for neutron generation. Tritium contamination is a major source of radioactive waste in a D-T neutron generator, which requires very careful handling. Alternatively, a D-D neutron generator is nearly free from tritium contamination, since only a small amount of tritium is produced by the D(d,p)T reaction. D-D neutron is more easily moderated to thermal neutron and requires less radiation protection shield, since the energy of a D-D neutron is only about 1/6 of that of a D-T neutron. In addition, the drive-in target in a D-D neutron generator is continuously loaded with the incident deuteron even though the concentration is balanced by a loss mechanism during the beam exposure. Hence the effort of preparing for a target pre-loaded with deuterium can be saved. By taking these familiar facts into consideration, a D-D neutron generator was developed with an intensity of 10^8 n/s using a titanium drive-in target [1]. A helicon plasma ion source was used to produce large current deuteron beam, which once had achieved large current proton beam of 50 mA at 34 kV and an additional one with a high monatomic fraction of 94% [2]. Titanium drive-in targets were made of pure, commercial grade II titanium, which were fabricated by lathe cutting. Neutron generation rate was measured by counting protons from the D(d,p)T reaction using a Si detector [3]. When the neutron generator was assembled, the deuteron beam within a current range of 0.8 - 8 mA was available and the beam could be accelerated up to 97.5 keV. The maximum rate in the test-run was 1.9x10^8 n/s, which was achieved by irradiating a 7.6 mA deuteron beam on the target at 94.0 keV. And the operation of the neutron generator was fairly stable, such that the neutron generation rate was not seriously altered by high voltage breakdowns. However the neutron generation efficiency was rated as low as 10% compared to an idealistic case of irradiating 100% monatomic deuteron beam on a perfect TiD_2 target. The factors causing the low efficiency will be discussed.

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A New Method of Tunable Gamma-ray with a Fixed Energy Electron Beam

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Tunable quasi-monochromatic gamma-ray from the Compton backscattering of the laser beam with an electron beam circulating a storage ring is attractive source for the nuclear science. Since the storage ring is mostly operated with fixed electron energy, however, methods for tuning the gamma-ray energy should be investigated. As well known, the

energy of the Compton backscattering gamma-ray is determined by the scattering angle of the gamma-ray. We propose a new method (collimator-absorber method) to generate tunable gamma-rays by selecting the scattering angle of the Compton backscattered gamma-ray using a collimator and an absorber. The collimator defines the low cut-off energy of the Compton backscattering gamma-ray beam. On the other hand, the absorber which is placed at the 0 degree scattering angle, high energy part of the gamma-ray will be absorbed. Therefore a tunable gamma-ray can be obtained by changing the solid angle of the collimator and absorber. A proof of principle experiment has been performed at the laser-Compton gamma-ray facility in AIST. We used a collimator with 8 mm in diameter placed 6.2 m behind the laser-electron colliding region. An 8 mm dia. x 10 cm lead absorber was located at 4-5 m downstream. The experimental result showed that the collimator-absorber method could generate tunable gamma-rays. The energy spread of the tunable gamma-ray beam was about 25% and the gamma-ray yield was -20% of the Compton backscattering gamma-ray beam. Numerical simulations based on the EGS4 well reproduced these experimental results. We found that the broad energy spread was mainly due to the beam emittance of the electron beam.
This work was supported by Grant-in-Aid for Scientific Research from the Ministry of Education, Culture, Sports, Science and Technology #19540289.

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A 12 MeV Gamma Source for Active Interrogation

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Mono-energetic gamma sources are sought for active interrogation systems that detect special nuclear materials in, for example, cargo containers, trucks and other vehicles. The advantage of such sources over available bremsstrahlung sources is a much lower radiation dose to the cargo. Mono-energetic gamma sources avoid the high flux of photons with energies below the fission threshold that is part of a bremsstrahlung spectrum with its exponential falloff. We utilize the 11B(p,g)12C reaction to produce 12 MeV gamma-rays that are close in energy to the peak of the HEU photo-fission cross section. A resonance at 163 keV allows the production of gammas at low proton acceleration voltages, thus keeping the gamma generator comparatively small and simple. A coaxial design has been adopted with a toroidal-shaped plasma chamber surrounding a cylindrical gamma production target. The plasma discharge is driven by a 50 kW, 2 MHz rf-power supply. The rf-power is coupled into the plasma by a circular rf-antenna consisting of a conductor inside a water-cooled quartz tube. Permanent magnets embedded in the walls of the plasma chamber generate a multi-cusp field that confines the plasma and allows operation at higher plasma densities and lower gas pressures. About 100 beamlets are extracted through a slotted plasma electrode that is ~50% transparent towards the target at the center of the device. The plasma chamber is at ground potential and a negative 180 kV voltage is applied to the target for accelerating the protons beams towards the target. The target consists of LaB6 tiles that are brazed to a water-cooled cylindrical structure. The beam is pulsed at 500 Hz with 20 micro-sec long pulses, and a 1% duty factor by pulsing the ion sources rf-power. The time-averaged

beam current is 1 A. A first version of the gamma source has been built for low duty factor experiments and testing. The design of the device and first test results will be presented.

Work supported by the Department of Homeland Security's Domestic Nuclear Detection Office under Award No. CFP06-TA02-SL11. Work performed by Sandia National Laboratories operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000 and by Lawrence Berkeley National Laboratory under Department of Energy contract number DE-AC02-05CH11231.

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Numerical Simulations of Pillar Structured Solid State Thermal Neutron Detector

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This work reports numerical simulations of a novel three, dimensionally integrated, B-10 and silicon p+, intrinsic, n+ (PIN) diode micropillar array for thermal neutron detection [1-2]. The inter-digitated device structure has a high probability of interaction between the Si PIN pillars and the charged particles (alpha and Li-7) created from the neutron - B-10 reaction. In this work, the effect of pillar height, applied voltage and discriminator value on thermal neutron detection efficiency, charge transit time and neutron to gamma discrimination are investigated via simulation. The simulation results are shown to agree with measurement results. To calculate the efficiency of thermal neutron detection, three dimensional numerical simulations were performed. Monte Carlo N Particle transport code (MCNP) [3] was used to calculate the neutron interaction histories within the pillar array. Stopping Range of Ions in Matter (SRIM) [4] code was then used to calculate the amount of energy lost by the ionized alpha and Li-7 particles in the B-10 portion of the detector, as well as the amount of energy deposited in the Si pillars. Silvaco's Atlas was then used to calculate the transport of the electrons and holes generated by the alpha and Li-7 particles in the Si diode portion of the detector. In this work the simulated pillar geometry had a diameter of 2 microns, a pitch of 4 microns and the height was varied between 10 microns and 100 microns. To calculate the detection efficiency, the number of interaction events that result in a collected energy above a minimum threshold was divided by the total number of neutrons incident on the detector. Detectors with 10 microns, 20 microns, 50 microns, and 100 microns tall pillars were calculated to have intrinsic efficiencies of 7.5%, 23%, 50%, and 70% respectively at a discriminator value of 100 keV. This is in good agreement with the measured efficiency of 7 % for a 12 microns tall pillar at -2 V [2].

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This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344. LLNL-ABS-401440

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Application of GEANT4 to the Simulation of Microcalorimeter Detectors

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GEANT4 is a versatile Monte Carlo code for simulating the interactions of radiation with matter. GEANT4 has proven to be an effective toolkit for the simulation of a wide variety of detectors. We are interested in studying the application of GEANT4 to a new type of sensor technology for X-ray and gamma-ray measurements. Microcalorimeter detectors based on transition-edge sensors coupled to bulk absorbers are an emerging technology for hard X-ray and soft gamma-ray measurements. Recent results from a microcalorimeter array have demonstrated energy resolution as low as 22 eV FWHM at 100 keV incident energy for the best sensor, and 45 eV FWHM for the combined resolution of an 11 pixel array. As microcalorimeter array technology matures, the use of simulation tools will become increasingly important. There are several applications for simulations, including assessment of the technology for specific measurement scenarios, guidance in the design of the detectors and cryostat, and interpretation of measured data. For cryogenic microcalorimeter detectors, the measurement of photon energy relies on the collection of heat deposited by the photon in the bulk absorber. This process differs from more conventional photon detectors using scintillators (light collection) or solid state technology (charge collection). While the GEANT4 Monte Carlo code has been proven quite capable of accurately reproducing observed data from these conventional detectors, we are interested in studying whether it can also reproduce the response of our microcalorimeter sensors in the hard X-ray and soft gamma-ray regime. Our approach uses the electromagnetic physics interactions of GEANT4, and assumes that all deposited photon energy in the sensor is converted to heat and collected. We present comparisons between measured and simulated microcalorimeter data, to assess the effectiveness of GEANT4 simulations for this emerging technology. We also use the simulations to explore the design space of absorber materials and cryostat designs.

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Increasing Detection Sensitivity within Compton Imaging Systems using Model-Based Signal Decomposition Methods

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Position sensitive, high-purity germanium (HPGe) planar orthogonal strip detectors are currently being used for an increasing number of Compton gamma-ray imaging applications where high efficiency is required. This research involved the investigation of detection sensitivity using Compton imaging with thick high-purity germanium double-sided strip detectors with a strip pitch of 2mm. Compton imaging requires the ability of the detector system to determine the position and deposition energy of multiple interaction sites resulting from both incoherent scattering and photoelectric events. In the germanium detector, there is a high probability that multiple interactions occur within a mean distance of approximately 5mm. Interactions that occur in such close proximity tend to induce current in the same set of electrodes and therefore the resulting signals exhibit composite features. In these cases, first-order position algorithms that have been developed for isolated interactions are unreliable. An event selection criterion is normally used to ensure that imaged event sequences have a minimum separation distance of 8-10mm, however, this leads to a major loss mechanism with respect to imaging efficiency. To address these composite signals, this research applied advanced charge transport models for the drift and charge spreading processes for secondary charge carriers within the detector in order to compute a set of electrode signal pulse shapes. These signals are correlated to discrete interaction positions and deposition energies and can be used as a basis set for the detector response. An inversion algorithm has successfully been implemented that can decompose multiple interactions with a minimum separation distance of ~2mm. Scanning experiments have been performed using a collimated fan beam that has shown in a spatial uncertainty for isolated interactions of ~400 um. This increase in spatial resolution results in a much-improved angular resolution within the gamma-ray image. In addition, a measurement using a bare Cs-137 point source in the far field has shown nearly a 3-fold increase in imaging efficiency for 662 keV incident gamma-ray energies by allowing the decomposition of multiple events with separation distances down to 2mm. In this case the analysis of detection efficiency, which combines the effects on angular resolution and imaging efficiency, was shown to increase by 30-40%.

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RadSrc: Calculating Gamma-ray Signatures from Aged Mixtures of Heavy Nuclides

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The intrinsic source spectra for heavy nuclides are extremely complex and often the daughter products in the decay series dominate. Calculating the correct intrinsic source spectrum requires determining the precise isotopic composition of the particular mixture, which changes over time, and identifying the complete decay chains and lifetimes for all of the daughter nuclei. We have created and distributed a free, open-source software package that calculates the intrinsic gamma-ray spectrum from the nuclear decay of a mixture of radioisotopes. It implements the Bateman solution of the standard equations of radioactive-series growth and decay to determine isotope concentrations, at a user selectable age, and processes a database of decay energy lines to generate gamma-ray intensities from all decay chains. We provide an interactive program for studying complete spectra, a function library (callable from C, C++, and Fortran), and interfaces to popular Monte Carlo transport codes (MCNP, MCNPX, Geant4, and COG) so that the gamma rays can be sampled and tracked directly by the parent code. The RadSrc suite is open source and can be downloaded from http://nuclear.llnl.gov/simulation.

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Positive SNM Gamma Detection Achieved through Synthetic Enhancement of Sodium Iodide Detectors

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In the past decade, a number of researchers have worked towards improving poorly resolved spectra from room temperature scintillators with some success. In this paper, we present a significant leap forward in progress with our post-processing algorithm, ASEDRA (Advanced Synthetically Enhanced Detector Resolution Algorithm). ASEDRA has been designed to post-process scintillator detector spectra to enable photopeaks to be detected with high accuracy, even in the presence of convoluted sources. All current work with ASEDRA has focused on post-processing sodium iodide (NaI(Tl)) scintillator pulse height spectra to synthetically augment the spectrum to enable photopeak identification at a level consistent with detectors operating at approximately one percent inherent resolution, depending on the application. Post-processing with ASEDRA requires a few seconds on a standard laptop, without prior knowledge of any specific spectrum components, and gamma ray lines are extracted with high accuracy. Typically, photopeaks are identified to within a percent or less (with good statistics) of their true photopeak energies, even for completely convoluted, complex spectra. The multi-step processing methodology in ASEDRA will be presented in the full paper applied to SNM sources, demonstrating that post-processed NaI(Tl) detector output from ASEDRA is directly comparable with the resolved spectra from high resolution nitrogen cooled semiconductor detectors (HPGe). METHODOLOGY: ASEDRA incorporates a multi-step sweep procedure to extract photopeaks; it begins with an initial novel denoising algorithm based on an adaptive Chi-square metric called ACHIP to remove stochastic noise from low count spectra, and preserve fine detail. Then, sweeping initially from the high energy end of the spectrum, a novel detector response algorithm is applied using Detector Response Functions (DRFs), derived from high resolution, pre-computed Monte Carlo transport computations. DRFs are applied through scaling to sequentially strip and deconvolve the complete spectrum attributed to identified photopeaks, revealing new features in the detector spectrum. This process is repeated until the residual spectrum no longer contains peaks that meet the criteria for DRF attribution. Side by side tests of a 2 x 2 inch NaI(Tl) detector spectrum post-processed by ASEDRA using an identical source and geometry setup with a HPGe detector will be presented to demonstrate that the methodology in ASEDRA is highly accurate and effective. In addition to trivial "check" scenarios with simple sources, such as validations with Co-60 and Cs-137, ASEDRA results with more complex sources, including SNM will be presented. Side by side tests with NaI(Tl)-ASEDRA and HPGe using 152Eu, unshielded and shielded weapons grade plutonium, as well as natural uranium will be presented to demonstrate the excellent performance achievable using ASEDRA to render accurate and detailed gamma ray signatures with sodium iodide, even in the case of a very complex SNM spectrum. CONCLUSIONS: Based on detailed testing, presented results will demonstrate that the ASEDRA software tool with ACHIP noise removal enhances photopeak identification in NaI(Tl) spectra competitive with detectors yielding ~one percent inherent resolution. Finally, the methodology employed in ASEDRA could be applied to spectra collected by

other detector materials. Overall, we expect our approach could dramatically impact current applications of scintillator detectors.

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A Novel Approach to assess the Spatial Resolution of Position Sensitive Detectors equipping 2D Neutron Tomographic Systems

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Tomographic systems have their performance deeply affected by the finite spatial resolution of the detectors equipping them, as it precludes the reproduction of sharp edges and the separation of close features. The poorer the detector resolution, the stronger would be the image degradation, and hence, it is a rough qualitative measure of that resolution. As other spoiling agents, such as electronic noise, statistical fluctuation and beam divergence also play significant roles in the process, the contribution of the detector resolution itself is overwhelmed by them, making thus difficult to assess its single impact. This assessment is nevertheless very important, as it allows to forecast - by using of a proper simulator - the potential improvement of the image quality achievable by a better detector resolution. Some techniques to measure the detector resolution require the determination of the Line Spread Function (LSF), whose full width at half maximum (FWHM) expresses the detector resolution. Since this function is somewhat difficult and cumbersome to be directly experimentally measured, it is rather replaced by a Gaussian fit of the derivative of the Edge response Function, which is much easier to obtain. This paper presents a new method to determine the detector resolution, as a by-product of an image processing employing an unfolding of the convoluted position spectra (used as projections to recover the image), and a Gaussian - of unknown width - representing the detector's LSF. A deconvolution undertaken with a LSF narrower than the actual detector resolution would not correct properly the degradation caused by it, while a broader one would overcorrect its spoiling effect, yielding images exhibiting an apparent better separation power. However, this illusive improvement is achieved due to a violation of the aspect ratio of the image features, as ratified by a properly tailored test-object. Therefore, a plot of the measured aspect ratio against the LSF width used in the deconvolution yields a curve, which furnishes the detector resolution at the point given by the known aspect ratio of a rectangular insert in the test-object. The algorithm employed to perform the deconvolution has been written in Fortran language, being capable to deal with experimentally acquired position spectra, as well as to generate them in order to simulate detectors of different resolutions. It has been applied to measure the resolution of a position sensitive detector equipping a 2D neutron tomographic system, and the results were compared with other conventional techniques. KEYWORDS: Detector Resolution; Neutron Tomography; Position Sensitive Detector; Image Improvement.

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Computer-Aided Detection of Solitary Pulmonary Nodules on MDCT Images with One-Dimensional Morphologic Matching Algorithm

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Lung cancer continues to rank as the leading cause of cancer-related death around the world. The computer-aided detection (CAD) of suspicious regions in CT lung images can be a helpful technique to diagnose lung cancer. In this study, a novel CAD algorithm for the detection of solitary pulmonary nodules (SPN) with one-dimensional morphologic matching analysis will be suggested. Our CAD algorithm is the faster and more effective algorithm than 2-D or 3-D based morphologic matching algorithm. Our CAD algorithm begins by automatically segmenting the thorax and lung region from the CT images. A gray-level thersholding method is applied to the lung-segmented image with a fixed attenuation threshold (-300 HU). Each connected soft-tissue object within the lung region is segmented and labeled. Each connected two-dimensional soft-tissue object is separatelly projected onto the x- and y-axis. The one-dimenional projections of the ideal circle are also calculated as the gold standard. Then, the covariance values of test object and gold standard are acquired for the evaluation of morphorogic similarity between them. The decision criteria of covariance is 0.77. There are 75 nodules in tested 43 cases, and 130 nodule canidates are found out by our CAD algorithm. Resultly, the 68 nodules are discovered among the candidates (sensitivity = 91%) and 62 tissue objects are misunderstanded as lung nodule (1.4 per case). Two- or three-dimensional based algorithms are genealy complicated and require much running-time. The novel algorithm using one-dimensional morphologic matching analysis can be a simple and effective method for lung nodule detection.

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Validation of GEANT4 Electromagnetic Physics Models for the Evaluation of Proton Computerized Tomography

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Proton computed tomography (pCT) is a promising alternative to conventional x-ray CT for advanced proton treatment planning at the growing number of proton therapy centers. High Energy Physics (HEP) solutions for pCT, including calorimetric measurements, tracking techniques, etc., are likely to be implemented in pCT systems. As shown in recent years, the Geant4 Simulation Toolkit is a useful tool for pCT modeling. GEANT4 provides a large set of physics models describing electromagnetic interactions of protons with matter, but it is currently not clear how accurate these models reproduce low energy proton spectra seen in pCT. This work presents final proton energy spectra of protons passing trough a polyethylene target obtained with GEANT4.6.2 and GEANT4.8.2 using

ICRU-49 and Ziegler-2000 hadron models. A comparison was made with experimental proton data, spectra obtained by solving the Fokker-Plank transport equation, and SRIM2006 simulations. A statistical analysis was performed to quantitatively estimate the compatibility of the Geant4 electromagnetic models with the experimental data. The statistical analysis also highlights the respective strengths of the different Geant4 models. Work supported by the Brazilian agencies CNPq, CAPES and Fundacao Araucaria.

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Theoretical Study of Proton-Nucleus Interactions via Monte Carlo Multicollisional Intranuclear Cascade Model Plus Evaporation/Fragmentation Processes in 28Si

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In the last years have been increasing the efforts in order to develop more effective models to describe and predict the effects induced by radiation in electronic devices. In this sense, the interaction of protons with those devices, particularly which operate in space, is a topic of paramount relevance. It is important to note that, although the majority of them are mainly made with silicon, experimental data on p+Si nuclear processes is very sparse. In this work we have used a quite sophisticate Monte Carlo multicollisional intranuclear cascade code for pre-equilibrium emission, plus de-excitation of residual nucleus by two ways: evaporation of particles (mainly nucleons, but also composites) and possibly fragmentation/fission in the case of heavy residues, in order to study some observable of nuclear interaction of protons between 100-200 MeV in a 28Si target. The code was developed in our group, with very recently improvements that take into account Pauli-blocking effects in a novel and more precise way, as well as a more rigorous energy balance, an energy stopping time criterion for pre-equilibrium emission and the inclusion of deuteron, triton and 3He emissions in the evaporation step, which eventually concurs with fragmentation/break-up stage. The fragment mass distributions, as well as the multiplicities and the spectra of secondary particles, are shown as preliminary results and compared with previous ones reported for that nucleus in this energy range.

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Extended Radiation Source Imaging with the Prototype Compton Imager

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We have constructed a prototype Compton imager (PCI) which consists of three planes of silicon pixel detectors as a scattering detector followed by an array of CsI(Tl) crystals as an absorbing detector. The CsI(Tl) array is mounted directly behind the silicon detectors. The relative alignment and spacing of the silicon detectors and CsI array is adjustable. We will show images of multiple point and extended sources from the PCI (and from

simulations of the PCI). Simple back-projection algorithms are not sufficient to resolve extended shapes, but iterative algorithms provide the necessary deconvolution. Maximum Likelihood Expectation Maximization (MLEM) is an iterative algorithm that reconstructs the most probable source distribution for a given data set. MLEM attempts to reconstruct the true source distribution by finding successive approximations starting from an initial guess. We use back-projected images as an initial guess. Each data set imaged is different, but the number of iterations required to resolve an image is typically 10 to 20.

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Hyperspectral Imaging with Wavelet Transform for Colon Tissue Biopsy Samples

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Hyperspecral Images contain rich and fine spectral information for human colon biopsies on a tissue micro-array. The prototype tuned light source generates combinations of visible light at 128 different wavelengths. These transilluminate the samples, passing through a Nikon Biophot microscope and into a CCD camera with 400X magnification. Dimensionality reduction and segmentation is achieved using Daubechies-4 wavelet filters. Wavelet textural features are extracted for classification of the hyperspectral data. Features are based on the idea that development of Colon camcer alters the macroarchitecture of the tissue glands. We investigate the effect of the wavelet textural features on the classification accuracy for benign and malignant classes. Experimantal results indicate that the incorporation of wavelet textural features with gaussian kernel support vector machine lables the two classes with reasonable accuracy.

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GEANT4 Simulation of a Cosmic Ray Muon Tomography System with Micro-Pattern Gas Detectors for the Detection of High Z Materials

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High-Z material such as Uranium or Plutonium could be smuggled across international borders by carefully shielding the emanating radiation inside other material such as lead to keep them undetected by standard radiation detection techniques. Muon Tomography (MT) based on the measurement of multiple scattering of atmospheric cosmic ray muons traversing shipping containers is an excellent candidate for identifying threatening high-Z material. The MT technique uses tracking and scattering angle information of charged particles traversing cargo to discriminate high-Z from low-Z and medium-Z material. Since position-sensitive detectors with high spatial resolution should be particularly suited to identify and locate possible threat material hidden in a cargo container via MT, we propose to use compact Gas Electron Multiplier (GEM) detectors as tracking detectors for a Muon Tomography System (MTS). We present a detailed GEANT4 simulation of a GEM-based MTS for various scenarios of threat material detection. We report preliminary analysis results on the achievable Z-discrimination power, effects of placement of high Z material and shielding material inside the cargo, and detector resolution effects. We discuss the reconstruction of the cosmic ray muon tracks crossing the material with a simple Point-Of-Closest-Approach (POCA) algorithm to form 3D tomographic images of the Z material.

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The Atomistic Simulation of Thermal Diffusion and Coulomb Drift in Semiconductor Detectors

Manhee Jeong, University of Michigan

In order to enhance the imaging resolution of gamma cameras over standard Compton camera and coded aperture designs, one can add momentum information to the kinematics by tracking the recoil electron that result from gamma-ray interactions. The initial direction of the recoil electron can be discerned from its meandering trajectory, as measured via the initial electron-hole charges' spatial distribution, which itself is extracted by measuring the induced current signal on the bounding electrodes of the detector. The extraction of the recoil electron direction is ultimately limited by those stochastic effects that significantly contribute to the charge motion; most notably, thermal diffusion. We model diffusion using two techniques, one found in the literature and based on the diffusion coefficient, the other based on the underlying physics in which the probability density function describing the random thermal motion is sampled to determine the random contribution to each charge's motion, which depends on its drift state as well as the surrounding crystallographic environment. As is shown, the effect of diffusion is always significant, but its effect can be mitigated if the charges are drifting with alacrity. Coulomb drift, which refers to the dynamic charge motion due to the electromagnetic forces of the space charge created during the radiation event, is usually neglected; however, it can also be important for highly ionizing particles. We thus quantify the effect of Coulomb drift and suggest methods by which its effect can be extracted.

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RADMAP, An Imaging System for Gamma-ray Mapping and Density Profiling

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The radiation and density modulation apertures (RADMAP) research project is carrying out an investigation at PNNL to develop a detection system that can simultaneously collect gamma radiation and object density information to create sophisticated images capable of revealing complicated source and non-source arrangements. Early design, performance results, and algorithm developments are presented. Modeling results and preliminary measurements taken with a laboratory prototype are presented. Details on the projected performance of a field system under construction are presented.

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Robust Optimization Techniques for Respiratory Motion Registration

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Use of dual-modal imaging techniques are quite common in today's medical imaging techniques. Although such techniques provide better diagnosis and accurately understand disease progressions because of scan time artifacts can be caused due to non-voluntary movements of the patient such as breathing. Although, literature has proposed methods such as gating or breath-holding, when obtaining a SPECT/CT or PET/CT scan such methods can be quite traumatizing to the patient. Hence, this research work is based mainly on respiratory motion correction in SEPCT/CT images. This paper however will describe an efficient optimization method for registering the scattered points. Firstly, CT data sets of the thorax generated by the NCAT phantom were used for obtaining surfaces of the lung. Secondly, these surfaces were then used for registering using rigid registration technique. In order to minimize the energy function and optimize Brent's method was used to obtain the resulting images.

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On the Benefits of Partitioning Detector Elements in Large-Area NaI(Tl)-Based Detection Systems

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Localizing gamma-ray interaction positions can allow Compton imaging in sophisticated systems, or simple coincidence or anticoincidence gating in simpler systems. For many gamma-ray detection applications, imaging systems are far too complex, and sodium iodide (NaI) scintillators are frequently used because they provide a practical combination of detection efficiency, energy resolution, and cost. This study assesses the potential benefits gleaned from partitioning a large-area NaI(Tl) detector into multiple smaller NaI(Tl) crystals, in the spirit of balancing interaction location sensitivity with a desire to keep the number of readout channels small in number. This parametric study relies heavily upon Monte Carlo simulations, although experimental verification of results will be presented when practical.

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Compton Imaging Using 3-Dimensional List-Mode Maximum Likelihood Expectation Maximizaton (3DMLEM)

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Compton imaging is a gamma ray imaging technique that has possible applications in radioactive material detection and the medical imaging industry. Compton imaging can localize the origin of a scattered gamma ray photon to a cone using a minimum of two position and energy measurements. In traditional 2-dimensional Compton imaging, the projected cone of each measured event is scribed on a plane at a set distance in space. In real world applications the source-to-detector distance is not always known a priori, therefore a method for determining the intersection plane is needed. Maximum likelihood expectation maximization (MLEM) is an iterative statistical algorithm that makes successive approximations to the most probable source distribution that would have led to the observed data. Conventional MLEM is performed in two dimensions, which still requires knowledge of the source-to-detector distance. We propose integration over all three spatial dimensions in order to maximize the probability in 3-space. Although 3-dimensional projection of events is computationally intensive, a reduction in computation time can be achieved by coarse binning of the image space. While the image space is binned more coarsely, the voxel size must remain on the order of the known uncertainty of the detector. The 2DMLEM algorithm requires the number of event sequences to exceed the number of pixels in the image in order to assure convergence, therefore the 3DMLEM algorithm will require more events. Images reconstructed with the 3DMLEM algorithm for point and extended sources will be shown. These reconstructed images will come from both simulations and data taken with the Los Alamos National Laboratory Prototype Compton Imager (PCI) which has three planes of silicon pixel detectors followed by a 42-element CsI absorber plane.

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Contextually Aware Nuclear Evaluation System

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Significant effort is underway throughout industry, academia and the federal laboratory system to develop systems capable of detecting the illicit importation of a nuclear weapon, special nuclear materials (SNM) or a radiological device. To increase system sensitivity, most of the focus has been devoted to improving detector performance (e.g., increasing detection efficiency or improving spectral resolution). Another approach, though, is to better utilize the existing hardware systems by folding contextual information (e.g., manifest information) into the analysis of the detector data. We are currently performing research in this area to exploit this untapped potential. Funded by the Department of Homeland Security, we are developing a contextually aware nuclear evaluation system (CANES) based on machine learning (ML) algorithms that are trained through repeated exposure to sample incidents and are subsequently able to return an assessment (classification) of a new incident. We present here the overall system design including data inputs, feature vector extraction, and system operation. We will show how the system is optimized to ingest domain expertise directly from nuclear analysts to provide both decision support assistance and complete analysis.

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Few-View Projection Reconstruction with the Iterative Reconstruction-Reprojection Algorithm and TV Constraint

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In applications of tomographic imaging, insufficient data problems can take various forms, such as few-view projection imaging, which enable rapid scanning with lower X-ray dose. In this work, an iterative reconstruction-reprojection (IRR) algorithm with total variation (TV) constraint is developed for few-view projections. IRR algorithm estimates the missing projection data by iterative extrapolation between projection and image space. TV minimization is a popular image restoration method with edge preserving. In recent study, it has been successfully used for reconstructing images from sparse samplings, such as few-view projections. Our method is derived from this work. The combination of IRR and TV achieves both estimation in projection space and regularization in image space, which may accelerate the convergence of the iterations. To improve the quality of the image reconstructed from few-view fan-beam projections, a short-scan type IRR is also approached to reduce the redundancy of projection data. Numerical simulations show that the IRR-TV algorithm is an effective algorithm for the few-view problem with sparse-gradient images.
This work is supported by National Natural Science Foundation of China (No. 10575059, No. 60772051), and National Natural Science Foundation of China for Young Scholars (No. 10605015).

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Design of a Hybrid Gamma-Camera with LaBr3

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An imaging and spectroscopy system of gamma-ray is designed that hybrids the imaging methods of Compton and coded aperture cameras. This design is flexible and able to be optimized in angular resolution and efficiency based according to the requirements of particular applications. This imaging system is numerically modeled to allow exploring the relationship between the efficiency and angular resolution for various geometries and configurations without time-consuming process of Monte Carlo simulation. This system has a configuration of two layers. The top layer serves as primary scattering layer that composes of an array of detectors with thinner LaBr3 crystals to enhance single Compton scattering than that in the detectors of the second layer that service as absorbing layer and resolves the shading patterns of the detectors in the first layer. The coded aperture imaging approach is proper for photons below 500 keV energy while Compton imaging approach is excellent for photons above 500 keV energy. The imaging performance of the hybrid imaging system is evaluated with Monte Carlo simulation where events of one hit and two hits are generated. The events of one hit are utilized to reconstruct image with coded aperture approach while the events of two hits are used in Compton imaging approach. The image reconstruction algorithms of direct and filtered back-projections are developed for instant or real time imaging applications. An image reconstruction algorithm of the ordered subsets expectation maximization (OS-EM) algorithm is developed for high resolution applications. The feasibility of this design is tested experimentally in a prototype.

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Fast X-ray Phase-Contrast Imaging using High Resolution Detector

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X-ray phase-contrast imaging is a newborn nondestructive testing and diagnostic technology in medicine, biology and materials science. It provides high sensitivity and contrast of weakly absorbing low-Z objects by measuring phase shifts of the X-rays. Successful experiments have been realized both using synchrotron radiation source and conventional X-ray source. The most potential method is based on grating using phase-stepping method to retrieve phase information. Generally this kind of method needs two gratings -- one (phase or absorption type) to obtain intensity pattern and the other is used as an analyzer grating. In fact, if we can resolve the intensity pattern downstream of the first grating directly the absorption grating can be omitted. The disadvantage of these methods is that the analyzer grating needs to be moved to obtain a sequence of the intensity pattern. For conventional X-ray source, it takes too long to obtain a high signal-to-noise image and thus brings unnecessary dose. The precision of repeat positioning is also a difficult mechanical problem for phase-stepping based method to obtain accurate phase information. These disadvantages limit practice and clinical applications of grating based on phase-stepping method. In this paper, we propose a phase-contrast imaging method using only one grating and a high resolution detector. The grating can be either an absorption grating or a phase one. The intensity pattern downstream the grating is recorded and analyzed by the high resolution detector directly. We use a spatial frequency phase demodulation method to retrieve phase information. Only one image is needed. Thus the structure of our system is greatly simplified compared to phase-stepping method and the dose is low. The idea is derived from spatial phase-shifting interferometry used in visible light range. In spatial phase-shifting interferometry, an tiled phase object is applied to generate a spatial phase shift. From the analysis of Fourier optics, we find that in grating-based phase-contrast imaging with monochromatized x-ray source, the intensity pattern downstream of the first grating has an analytic expression similar to that in spatial phase-shifting interfermetry, except that the former includes high frequency harmonics. However the high frequency harmonics are not the main ingredients that affect the retrieving of the phase. On the assumption that the phase of the object changes more slowly than the spatial frequency of the intensity pattern, our method is effective for fast phase retrieving. Both numerical simulation and actual experiments are performed to validate the new method at BSRF (Beijing Synchrotron Radiation Facility). The source-grating distance and source-detector distance are carefully chosen, the detector sampling of the intensity pattern downstream the grating must satisfy Shannon's law. We use charge coupled devices (CCD) from Princeton Instruments. The detector couples with a CsI scintillator and a coupling lens. The spatial resolution is 13 microns. The grating used in experiments is a phase or an absorption grating with tens of microns pitch for comparison. All experiments confirm the feasibility and effectiveness of our method.

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Digital Image Restoration Based On Simultaneous Pixels Detection Probabilities

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An image acquired by a digital detector includes degradation as a result of the simultaneous pixel detection. Here an image restoration on the basis of simultaneous pixel detection probabilities is proposed. These probabilities can be precisely determined by means of correlations measurement [V. Grabski, NIMA 586 (2008) 314-326]. The proposed image restoration is based on the solution of matrix equation. Non-zero elements of Toeplitz block matrix with ones on the main diagonal, is determined using simultaneous pixel detection probabilities. The number of non zero descending diagonals depends on the detector construction and is always not smaller than 8. To solve the matrix equation the Gaussian elimination algorithm is used. The proposed restoration algorithm is studied by means of the simulated images (with and without additive noise using simultaneous detection probabilities for General Electric Senographe mammography unit detector) and a small area (160x160 pixels) of real images acquired by the above-mentioned device. The additive noise in real image is present after restoration and almost has the same magnitude. The restoration of local area is exact in the window which is smaller than the restored one (12 pixels) for each dimension. In the restored small area (16x16 mm) of real images the pixel responses are not correlated which is considered as an independent check-up of the restoration process. The spatial resolution improvement is also analyzed by the image of an absorber edge as well.
The author is grateful to M-E Brandan and Y. Villasenor, for kindly providing access to the mammography unit, to radiological technicians of the National Institute of Cancer Research for technical support, to M. Grabska for preparation of the text and PAPIT-UNAM IN-115107 for the partial support.

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Development of Picosecond-Resolution Large-Area Time-of-Flight Systems

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John Anderson, Karen Byrum, Gary Drake (Argonne National Laboratory); Henry Frisch, Jean-Francois Genat, Harold Sanders, Fukun Tang (Enrico Fermi Institute); Jerry Va'vra (Stanford Linear Accelerator Center)

The measurement of time-of-flight (TOF) of relativistic particles in high-energy colliders with psec resolution would qualitatively change the ability to identify underlying parton-level processes at future colliders or upgrades of existing detectors. We are exploring a psec-resolution TOF system using micro-channel plates (MCP's) incorporating: a source of light with sub-psec jitter, in this case Cherenkov light generated at the MCP face (i.e. no bounces), short paths for charge drift and multiplication, a low-inductance return path for the high-frequency component of the signal, optimization of the anode for charge-collection over small transverse distances, and the development of multi-channel psec-resolution custom readout electronics directly mounted on the anode assembly. In parallel, we are developing a detailed simulation of the system, from the incoming particle traversing the radiator to the digital output of the electronics, in order to perform optimization of MCP design in software. We have measured the timing properties of three MCP-PM's from Photonis; one with 1024 anodes and the other two with 64 anodes. The 1024-anode 10-micron pore tube uses a charge-collection scheme at the anode to provide equal arrival time of the signal independent of the hit position of incident light on the face of the tube. The two 64-anode 10-micron pore tubes have a commercially available collection scheme and were used to find a limit on the timing resolution. We have performed these measurements using a newly assembled test-stand based on a Hamamatsu PLP-10 picosecond laser and a commercial CAMAC readout electronics system. We present these results and compare timing properties to earlier versions of the charge collection scheme.

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A Detection System Based on Nuclear Resonance Fluorescence Technique

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Nuclear Resonance Fluorescence (NRF) is the process of resonant excitation of nuclear levels of a target nucleus by absorption of electromagnetic radiation and subsequent decay of these levels by re-emission. This technique can be used to non-intrusively interrogate a sample of interest. The presence of interesting isotopes could, in principle, be inferred from the presence and amplitude of either the preferential attenuation of incident photons at related resonant energies, or by the emission of photons at these energies. In a detection system utilizing this latter technique, samples are exposed to intense interrogation irradiation, usually bremsstrahlung photons with continuous energy distribution. Detectors with high detection efficiency and excellent energy resolution are located outside the beam at a backscattering angle, collecting the emitted resonance photons that have discrete energy distribution exclusively related to the isotopics. An NRF experimental system was setup in the Radiation Laboratory at the University of Notre Dame using their 3 MeV Van de Graff accelerator. The accelerated electrons struck our water-cooled converter stage. Ozone generation was minimized by running nitrogen over the converter surface. The 3 MeV photons generated are highly penetrating and can reach samples shielded by thick lead bricks. The whole system was simulated using a modified version of MCNP5 code with NRF physics added. A custom spectroscopy system was developed using a fast ADC and FPGA. Real time digital signal processing was implemented on the FPGA chip. System performance using different detectors has been evaluated, including the fast lanthanum halides and HPGe detectors. NRF effects are reported from various samples, including boron, silicon, aluminum, and germanium. The relevance to special nuclear materials will be discussed.

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Design and Simulation Result of n Substrate Reverse Type Avalanche Photodiode

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We will present progress in the simulation study of the n substrate reverse type avalanche photodiode (APD) with the diffusion method and epitaxy method. The resistivity of n substrate wafer was 380 um, which was 5 kohm-cm. The devices had basically a five (p+pnn-n+) or six (p+p-pnn-n+) layer structure. In this simulation, using Silvaco Athena and Atlas which is one of the commercially available simulation package for silicon devices. We studied and consequently checked their electrical characters such as current and break-down voltage, spectral responsivity and external quantum efficiency. The PN junction was formed by deep diffusion of boron and phosphorous leading to peak compensated doping concentration of ~10^16 /cm3. The PN junction is located at ~3.3 um deep from the entrance window. When reverse bias is applied across the bulk peak electric field of ~300 KV/cm. A breakdown occurred at around 400 V and gain of ~100 for 500 nm photon was achieved at 390 V reverse bias. We will be designed and fabricated n substrate reverse type APD based on this study.

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Silicon Photomultiplers for PET/MRI Application

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Novel solid state photon detectors such as the silicon photomultiplier (SiPM), a CMOS manufactured Geiger-mode matrix of APD cells, rival photomultiplier tube performance in gain, sensitivity, speed, efficiency, and stability; and have the added advantage of being insensitive to magnetic fields. These characteristics, in addition to several other

advantages such as being compact, requiring low bias voltages, and being inexpensive to produce, make SiPMs a candidate for replacing PMT technology in many different applications. For the purpose of combining positron emission tomography (PET) and magnetic resonance imaging (MRI) into a single, dual modality instrument, the SiPM appears to be an ideal replacement for magnetically sensitive photomultiplier tubes. We are investigating SiPM performance under the demands of a complete PET/MR system to validate their advantages. Application to PET/MR requires that the SiPM must operate normally under the influence of the MR static magnetic, pulsed gradient and radio-frequency fields. To measure and quantify any change in performance we have acquired spectral SiPM data whilst performing controlled MR gradient switching, applying radio-frequency pulses, and standard MRI imaging sequences with the SiPM positioned in the MR system. To highlight any performance issues throughout the wide dynamic range of the devices, we have acquired both "single photoelectron" and PET-equivalent energy spectra. The SiPM was fully exposed to the static, gradient, and RF fields while tethered to the end of two 3m lengths of coaxial cable for biasing and read-out. The SiPM output was converted to a voltage signal before transmission. The SiPMs used in these experiments were produced by Hamamatsu and FBK-IRST. Single SiPM devices have been tested, though larger area arrays and matrices for position-sensitive readout are currently being developed. A pulsed LED triggered the SiPM with in a static 1T magnetic field during the maximum dB/dt of a customized MRI gradient cycle. These acquisitions were compared with data measured in terrestrial magnetic fields.

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Evaluation of Silicon Detectors with Built In JFET for Biomedical Applications

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This paper presents initial results from electrical, spectroscopic and Ion Beam Induced Charge (IBIC) characterisation of a novel silicon PIN detector, featuring an on-chip n-channel JFET and matched feed-back capacitor integrated on its p-side (front-side). The front side biasing and close to 100% electron and hole collection provides an almost 100% n-side (back-side) fill factor. The detector is specifically designed for use in high resolution gamma cameras, where a pixellated scintillator crystal can be directly coupled to an array of silicon photodetectors. The on-chip JFET is matched with the photodiode capacitance and acts as the input stage of an external charge sensitive preamplifier (CSA). The integrated monolithic feedback capacitor eliminates the need for an external feedback capacitor from the external electronic readout circuit, improving the system performance by eliminating the detrimental effect of uncontrollable parasitic capacitances. An optimised resolution of 152 electrons RMS was obtained with a shaping time of 2 us and a total capacitance of 2 pF. The energy resolution obtained at room temperature (21 C) at 27 keV (direct interaction of I-125 gamma rays) was 5.6%, measured at full width at half maximum (FWHM). The effective role of the guardring in minimising the leakage current between the cathode and anode of the reverse-biased photodiode is clearly demontrated by the IBIC images.

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A Si-APD Timing Detector Sensitized by Secondary Radiation, for Nuclear Resonant Scattering using Synchrotron X-Rays
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A silicon avalanche-photodiode (Si-APD) has been used for nuclear resonant scattering experiments using synchrotron x-rays as a timing detector. The Si-APD detector shows a good time resolution of 100 ps to 1.5 ns, and a wide dynamic range of count-rate, 109 - 1010 by a fast output pulse. In the measurement of time spectra, the fast response is useful for recording a decaying structure by delayed radiation emitted from excited nuclei after the prompt radiation. However, due to a small cross section of Si (Z=14), the detector efficiency decreased to less than 1% at 50 keV for a 100-um thick APD. Nuclear resonance scattering using synchrotron x-rays is now extending its application to a higher energy region of nuclear levels. To improve efficiency for a high-energy photon, we can use a stack of Si-APDs, 45 deg. inclined to the incident x-ray beam. We used the APD device having a diameter of 3 mm and a 150-um thick depletion layer. The effective thickness of the stack reached 1.7 mm. Moreover, detecting secondary radiation, x-rays and electrons, emitted from metal foil put between the APDs, is useful for obtaining a better efficiency of the timing detector. We assembled a detector having eight niobium plates 0.025-mm thick, put in the front of each APD. Using synchrotron x-rays of 67.41 keV, the efficiency increased to 10% for the incident beam, while the efficiency of 7.5 % was obtained only with eight Si-APD plates. Nb K x-rays and photoelectrons were recorded in an energy spectrum of the APD detector, in addition to the absorption of the incident x-rays in silicon. Time spectra of the APD detector were also investigated with and without metal foil. The peak profile had a shape determined by a structure of the APD itself and by the secondary radiation. The detector was applied to the measurement of Synchrotron radiation-based perturbed angular correlation (SR-PAC) on Ni-61 (excited level: 67.41 keV, half-life: 5 ns). Measured spectra will also be shown at the conference.

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High-Resolution Monolithic CMOS Sensor Systems for Charged-Particle Imaging
Stuart Kleinfelder, University of California, Irvine
Mark Ellisman, Liang Jin, Anna Milazzo, Nguyen Xuong (U.C. San Diego)

CMOS image sensors that have been optimized for charged particle imaging applications, such as electron microscopy and particle physics, have been designed and characterized. These are successful in recording minimum-ionizing charged particles with high signal to noise without the use of hybrid technologies such as separate high-resistivity silicon planes or scintillating materials. Based on standard CMOS Active Pixel Sensor (APS) technology, the sensor arrays uses an 8 to 20 um epitaxial layer that acts as a thicker sensitive region for the liberation and collection of ionization electrons resulting from impinging charged particles. This results in a 100% fill factor and a far larger signal per incident charged particle than a standard CMOS photodiode could provide. Several complete devices, with their performance results and sample images, will be presented.

Complete devices include a 1 Mega-Pixel camera and a 0.25 MP test device that includes massively-parallel per-column analog to digital conversion. Devices have been extensively tested in a Transmission Electron Microscope, including by the use of mosaic image formation and tomographic cross-sectional image generation. The design and performance a new camera that includes parallel per-column programmable gain (x1 and x10), global or row-wise reset, correlated double sampling circuitry, highly-parallel per-column 10-bit A/D conversion, as well as fast parallel readout will also be presented. This device is currently being reconfigured into a 16 M-Pixel camera that, via its fast parallel conversion and readout, should maintain excellent frame rates of up to 25 fps with 10 bit conversion.

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Modeling and Analysis of Charged-Particle CMOS Image Sensor Arrays

Stuart Kleinfelder, University of California, Irvine (UCI)
Shengdong Li (UCI), Howard Matis (LBNL)

Direct-detection CMOS image sensors optimized for charged-particle imaging applications, such as electron microscopy and particle physics, have been designed, fabricated and characterized. These devices directly image charged particles without reliance on image-degrading hybrid technologies such as the use of scintillating materials. Based on standard CMOS Active Pixel Sensor (APS) technology, a majority of these sensor arrays uses an 8 to 20 um epitaxial layer that acts as a thicker sensitive region in the generation and collection of ionization electrons resulting from impinging high-energy particles. A range of optimizations to this technology have been developed via simulation and experimental device design. These include the simulation and measurement of charge collection efficiency vs. recombination, effect of diode size and stray capacitance vs. signal gain and noise, and the effect of different epitaxial silicon depths. Simulations are presented that accurately model the performance of these and other devices. These are Monte-Carlo simulations that model the ionization, transport and collection of electrons in the bulk and epitaxial silicon areas as well as the collection diodes. Discussion will include device parametrization and boundary conditions, random generation of ionization profiles via Bichsel's algorithm, modeling recombination, effects of pixel pitch and silicon thickness on resolution, collection diode area on signal to noise ratio, impinging particle energy on signal to noise and other issues. Simulations have been vetted by comparison to several experimental devices that systematically vary parameters such as pixel pitch and diode area.

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Low-Noise CMOS Sensors for Charged-Particle Imaging using Per-Pixel Correlated Double Sampling

Stuart Kleinfelder, University of California, Irvine (UCI)
Mona Ahooie (UCI), Howard Matis (UC Lawrence Berkeley National Laboratory)

Monolithic CMOS cameras for direct imaging in electron microscopy and other radiation imaging applications have been developed, including complete cameras of up to 1 M-pixels, and have been used to capture images with superior resolution to that of commercial CCD-based systems. Optimizations for these sensors have been made via simulation and experiment, including studies of the impact of epitaxial silicon ionization region thickness, pixel pitch and diode size optimizations, and per-pixel correlated double sampling (CDS) technology. The per-pixel CDS scheme has demonstrated reductions in kT/C noise by a factor of four. It requires only one read instead of two reads plus pre- and post-integration subtraction, and is hence faster than alternate schemes. In addition, observation of Random Telegraph Signal noise (RTS) in small-capacitance pixels is demonstrated at different Vgs conditions. Finally, extensions of the basic CDS scheme to include hit detection and sparse data readout will be discussed.

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

Stuart Kleinfelder, University of California, Irvine (UCI)
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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.

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New Approach to Solid State Photomultipliers

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During the past few years developments of solid state analog of PMT become more and more urgent. Usually one names so photodetector with internal amplification having, like PMT, combination of high gain, low noise and fast response time which are necessary for a few- photon detection ability. We present a new generation of solid state photomultipliers based on use of discrete amplification mechanism (DA) for internal amplification of signal in photodetector. Discrete amplification is new general approach to the problem of super weak signal detection. Accordingly to the approach input signal charge is distributed to separate independent amplification channel so that each of signal electrons is amplified in separate channel. Amplified charge packets from the all channels form output signal. A number of the packets corresponds to a number of electrons in input signal. Such amplification method allows one to detect weak electron signal up to one-few electron precisely with high speed of operation. Base elements of discrete amplifier are signal distributor, threshold avalanche multichannel electron amplifier and reader of amplified charge packets. Use of discrete amplification technology allow to create specific device designs adjusted to concrete application by use of different variants of signal distributing, implementations of multi-channel amplifier and its integration in the detector, as well as different reader types. Amplification Technologies Inc. had developed DA WS series photodetectors that appropriate to detect week optical signal in analog and photon counting mode at wide spectral range. DA WS photodetectors has important specific advantages: wide and flat spectral characteristic, high photon detection efficiency at wide dynamic range. Their high voltage and thermal stability can be also interesting for developing of multi element detection systems on their base. In radiation measurements and application use of DA WS photodetectors can be wide enough including scintillator radiation detectors.

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High Quantum Efficiency PMT for Field Homeland Security Instruments

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Florence Lherbet, Eric Rossignol, Francois Fouche (Photonis France SAS), Paul Hink (Photonis USA)

To exploit enormous potential of cerium doped lanthanum bromide scintillator in homeland security applications very dedicated light sensor is required. This work reports on the performance of new photomultiplier developed by Photonis and dedicated to in field instruments routinely used in homeland security. The PMT of the diameter of 38 mm and very low profile of 72 mm is compatible with the form factor of hand held instruments and well suited for combination with LaBr3(Ce) crystal due to CLARITY photocathode characterized by quantum efficiency of about 40 % for light wavelength of 404 nm. Pulse width discrimination provides excellent energy resolution up to high detector loads, and for very low detection thresholds. Moreover, due to improved dynode structures which are better adapted to the intense light flashes of LaBr3 excellent linearity over broad energy range and very good gain stability as a function of count rate were obtained.

Scintillators
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Electronic Structure Studies and Predictions for new Ce-doped Gamma Detector Materials

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Rostyslav Boutchko, Anurag Chaudhry, Stephen Derenzo, Marv Weber, Lin-Wang Wang (LBNL)

The purpose of this work is to theoretically establish correspondence between the scintillation properties of crystalline materials doped with cerium and electronic structure parameters that can be computed for these materials. We have performed first principles electronic structure calculations for many different cerium doped compounds using density functional based methods to determine the positions of the 4f and 5d states relative to the valence and conduction bands of the host materials. We find good qualitative agreement with experimental results for known scintillators and non-scintillators for the systems studied. From our theoretical studies we have developed a set of four criteria to determine if a material can be a bright Ce activated scintillator. (1) The size of the host material bandgap (2) The energy difference between the VBM (Valence Band Maximum) of the host material and the Ce 4f level valence (3) The energy difference between the occupied Ce 5d excited state $(Ce3+)^*$ and the host material CBM (Conduction Band Minimum) (4) The level of localization of the $(Ce3+)^*$ electron state on the Ce atom. We have subsequently calculated these four criteria for new materials to determine if they are good candidates for high luminosity Ce activated scintillators. We will present results for different families of materials including BaY halides, BaLa halides and borates where we find very good agreement with known compounds and also make predictions for new Ce activated scintillators. We will also present some band gap engineering studies where we take a known three element compound and add in a fourth element to improve its scintillation properties based on theoretical predictions.
Research supported by the U.S. Department of Homeland Security and by the U.S. Department of Energy under Contract No. DE-AC02-05CH11231

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First Principles Calculations for Ce-doped Rare-Earth Oxyhalides REOX (RE = Y,La, X = F, Cl, Br, I) for Gamma Detector Materials

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This work presents the results of first principles electronic structure calculations for cerium doped rare-earth oxyhalides REOX (RE = Y, La; X = F, Cl, Br, I) performed using the pseudopotential method based on the local density approximation in density functional theory. The positions of the 4f and 5d states relative to the valence band maximum and conduction band minimum of the host material are determined. Qualitative predictions of the brightness of Ce^{3+} activated luminescence in the doped material is made based on the following criteria: (1) The size of the host material bandgap (2) The energy difference between the VBM (Valence Band Maximum) of the host material and the Ce 4f level valence (3) The energy difference between the occupied Ce 5d excited state $(Ce^{3+})^*$ and the host material CBM (Conduction Band Minimum) (4) The level of localization of the $(Ce^{3+})^*$ electron state on the Ce atom. We have performed calculations to determine if these doped compounds are candidates for Ce activated scintillators. Our theoretical investigations indicate that Ce^{3+} activated yttrium oxybromides and oxychlorides should show better luminescence as compared to others. These families of materials have been synthesized and the experimental results agree with our prediction. Research supported by the U.S. Department of Homeland Security and by the U.S. Department of Energy under Contract No. DE-AC02-05CH11231.

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Scintillation Properties of the Novel Single Crystal Cerium Dicyanoargentate

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Cerium activated crystals have attracted much attention due to their potential application as fast scintillator materials. We present optical and x-ray luminescence results from the novel single crystal cerium dicyanoargentate. Single crystals of the form $Ln[M(CN)_2]_3$ (Ln=trivalent rare earth; M=Ag, Au, or both) have a layered structure consisting of alternating layers of $M(CN)_2^-$ ions and Ln^{3+} ions. Recent work on this type of crystal has focused on energy transfer from the metal dicyanide donor to the rare earth acceptors, including Tb^{3+} and Eu^{3+}. Crystals of $Ln[Ag(CN)_2]_3$ are particularly interesting because they exhibit site-selective excitation. However, the luminescence intensity in these crystals is vanishingly weak at ambient temperatures. In contrast, the cerium dicyanoargentate crystal displays strong luminesence at all temperatures between 78 K and 295 K. The photoluminescence reveals broad, overlapping dicyanoargentate and cerium emissions, which are decomposed into three Gaussians. These include a characteristic dicyanoargentate emission at 350 nm, and the Ce^{3+} 5d-4f transitions at 359 nm and 391 nm. Excitation measurements show that the 4f-5d Ce^{3+} absorption overlaps the 320 nm emission of the dicyanoargentate ions, leading to a strong coupling between the dicyanoargentate energy donors and Ce^{3+} acceptors. In addition, the decay time of the cerium luminescence has been measured using pulsed x-rays and is found to be 19 ns, indicating that this crystal has good potential for application as a scintillator material.

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Properties of vacuum deposited CsI(Tl) and ZnSe(Te) scintillator layers

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Thin scintillating films are widely used for the imaging applications in X-ray and gamma radiation. In this communication investigations of structure, morphology, scintillation properties of CsI(Tl) and ZnSe(Te) films are presented. CsI(Tl) become almost standard as the scintillating layer in the medical imaging systems. Other compound is the known ZnSe(Te) scintillator [1] which investigation as thin film scintillator started lately [2,3]. Layers of both materials were produced by the physical vapor deposition. Peculiarity of CsI(Tl) films to grow in the columnar morphology [4] was proved. ZnSe(Te) layers also display the tendency to directional growth but less expressed than as CsI(Tl). X-ray diffraction examinations show the polycrystalline structure of ZnSe(Te) layers with preferred [111] close packed growth direction. In the CsI(Tl) layers dominant orientations of columnar blocks [110] and [112] were observed that is attributed to the charge neutrality of corresponding crystallographic planes. Scintillation properties of CsI(Tl) layers were examined using radiation of the Pu 239 alpha particle source. Pulse height spectra of the layers were compared with that of the reference CsI(Tl) crystal possessing light yield of 48000 ph/MeV. Investigations had shown that optimal concentration and uniform distribution of activator in the layer are the key factors that allow to attain the light output and energy resolution of layers close to the values of the bulk crystal. ZnSe(Te) layers were annealed in the Zn vapor ambient after deposition [5] to improve their scintillation efficiency. Photoluminescent spectra of the layers excited at 490 nm wavelength radiation of Xe lamp had shown the presence of the luminescent peak at 640 nm that correspons to the strong working band of the commonly used ZnSe(Te) scintillation crystals. Radioluminescent spectra were obtained under irradiation of X-ray tube operated at 25 kV and display strong luminescent peak at the same position. Light yield of the layers was estimated in relation to that of the bulk ZnSe(Te) crystal using radiation of X-ray tube at 90 kV. It was found that the light yield of the 380 mkm thick layer deposited on the ceramic Al_2O_3 substrate reaches about 50% of the 1 mm thick ZnSe(Te) crystal. References:

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Comparative Study on the Crystallization Behavior and Luminescence Properties Between LSO and LPS Crystals

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Lutetium oxyorthosilicate (Lu_2SiO_5, shorten as LSO) and lutetium pyrosilicate ($Lu_2Si_2O_7$, shorten as LPS) were two congruent compounds existed in the Lu_2O_3-SiO_2 binary system. LSO has been proved to be an excellent scintillation crystal and applied in

PET, but LPS is a new found scintillation crystal with density of 6.23 g/cm3, decay time of 38 ns, absence of afterglow as well as high temperature stability. They are similar in chemical composition, but different in crystal structure. Therefore, it's interesting to compare their crystallization behavior and scintillation properties. The starting materials are Lu2O3, SiO2 and CeO2 powder with the purity of greater than 99.99%. They were weighed based on the stoichiometry of Lu2(1-x)Ce2xSiO5 and Lu2(1-x)Ce2xSi2O7. The activator, CeO2, was doped into above mixture at the content of x = 0.3%. Both LSO and LPS crystals were grown with Czochralski. Their crystallization behavior and scintillation properties are discussed in this paper. Both of LSO and LPS crystals are different in crystallization behavior. The former is easy to crystallize with dimension as big as 80 mm in diameter, but the latter is difficult to grow with diameter more than 30 mm. Cleavage of (110) planes in LPS crystals are quite easy to cause cracking. On the other hand, the difference of thermal expansion coefficients along [100] direction is three times bigger than that along [001]. The big stress might be the main reason lead to the cracking of LPS. The cut-off edge of LPS:Ce shifts about 25 nm toward UV corresponding to LSO:Ce crystal (380nm). This shifting is favorable for the reduction of self-absorption on the light yield. Under excitation of 358 nm, LSO:Ce emits a broad band with maximum at 403 nm and a shoulder around 423 nm, but the emission of LPS:Ce crystal can be fitted into two emission components, peaking at 380 and 410 nm respectively. Compared with LSO:Ce, LPS:Ce has about 20 nm shorter in emission wavelength, even though their excitation wavelengths are quite similar. The great difference is that LSO:Ce presents a very strong decaying afterglow, but LPS:Ce doesn’t show any afterglow. These differences in luminescence might originate from the different structure in these two kinds of crystals. Heat treat experiment approved that the annealing in atmosphere can greatly improve the light output of LPS:Ce, however, annealing in hydrogen atmosphere can reduce the light output. This effect reveals that some defects related to the oxygen vacancies exist in the crystal lattice of LPS:Ce crystals. They should be responsible for the poor light output of LPS and afterglow of the LSO crystals.

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An Investigation of the Effects of Calcium Codoping in YSO:Ce

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From initial studies of YSO:Ce scintillators, it was found that the electron traps play a significant role by increasing the decay time and adding additional decay time components in the decay scheme. This effect was observed by measuring the decay scheme using a Bollinger-Thomas setup at room temperature and comparing it to the same measurement taken at 40K. The measurement seen at 40K showed that when the traps become saturated, the trap lifetimes are at the order of years and become insignificant in the decay scheme. This effect results in a shorter decay time and fewer decay time components in the decay time spectrum. It was also observed that codoping LSO:Ce with calcium suppress some of the traps and change the scintillation mechanism with a resulting faster decay time and greater light output. An investigation was performed to see if the same codoping of calcium in YSO:Ce would result in a similar increase in light output and lowered decay time. From the initial results, it was observed that the decay time of the codoped YSO decreased by 10 nanoseconds. The investigation also looks at the differences of decay schemes imposed by the calcium introduced to the system when compared to room temperature and 40K data of YSO:Ce without calcium.

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Trends in the Electronic Structures of Halide Scintillators

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Recently, several new halide scintillator materials have shown promise for gamma detection and spectroscopy. These include LaBr3:Ce3+, various elpasolites also activated with Ce3+, and SrI2:Eu2+. On the other hand, activated LaI3 samples reported to date do not have good scintillator performance. Here we report calculated electronic structures for a variety of halide materials including EuI2, SrI2, various binary rare earth trihalides, and elpasolites. These calculations were done within density functional theory using the general potential LAPW method using relaxed crystal structures. We find that the trends in the electronic structure can be understood in terms of electronegativity differences and bonding topology, especially anion overlap. The results in particular show that LaI3 has a very much smaller band gap than materials like LaBr3, which is understood in terms of the different crystal structure of the iodide, and which explains the difficulty in activating the material to obtain good scintillator performance. This work was supported by DOE, Office of Non-Proliferation Research and Development, NA-22.

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Influence of Different Defects on Radiation Stability of Cadmium Tungstate Single Crystals

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High efficiency scintillation single crystals of cadmium tungstates (CWO) are widely used in X-ray tomographic equipment and radiation monitoring instruments due to their properties (small radiation length, high scintillation efficiency, low afterglow et al). However, modern requirements to radiation monitoring instruments make it necessary to improve the operational parameters of scintillation materials, including improvement of their radiation stability. The results of measurements of light output, afterglow, optical transmittance of CWO crystals with different defects after irradiation (Co-60, dose from 100 to 100,000 Gy) are reported in this work. Radiation effects in CWO crystals were shown to be related to the formation defects in of oxygen sublattice. In some CWO samples, the dose of 1000 Gy caused destruction of defects responsible for indused absorption. CWO:Li crystals have a stable defect structure, which is responsible for color and trapping centers. Formation has been noted of identical structural defects in CWO crystals annealed in a reductive medium (hydrogen) and those doped with Me3+, these defects being responsible for formation of color centers stable to radiation.

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Knowledge-based Estimation of Electronic Properties in Ternary Materials

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While the performance metrics for a candidate compound can be clearly defined once the material has been made, the time intensity of search processes for new materials based solely upon experimental data can be prohibitively slow and is highly dependent upon the synthetic expertise of the investigator. A particularly vexing problem for the development of scintillating materials has been the estimation of band gap. Knowledge-based methods for band gap estimation have particular utility for evaluation of candidate compositions where there is little or insufficient structural information. In this paper, we show the predicted vs. experimental band gaps for a series of insulating compounds (Eg > 4.5 eV) using a structure-less based prediction. The first step in this process was development of a sufficiently diverse set of electronic descriptors to adequately define the variation in the electronic behavior of these materials. Initial descriptor sets were taken from the work of Villars and Van Vechten/Phillips. Subsequent analysis of the first order relationship noted redundancies in the original descriptor basis set, and suggested non-obvious areas for descriptor augmentation such as volume normalized energy densities. Analysis of the second order relationship shows both encouraging correlation (R2>0.9) and the local nature of the electronic model. Acknowledgement: The Pacific Northwest National Laboratory is operated by Battelle Memorial Institute for the US Department of Energy under contract DE-AC06-76-RL1830. The authors gratefully acknowledge financial support from the PNNL Laboratory Directed Research and Development Project.

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Development and Characterization of Two-dimensional Scintillating Fiber-optic Dosimeter for High Energy Electron Beam Therapy

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Nowadays, many kinds of dosimeters such as ion chambers, silicon-diode detectors, diamond detectors, liquid ion chambers and radiographic films have been developed and used to measure dose and dose rate for electron beam therapy dosimetry. However, they have problems that include a rather large sensitive volume, dose rate dependence, complicated construction and lack of real-time measurements, which inhibit accurate dose measurements. To overcome these problems, a dosimeter should have a small sensitive volume for high resolution measurements in regions of high dose gradients, and should have water-equivalent characteristics to avoid complex conversions that originate in dose measurements due to material differences. Additionally, real-time measurements should be possible; and there should be no corrections such as temperature, pressure or humidity for accurate dose measurements. As one candidate, a fiber-optic dosimeter using an organic scintillator has been developed and successfully applied to measure high-energy electron beams in radiotherapy dosimetry. Generally, fiber-optic radiation

sensors for radiotherapy dosimetry applications use an organic scintillator probe, an optical fiber and a light-measuring device. Organic scintillators can emit visible light which is proportional to the absorbed electron dose rate and can minimize dose distribution perturbation in a solid water phantom because they are very small and nearly water-equivalent. An optical fiber is usually made of plastic or glass, which is used to guide the light signal from a scintillator probe to light measuring devices. As a light pipe, plastic optical fiber (POF) has many advantages such as good flexibility, easy processing, great lengths and no interference from electromagnetic fields. Therefore, a fiber-optic scintillating dosimeter is one of the most promising tools for electron beam therapy applications. However, there is a disadvantage of fiber-optic dosimeter when a high-energy electron beam is irradiated. Two kinds of light signals, such as scintillating and Cerenkov light, are generated in a fiber-optic dosimeter. The scintillating light signal is produced in the scintillator and Cerenkov light could be produced in the POF itself. Both light signals are transmitted through a POF to a remote light- measuring device and there should be a difficulty to detect real light signal (scintillating light) generated in the scintillator on a fiber-optic dosimeter. Therefore, it is very important to remove Cerenkov light for accurate dose measurements in fiber-optic dosimeters irradiated with a high-energy electron beam. In this study we have developed a two-dimensional fiber-optic dosimeter array using organic scintillators and POFs to measure two-dimensional dose distributions and percent depth doses (PDDs) in a solid water phantom for high energy electron beam therapy dosimetry. The scintillating lights generated by each organic sensor probe in a solid water phantom are guided by 10 m POFs to the charge-coupled device as a light-measuring device. The study's objectives are to measure and obtain two-dimensional electron dose distributions and PDDs in a solid water phantom using a fiber-optic dosimeter array. Also, Cerenkov lights are measured and eliminated using an optical discrimination method. Two kinds of optical filters such as such as cutoff and bandpass will be used between SMA fiber-optic connectors to eliminate a Cerenkov light.

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CeCl3(CH3OH)4 - Cerium Chloride-Methanol Adduct Single Crystals: A New Metal-Organic Scintillator Material

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A new metal-organic scintillator, CeCl3(CH3OH)4, has been identified and its molecular structure determined by means of single-crystal x-ray diffraction refinement. Large, transparent single crystals (> several cubic cm) of this new metal-organic scintillator were grown from a seeded methanol solution in a temperature-controlled bath, and the solubility characteristics are such that it appears that this material will be amenable to growth by means of the rapid growth methods applied to the formation of very large KDP single crystals. Energy spectra of the cerium chloride-methanol adduct single crystals were obtained using 662 keV gamma-ray photons from a 1 uCi source. Using a shaping time of 0.5 us, light yields of ~16,600 photons/MeV were obtained by comparison with the light yield from a 1 x 1 x 1 cm3 bismuth germanium oxide (BGO) reference scintillator crystal. The CeCl3(CH3OH)4 light yield was 260% of that of a BGO scintillator with a nominal light yield of 6400 photons/MeV - yielding a value of 16,600 photons/MeV for CeCl3(CH3OH)4 without corrections for the photomultiplier tube efficiency. Using the same experimental configuration described above, an energy resolution of 11.2% was obtained at 662 keV. The CeCl3(CH3OH)4 scintillator decay time for gamma-ray excitation was measured using the time-correlated single-photon-counting (Bollinger-Thomas) method, and a nominal value of 59 nsec was obtained. X-ray-excited luminescence spectra were measured at an excitation energy of 35 keV in both reflection and transmission geometries. The peak emission of the X-ray excited luminescence spectrum occurs at 364 nm. Based on our initial measurements made using both Cf-252 spontaneous fission neutrons and 14 MeV neutrons, this class of materials may also prove to be of particular interest for fast-neutron detection applications. This material apparently represents the first example of a rare-earth metal-organic scintillator that is applicable to x-ray, gamma-ray, alpha particle, and neutron detection, and this new finding offers the future promise of identifying other metal-organic molecular systems that have the potential for serving as efficient radiation detection materials.

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Cherenkov and Scintillation Properties of Cubic Zirconium

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Cubic zirconium (CZ) is a high index of refraction (n =2.17) material that we have investigated for Cherenkov counter applications. Laboratory and proton accelerator tests of an 18cc sample of CZ show that the expected fast Cherenkov response is accompanied by a longer scintillation component that can be separated by pulse shaping. This presents the possibility of novel particle spectrometers, which exploits both properties of CZ. Other high index materials being examined for Cherenkov applications will be discussed. Results from laboratory tests and an accelerator exposure will be presented and a potential application in solar energetic particle instruments will be discussed.

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Characterization of Large Frustum CsI(Tl) Crystals for the R3B Calorimeter

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A versatile experimental setup has been proposed to perform kinematically complete measurement of reactions induced by high-energy radioactive beams at FAIR in Darmstadt, Germany. The experiment, named R3B, devises the construction of a calorimeter for the detection of gammas and light charged particles originated in these nuclear reactions. The main properties of this device, high total absorption efficiency (greater than 80% for gammas up to 15 MeV in the laboratory frame) and good angular resolution(approx 1 deg for theta around 35 deg), are imposed by the very particular kinematics of energetic gamma-rays emitted by sources moving with relativistic velocities. In order to ensure these nominal values in all the angular domain, the polar-angle segmentation and the thickness of the scintillation material are optimized for separate angular regions. All these considerations determine the geometry of this device . On the other hand, the intrinsic resolution of the scintillator material should be enough

good to allow this detector to act as spectrometer (DeltaE/E around 3% for 1 MeV gammas). To guarantee the polar angle segmentation, we propose a detector divided into frustum-like crystals (around 5000 crystals with a average size 10x20x150 cm3). We will present in this paper the energy resolution measurements of frustum-like CsI(Tl) crystals coupled to large area avalanche photodiodes (Hamamatsu S8664 - 20x10 mm2) specifically developed for this project. The energy resolution measurements were performed after optimization of the crystal shape, surface treatment, wrapping, optical coupling, APD's bias-voltage and APD's temperature stabilization. We also studied the dependence of the energy resolution with electronic parameters as bias voltage, amplifier gain, spectroscopic shaping time, multichannel acquisition time, etc. We have looked for the combination of these parameters that provides the best energy resolution for several frustum shape CsI(Tl) samples of different providers.

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The Effect of Calcium Codoping on Praseodymium Doped LSO

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Cerium-doped lutetium oxyorthosilicate (LSO) is a well-known scintillator whose high density (7.4 g/cc), high light yield (~6 times that of BGO), and fast decay time (~40 ns) make it especially well suited for use in Positron Emission Tomography. Recent work has shown that calcium codoping has a significant positive impact on the scintillation properties of cerium doped LSO, increasing the light yield and shortening the decay time, in some cases to the ~ 30ns range. This current study extends that work to additional activators. Praseodymium doped LSO single crystals, with and without calcium codoping, have been grown via the Czochralski method. The dopant concentrations were on the order of 0.2 atomic percent with respect to Lu. Scintillation light yield and decay time have been measured, and emission and excitation spectra have been acquired. The results show that, in addition to its effect on cerium doped LSO, calcium codoping also has an impact on praseodymium doped LSO. One striking example is in the emission spectrum at 260nm excitation; in Pr:LSO, a more complex structure is seen, with multiple peaks. In Pr:Ca:LSO, only the 610nm peak remains intact; the shorter wavelength emissions are significantly reduced. Another effect can be seen in the decay time; using a two-component exponential decay, it can be seen that calcium codoping favors the fast component of decay at the expense of the slow.

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Characterization of Scintillation Crystal BaCl2 at Low Temperature

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The scintillation crystal of BaCl2 was grown by Czochralski method. The grown crystal was cut into a size of 10 x 10 x 5 mm3. Scintillation properties of the crystal such as pulse height spectra, energy resolution and fluorescence decay time were measured with

the Cs-137 gamma ray source at room temperature. We measured the temperature dependence of the scintillation light yield and decay time for the BaCl2 crystal with a photomultiplier tube (PMT). The BaCl2 crystal cooled down from room temperature to 10K in compressed helium gas. We measured the light yield and decay time change of BaCl2 crystal from 10K to room temperature. The light yield of BaCl2 at 200K was three times higher than that of room temperature. The decay time was getting slower as temperature decreases.

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Development of Radiation Detectors Based on II-VI Compounds

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Chalcogenide scintillators (CS) based on activated ZnSe crystals (ZnSe(DOP)-type, where DOP - Te, Cd, Al, O etc.) have luminescence maximum 600-640 nm, radiation conversion efficiency - up to 22% (absolute light output up to 70000 ph/MeV), decay times - 0.5-2 mcs and 30-50 mcs ("fast" and "slow" types of CS), afterglow level - less than 0.02% after 5 ms, and radiation stability - more than 500 Mrad. The unique combination of output characteristics, scintillating and semiconductive properties of CS ensures the possibility of development of combined detectors intended for new type of high sensitivity/resolution multi-energy radiography and antiterroristic custom safety introscopy, dosimetry and spectroscopy of ionizing radiation of various types - X- and gamma-rays, charged particles, UV radiation, etc. It is shown that this combination also allows to create AIIBVI heterostructure-photoreceivers of intrinsic luminescence of the scintillator directly on the ZnSe(DOP) crystal surface, and this permits the development of integrated detectors of the ZnSe(DOP)/pZnTe-nCdSe, ZnSe(DOP)/pZnTe types. Improved UV photodetectors for A, B, and C ranges (200-400 nm) with metal-semiconductor junction based on activated ZnSe(Cd,Te) crystals are described.
This work are supported by the INTAS 05-104-7519 and STCU #4115 Grants.

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Problems of Manufacturing Nanocrystalline Yttrium Silicate Materials

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An idea of manufacturing scintillation nanopowder materials attracts a certain interest of scientists and producers due to some new possibilities of producing ceramic scintillation materials as an alternative to single crystalline scintillators. It is very important because the procedure of single crystal growth is a long-stand, power-intensive and rather expensive process. Generally ceramic materials can be prepared by powder metallurgy methods. However these methods do not allow preparing transparent samples. In our opinion, solution of this problem may be connected with preparing scintillators in nanocrystalline structural condition. Besides, nanocrystalline scintillation materials if used as precursors for single crystal growth may give single crystalline scintillators with much better performance. One of the methods applied for producing nanopowders is sol-gel procedure. The method is widely used for manufacturing nanophase organic compounds, optical materials and composites. The sol-gel process is based on producing gel of sol with the follow-up production of powders through calcinating the gel. The developed nanotechnology makes possible to prepare number of standard scintillation materials, among them - yttrium silicates. Using the modified sol-gel process there was synthesized yttrium orthosilicate Y2SiO5. As initial materials were used yttrium oxide Y2O3 and tetraetoxysilan Si(OC2H5)4. There were studied structure conditions of the powders obtained after thermochemical synthesis at different temperatures. Diffraction studies of the obtained samples showed that the silicate obtained as a result of synthesis at 800oC was amorphous for X-rays. Synthesis at 900oC resulted in the formation of monoclinic nanocrystalline structure. The same structure was formed at the synthesis at 1000oC. The monoclinic structure was stable up to 1050oC; above this temperature it transformed into monoclinic structure of some other type.There are known various modifications of yttrium silicates: Y2Si2O7 with triclinic, monoclinic orthorhombic structures as well as the structure not yet identified; there are also Y4.67(SiO4)3O with hexagonal structure and Y4Si3O12 with a nonidentified structure. In our experiments there were synthesized different types of yttrium silicates: Y4.67(SiO4)3O (a), yttrium pyrosilicate Y2Si2O7 with monoclinic structure (b), yttrium oxyorthosilicate Y2SiO5 with monoclinic structure (c) and it was established that any deviations from the certain modes resulted in the formation of Y2O3 together with the mixture of Y4.67(SiO4)3O and Y2SiO5 silicates.There were conducted experiments on fabricating scintillators in nanocrystalline condition via using the Spark Plasma Synthesis (SPS) method. Combined influence of the processes having place during SPS are considered as satisfactory for compaction of nanopowders without the loss of nanocrystallinity. However the first samples sintered in SPS device were not transparent. At present the process of fabricating nanocrystalline scintillation materials via using SPS device is in the process of establishing and we suppose to prepare transparent scintillators in nanocrystalline condition with monophased structure.

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On Radiation-induced Processes in GSO:Ce Crystals

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The results of studies of radiation-induced processes (variation of optical, luminescent and scintillation properties) occurring under gamma-radiation (E~1.2 MeV) with doses D=10^2-10^7 R in GSO:Ce crystals are reported. Both untreated samples and samples that had undergone special after-growth thermal treatment in different gaseous media (vacuum, oxygen-containing atmosphere) were used. The preliminary vacuum treatment was carried out in different regimes of "heating - maintaining at a stable temperature - cooling". At D10^6 R the speed of the optical-luminescent parameter variation is decreased. It has been shown that deep capture levels with Ea=0.70-0.84 eV are related to thermally unstable defects of the radiation origin, which are annealed at T>500 K. Effect of stoichiometry of the crystal composition have been considered, which, alongside with cerium activation, determines the limits of radiation stability of GSO:Ce crystals.

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Peculiarities of Cascade Photon Emission and Energy Storage in $M_{1-x}Pr_xF_{2+x}$ (M=Ca, Sr, Ba) Crystals

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Recently, Pr-doped crystals have become an object of research for new scintillation media. The presence of cascade emission photons in such crystals is yet another argument in favor of the research, since this phenomenon enables to produce two photons per one quantum absorbed. At high concentrations of RE^{3+} ions (x ~= 0.1), solid solutions may well form such compounds as $M_{1-x}Pr_xF_{2+x}$ with the fluorite structure. In the lattices of this type, RE ions are not distributed statistically over the locations of M^{2+}, but they form nanosized inclusions or superlattices [1]. The goal of this research was to study the effects of concentration and structural state of Pr^{3+} ions on implementation of the photon cascade emission as well the energy storage in $M_{1-x}Pr_xF_{2+x}$ (M=Ca, Sr, Ba) crystals. Luminescence spectra of mixed compounds are discussed. In $Sr_{0.65}Pr_{0.35}F_{2.35}$ and $Ba_{0.65}Pr_{0.35}F_{2.35}$ the first step of CPE is suppressed, with the second one being more pronounced. Typical f f luminescence lines are broadened, as compared with the PrF_3. An assumption can be made that the differences in the emission should be associated with the ratio of M^{2+} and Pr^{3+} radiuses. Spectrum analysis does not allow bringing out some type or another of the superlattice which is inherent to the material, but it indicates clearly the presence, at one and the same time, of different types of $M_xPr_yF_z$ cluster in mixed crystals. Yet another specific feature of the mixed fluorites is their different radiation induced coloration relative to the MF_2 crystals. None of the induced bands in $M_{1-x}Pr_xF_{2+x}$ corresponds to those appearing in pure and weakly Pr doped fluorides. The data obtained are discussed from the standpoint of structural defects and cluster formation specifics in the highly concentrated solid solutions that have the fluorite lattice.
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Cerium and Yttrium Distributions in LSO crystals and their Influence to Optical and Scintillation Properties

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We present in this paper a study on the correlation between optical and scintillation properties and the concentrations of cerium and yttrium doped in lutetium yttrium oxyorthosilicate crystals (LSO:Ce). A large size LYSO:Ce single crystal bole (60mm in diameter and 250 mm long) was grown by Czochralski method at Sichuan Institute of Piezoelectric and Acousto-optic Technology (SIPAT), Chongqing, China. A total of eleven cubes of 17 mm were cut from this bole. Glow Discharge Mass Spectrometry (GDMS) analysis was performed to measure the concentration of cerium and yttrium in these samples. The segregation coefficients of cerium and yttrium were found to be 0.30 plus/minus 0.01 and 0.88 plus/minus 0.04 respectively. Optical and scintillation

properties, such as optical transmittance, light output, decay kinetics and energy resolution, were also measured for these samples. It was found that the optimized cerium concentration in LYSO:Ce crystal is in a range between 200 ppmw and 300 ppmw. Cerium concentration higher than 300 ppmw in LYSO:Ce crystals would deteriorate crystal's transmittance and light output. Correlations between cerium and yttrium concentrations and the corresponding optical and scintillation properties will also be reported.

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Cerium Activated Scintillation in Yttrium Halides: First Principle Theory and Prediction

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Recently, high luminescence scintillation has been observed in YI3:Ce crystals. In our group, Ce-scintillation has been observed in YCl3 and YBr3. In this work, we present a systematic study of scintillation in four Ce-doped yttrium halides. Last year, our group demonstrated successful application of a method of gauging scintillation properties of Ce-doped crystals based on first-principle calculations using density functional theory. This method has been developed as an integral component of a High Throughput Scintillator Discovery facility based at the Lawrence Berkeley National Lab. By analyzing the energies and spatial localization of the highest occupied band in the ground state and in the lowest excited state, we are able to make predictions about the possibility of scintillation in a large group of compounds. In this paper we present the details of our theoretical approach in application to yttrium halides and compare them with the available experiments. Our results yield a prediction of Ce-based scintillation in YF3 and YCl3. By the time of the conference, we expect to have the experimental validation of this phenomenon. We also plan to obtain theoretical results for YBr3. We claim that our method is the first example of application of first-principle theoretical calculations to predict the presence or absence of scintillation in crystals using only the structural information about materials.

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Crystal Growth and Scintillation Properties of Rb2CeBr5

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Crystal growth, luminescence and scintillation properties of Rb2CeBr5 crystal are presented. The crystal was grown with the Bridgman method using two zone transparent furnace and was cut to dia.10mm, length 5 mm. The investigation of the Rb2CeBr5 luminescence and scintillation properties was performed under the excitation by UV and gamma-ray at room temperature. The emission spectrum of the Rb2CeBr5 was observed in the range of 360~440 nm, peaking at 390.5 nm, which is due to the 4f ->5d transitions

of the Ce3+ [1]. The decay time of the Ce3+ emission was composed two components. The fast component was 56.1ns (98.8%), and the slow component was 329.9 ns (1.2%). The energy resolution of the Rb2CeBr5 single crystal was obtained to be 11.8% for the Cs-137 662 keV gamma-ray. The relative signal of the Rb2CeBr5 crystal by the Cs-137 gamma-ray is about 3.2 times higher than that of a CsI:Tl crystal when bi-alkali PMT was used. The non-linearity in the gamma-ray energy and alpha/beta-ratio of the crystal was also measured.

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Characterization of Cerium Fluoride Nanocomposite Scintillators for Neutron Capture Measurements

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Current research in weapons physics, the nuclear fuel cycle, and astrophysics require neutron capture cross-sections of isotopes with half-lives less than several hundred days. However, the high decay rate of the isotope sample and the high neutron flux required for this measurement result in a high background rate, necessitating a detector with a fast signal decay time. Current neutron capture experiments, such as NTOF and DANCE, are unable to measure these cross-sections. A possible solution is the use of nanocomposite scintillators, consisting of nanoparticles of an inorganic scintillator dispersed in a matrix material. Since nanocomposite scintillators do not require the growth of large crystals, they may permit the use of scintillating materials not currently available in the needed sizes and quantities. Cerium fluoride (CeF3) has been identified as a suitable scintillator for measuring neutron capture cross-sections of short-lived isotopes. We have successfully fabricated CeF3 nanoparticles with sizes < 10 nm. The nanoparticles have been dispersed in a solution optimized for light yield. The size, structure, and radiation detection characteristics of the particles have been measured. Their scattering behavior has been analyzed against a Rayleigh scattering model. In addition, requirements for the matrix material have been identified and selection of an appropriate matrix has begun. Several other potential scintillator materials have been identified and fabricated. Current results of the research will be presented. LA-UR-08-0541

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Luminescence of LuCl$_3$:Pr^{3+} under interconfigurational ($4f^2 -> 4f^15d^1and band gap excitation

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The optical properties of Pr3+ activated LuCl3 under interconfigurational 4f2 -> 4f15d1 and band gap (193 nm; X-ray) excitations have been evaluated. The luminescence of LuCl3:Pr3+ is found to be strongly dependent on the excitation energy: for energies less than the absorption edge of the host, the luminescence of LuCl3:Pr3+ is dominated by the 4f15d1$ ->4f2 interconfigurational optical transitions. When luminescence is excited by photons with energies corresponding to the absorption edge or the band gap of the host, the emission spectrum is dominated by the Pr^{3+} 4f2->4f2 intraconfigurational optical transitions. A model to account for the dependence of the emission behavior on the excitation energy is presented. The Cl^- ->Pr^{3+} charge transfer band is identified in the excitation spectrum of $LuCl_3:Pr^{3+}$.

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Measurement of Integral Efficiency in Detection of Fast Neutron Fluxes Using Inorganic Scintillators

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We have studied efficiency of detection of fast, resonance and thermal neutrons (En ~ 0,0025 eV - 10 MeV) by oxide scintillators CWO, BGO, GSO, ZnWO, etc, which are used in systems for detection of fissionable radioactive substances. A method for detection of neutrons and ways for its practical realization are proposed, ensuring high (up to 70%) integral efficiency of detection of fast neutrons in scintillator materials distinguished by high density and high effective atomic number (BGO, CWO, ZnWO,GSO, etc.). To ensure unambiguous correspondence between the facts of neutron interaction and appearance of counting pulse at the output of the detection system, optimized values of the integration time constant was determined for signals of cascade gamma-radiation. Questions are considered related to creation of new efficient types of neutron radiation detectors for detection of radioactive contamination sources and the presence of radioactive materials in objects intended for radiation control systems used in customs and nuclear security services.

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Fast, Low Afterglow Liquid and High Optical Index Scintillators for Fast-Neutron Spectroscopy and Imaging Applications

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For fast-neutron spectroscopy and imaging applications with high power lasers sources (e.g. Polaris (www.physik.uni-jena.de/~polaris/Forschung/F-Englisch/Petawatt/Eng-FP-Petawatt.html) and electron accelerators (e.g., ELBE (http://www.fzd.de/pls/rois/Cms?pNid=35), scintillators with fast light decay characteristic are required. Neutrons are emitted simultaneously with an intense gamma burst and are separated and energy-selected by Time-of-Flight methods. The first neutrons arrive at the spectrometer or imaging system ca 50 ns after the gamma flash. By that time the gamma-induced light signal of the scintillator has to decay to negligible values in order to detect the relatively weak neutron signals. Furthermore, for fast-neutron imaging applications, capillary fibre scintillators are considered for delivering position resolutions in the sub-millimetre range with detection efficiencies of several 10 %. This requires hydrogen rich, low-afterglow scintillator liquids of relatively high refractive index for efficient light conduction in capillary fibres made of quartz or borosilicate. In this contribution we report on our measurements and present results of light yields and glow curves of various commercial and home-made scintillation liquids.

Mixtures of different solvents (p-xylene, toluene, 1-Methylnaphthalene) and various primary and secondary fluors were used. These mixtures were enriched alternatively with nitrogen or oxygen. The oxygen is known to be a very effective quenching agent of the triplet state, responsible for the slow components of the scintillator's glow curve. For measuring the time-dependant light intensity the time-correlated single photon counting technique was selected, which allows to record the glow curve of a scintillator down to 5 - 6 orders of magnitude of its peak intensity. In this contribution we will describe the application of the fast scintillators, present the experimental method and discuss our results.

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Scintillation Properties of Large Area Composite Stilbene Crystal for Neutron Detection

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Stilbene is a good scintillator, which has been widely used as a neutron measurement. Inside scintillator, recoil protons by fast neutrons were produced from n-p scattering, and neutrons ionize indirectly the molecules of the scintillator. Stilbene single crystal has a good spectrometry characteristics and light yield in comparison with plastics and liquids, but they are more expensive and their diameters were not larger than 60-80 mm. Crystalline grains of stilbene have been preliminarily obtained by mechanical grinding of stilbene single crystals, and a large size composite stilbene scintillator was manufactured with crystal grains into organosilicone base. The major aim of this work is to compare detector responses of the large area composite stilbene scintillator of diameter 200 x 20 mm size and reference stilbene single crystal of diameter 25 x 20 mm size when they are used for the detectors of fast neutrons. To study a degree of heterogeneity of light yield, we have measured the response of the large area scintillator at different points of surface. The measurements were carried out by using BURLE 8850 and 8575 photomultiplier tubes and Hamamatsu 3584-08 photodiode. We measured and investigated response properties of alpha, beta, gamma and neutron. The neutron source used for this study is Cf-252 and mono-energy fast neutrons by using accelerator in Korea Institute of Geoscience and Mineral Resources(KIGAM). The measured results are compared to the response of a small size(diameter 25 x 20mm) stilbene single crystal. This work was carried out under the Nuclear R&D program of the Ministry of Science and Technology, Korea and supported by the iTRS SRC/ERC program of MOST/KOSEF.

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Large Volume $ZnWO_4$ Crystal Scintillator with Excellent Energy Resolution and Low Background

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Zinc tungstate single crystals are widely used in nuclear spectrometry, tomographic technics and for the low-counting experiments (to investigate the double beta decay processes, search for dark matter, study of rare alpha and beta decays). The purpose of our work was development of radiopure $ZnWO_4$ crystal scintillators with high scintillation characteristics and low afterglow. $ZnWO_4$ single crystals were grown by Czochralski method in platinum crucibles onto oriented seeds from raw charge obtained using high-temperature solid-phase synthesis by sintering of the metal oxides. Large volume zinc tungstate crystal scintillators (up to 50 mm in diameter and 100 mm length) with improved energy resolution and afterglow were developed as result of advances in crystal growth. The one-centimetre cube $ZnWO_4$ crystals showed energy resolution in the range 8 - 10% for 662 keV gamma-line of ^{137}Cs. A value of 13.7% has been obtained with a large sample dia.44 x 55 mm. Low level of afterglow (0.002%, 20 ms after excitation) was obtained with $ZnWO_4$ scintillators, while typical value for this crystal do not exceeds 0.1%. The radioactive contamination of a $ZnWO_4$ 26 x 24 x 24 mm detector was tested in the Solotvina Underground Laboratory. Alpha activity at the level of 2.4 mBq/kg (daughters of U/Th) was detected in the scintillator, ^{228}Th contamination is less than 0.1 mBq/kg, activity of ^{226}Ra does not exceeds 0.16 mBq/kg. The obtained results demonstrate ability to use $ZnWO_4$ in order to search for 2 beta-decay of Zinc and Tungsten, in nuclear spectrometry and tomographic technics .

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Fabrication of a Coherent Fiber-Optic Bundle Sensor Using Organic Scintillating Fibers for High Dose Rate Brachytherapy

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Brachytherapy is a procedure in which radioactive sealed source is placed directly into or near the cancer. To verify in vivo dose distribution in brachytherapy, a small insertable dosimeter with a real-time readout is required. Also, a dosimeter that can be used in brachytherapy should have a small sensitive volume for high resolution measurements because the radioactive source produces high dose gradients. As a promising candidate, the fiber-optic dosimeter using organic scintillator can be adopted because it emits visible light proportional to the absorbed electron and gamma dose rate and it does not disturb the radiation field due to its water-equivalent characteristics in a wide range of energies. Additionally, a dosimeter based on organic scintillator provides a fast real-time readings and the diameter of organic scintillators can be as small as 1.0 mm or less. In this study,

we have fabricated a coherent fiber-optic bundle using organic scintillating fibers for high dose rate brachytherapy. An organic scintillating fiber made out of a polyvinyltoluene (PVT) base with wavelength-shifting fluors is used. The emission color and peak of this organic scintillator is green and 492 nm, respectively. To fabricate a coherent fiber-optic bundle, the 1.0 mm diameter scintillating fiber is cut into 10 cm length, and 25 of them are bundled together and stacked in a 5 x 5 square metallic housing. This fixture is placed in a heated vacuum oven to make a fused bundle. After polishing a surface of the bundle, 25 plastic optical fibers (POFs) are glued to the 25 organic scintillators coherently to transmit a light signal to the light-measuring device. Each POF has 10 m length and 1.0 mm diameter. To measure multichannel light signals simultaneously, a charge-coupled device (CCD) is used and each light signal generated from an organic scintillator is guided independently to a CCD. The objectives of this study are to measure in vivo dose distributions of the high dose rate (HDR) brachytherapy source (Ir-192) and to find a location of the source in a body during cancer treatment. Additionally, normalized depth dose curves will be obtained easily using a coherent scintillating fiber-optic bundle sensor and a solid water phantom.

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The Growth and Scintillation Characteristics of CsI:CO3 Single Crystals

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We present luminescent and scintillation characteristics of CsI:CO3 single crystals. We grew CsI:CO3 single crystals by using the Czochralski method for different concentration of CO3 from 0.01 to 0.1mole-percent. The luminescent characteristics were measured with X-ray and electron beam to study the emission spectra of the CsI:CO3 crystals. The scintillation properties of the CsI:CO3 crystals such as fluorescence decay time, energy resolution, pulse height spectra, proportionality, relative light output were studied by using various gamma ray source and an alpha source with a photomultiplier tube (PMT) at room temperature. The absolute light output of these crystals was also measured with avalanche photo-diode (APD). In particular, the alpha/beta light ratio and possibility of a pulse shape discrimination between alpha and gamma quanta using an Am-241 alpha source will be presented.

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Temperature Dependency of a Semi-insulating GaAs Radiation Detector for Alpha-Ray

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In general, the requirement for a room temperature operation of a semiconducting material for a radiation detection is a large band gap energy such that the thermal generation of the signal carriers is kept to a minimum. The band gap of the GaAs is 1.42 eV and it is sufficiently wide to allow for its use as a radiation detector at room temperature. Detector structures have been fabricated by SI GaAs wafers grown by the LEC (liquid encapsulated Czochralski) growth method. The undoped semi-insulating wafers were an orientation of (100) and a diameter of 50.8mm. Front surface was polished and the back surface was etched after a lapping. Resistivity was measured as a 7.58 x 107 Ohm-cm and the Hall electron mobility was a 6,800 cm2/V-s. The dimensions of the GaAs SI bulk detectors were about 10x10 mm2 with a 350 um thickness. Prior to a metallization process, the surfaces of the GaAs wafer were etched by H2SO4 and H2O2 solutions and rinsed with de-ionized (DI) water, and the removal of an oxidation layer by a HCl solution was performed. Metal/semiconductor contacts on the surface were fabricated by using a thermal evaporator in a high vacuum condition. The prototype GaAs detector had circular metal contacts of Ni/Au at each side and the diameter of a circular contact was 5 mm. The current-voltage characteristics of GaAs semiconductor detector were measured by using HP parameter analyzer with voltage sources. We measured the leakage currents at different temperature conditions. Also, the radiation response was evaluated by gamma-ray source at variable operating temperature.

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Performance Characteristics for Thick Scintillator Flat Panel Detectors

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We have developed a process to deposit extremely thick, micro-structured CsI scintillator layers onto large-area x-ray panels. The performance of the detectors in terms of contrast to noise ratio (CNR), modulus transfer function (MTF), and the ability to resolve objects through various thicknesses of steel are discussed. The impact of extra-detector scatter on image quality will also be considered.

This work is funded under contract # HSHQDC-07-C-00036, Large Area X-ray Detector for Cargo Inspection, BAA 06-01, Exploratory Research in Nuclear Detection Technology, Domestic Nuclear Detection Office (DNDO), DHS.

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Improved Radioxenon Gamma Spectrometry Counting System and its Efficiency Calibration: Monte Carlo Simulation and Experimental Results at Enriched Xenon Counting Environment

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One of the atmospheric radioxenon monitoring methods for the Comprehensive Nuclear-Test-Ban Treaty (CTBT) is achieved using SPALAX (Systeme de Prelevement d'air Automatique en Ligne avec l'Analyse des radioXenons) and HPGe gamma-spectrometry. The system extracts xenon from the atmosphere and then measures the extracted concentration activity of radioxenon isotopes (Fontaine 2004). The four radioxenon isotopes 131mXe, 133mXe, 133Xe, and 135Xe activity concentration can be determined through analysis of their gamma-rays. The X-rays have been ignored frequently due to low efficiency in X-ray region, difficulties of efficiency calibration and lack of software for X-ray multiplets deconvolution. If the X-rays could be analyzed individually or simultaneously with gamma-rays, it would have several advantages over analysis of gamma-rays only, such as improved precision and enhanced detection limits. Theoretically the extension of the spectroscopic analysis to the X-ray region could offers possible improved precision in the analysis of metastable isomers and 133Xe ranging from several folds for 131mXe to several percent for 133Xe. This paper describes an improved counting system developed in CTBT Canadian radioxenon laboratory which gives satisfied efficiency both for X-ray and gamma-ray photon. The counting system consists of a BEGe detector and coupled with a carbon fiber window counting cell, which can perform a reliable and efficient radioxenon measurement. A semi-empirical calibration procedure was therefore adopted, which is combination of experimental measurement and mathematical simulation. Mathematical calibration tool is Monte Carlo simulation software named VGSL (Virtual Gamma Spectroscopy Laboratory) developed under the auspices of CTBTO (Plenteda, 2002). The Aatami software (CTBT Preparatory Commission, 2003) was used for gamma-ray peak shape fitting and X-ray multiplets deconvolution. The calculated full energy peak efficiency curve covers from 30 to 700keV and agrees well with experimental data points within accuracy better than 2%. The efficiency curve can provide radioxenon analysis both for X-rays and gamma-rays with high quality. The efficiency distortion near xenon k-absorptions at 35keV, which is caused by high concentrated xenon in the counting cell, has also been discussed.

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Imaging System for XRF Microtomography at LNLS-Brazil

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An X-ray Transmission Microtomography (CT) system combined with an X-ray Fluorescence Microtomography (XRFCT) system was implemented in the Brazilian Synchrotron Light Source (LNLS), Campinas, Brazil. The main of this work is to determine the elemental distribution map in reference samples and breast tissue samples in order to verify the concentration of some elements correlated with characteristics and pathology of each tissue observed by the transmission CT. The experiments were performed at the X-Ray Fluorescence beamline (D09B-XRF) of the Brazilian Synchrotron Light Source (LNLS), Campinas, Brazil. A quasi-monochromatic beam produced by a multilayer monochromator was used as an incident beam. The sample was placed on a high precision goniometer and translation stages that allow rotating as well as translating it perpendicularly to the beam. The fluorescence photons were collected with an energy dispersive HPGe detector (CANBERRA Industries inc.) placed at 90 degrees to the incident beam, while transmitted photons were detected with a fast Na(Tl) scintillation counter (CYBERSTAR-Oxford anfysik) placed behind the sample on the beam direction. The CT images were reconstructed using a filtered-back projection algorithm and the XRFCT were reconstructed using a filtered-back projection algorithm with absorption corrections.

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Fast Pulsed Neutron and Soft X-Ray Source For Detector Calibration*

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<u>*Brian Bures, presenting*</u>
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Alameda Applied Sciences Corporation (AASC) has built a bench-top source of soft x-rays (1-4keV) and fast neutrons (~10-40ns, 2.45MeV), that is portable and offers a high data rate for calibration of radiation detectors. The source is a Dense Plasma Focus (DPF) pinch that is driven by a ~500J/13kV capacitor bank. At currents of ~130kA, this source produces ~0.1J of soft x-rays and ~3E6 (DD) n/pulse. The soft x-ray and neutron pulse widths are ~10-40ns and may be controlled by adjusting the DPF electrode geometry and

operating parameters. This bench-top source may be operated at 1000 pulses/hour without cooling and exhibits pulse-pulse variations of ~40% (1-sigma) without active control. With implementation of simple flow and temperature control, this variation may be reduced to ~20%. Such pulse-pulse variation, when averaged over 1000s of pulses, would allow ~1% relative calibration of radiation sensors, in just a few hours. The pinch emits isotropically, allowing multiple sensors to view the source at the same time. Switching from soft x-ray to neutron mode is achieved by merely changing the operating gas fill from Ne, Ar, Kr etc to D2 or D2/T2. Fast scintillators and solid-state neutron detectors may be calibrated using the very fast pulses from the DPF. Standard portable neutron tubes emit >1us pulses, and fast Van De Graaff generators, which can give ~1ns pulses, are not portable. The DPF may be packaged into a 60cm dia. x 100cm tall tube and operated for ~1E5shots at a time with no maintenance. The DPF is also readily scalable to higher outputs. For example, a 2kJ version (1 m dia. x 1m tall) that delivers 300kA to the pinch and generates ~40J at 1 keV, ~2J at 3keV and ~3E8n/pulse has been demonstrated. Operation of the prototype source and its use with a soft x-ray spectrograph and soft x-ray sensors as well as neutron detectors are described in this paper.

* Work supported by the Defense Threat Reduction Agency

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Small-Angle X-Ray Scattering / USAXS/ Diffraction from Biological Samples

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The SAXS / USAXS / diffraction patterns from different tissues varies according to both genetic (species) and environmental (habitant differences). Trace elements have an important role in the organisms, and their physiological effects may vary according to the chemical forms in the organisms. The necessity of information about the diffraction patterns of low absorbing materials is one of the most important goals in the field of biological sciences. The understanding of these biological systems at the molecular level is very less and considerable amount of work is necessary in order to establish a more detailed molecular anatomy of these systems. X-ray diffraction pattern provides the crucial tool for determining the structure and enhancement of some desired property, for example biological activity. It is essential to know the diffraction patterns of these samples for their potential use as bio-indicators as they live in geologically different conditions. The beneficial implications of the knowledge of these diffraction patterns and hence perhaps the understanding of disease processes on a molecular level are enormous. It means that the information extracted from the diffraction pattern can be used to derive the molecular structure. Most biological systems, however, have some degree of spatial ordering and biological structures from these samples will provide extremely useful information. Utilization of SAXS to study soft-matter / biology is a challenging idea.

Important constituents in biological systems were chosen as starting points. Biological macromolecules are normally too complex to be studied directly. Yet is possible to examine their smaller constituent molecules and to extrapolate the collected information on the molecular configuration and on the nature of the bonding in macromolecules. In this way, some important conclusions might be expected in the future with an improved physical understanding. Because of the enormous X-ray fluxes available from synchrotron sources, SAXS studies on biological systems are uniquely informative, for example, from biological systems, will help to solve the molecular arrangements in the sample. The experimental observable is the dynamical structure factor S (Q, Z), which describes the atomic density fluctuations spectrum. At a given momentum transfer Q essentially unlimited energy transfer with constant instrument resolution. SAXS spectra (Intensity Vs Energy (MeV)) at different Q momentum transfer values, will explore new information about the biological systems. Biological structure provides the crucial tool for determining the structure and enhancement of some desired property, for example, biological activity. It is essential to know the biological structure of these samples for their potential use as bio-indicators as they live in geologically different conditions. The beneficial implications of the knowledge of these biological structures and hence perhaps the understanding of disease processes on a molecular level are enormous. It means that the biological structures can be used to derive the molecular structure. Most biological systems, however, have some degree of spatial ordering and biological structures from these samples will provide extremely useful information.

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Novel Three-Dimensional Gamma-Ray Emission Imaging Built On Compton Scattered Radiation

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Compton imaging is currently a topic of intense research. Despite numerous innovations, it remains a formidable mathematical and technical challenge. In this work, we advocate the detection of Compton scattered photons by the bulk of the medium volume surrounding the radiating object for imaging purposes, instead of their elimination as a nuisance. Collected data consists of series of compounded conical projections for each scattered photon energy (or scattering angle). Image formation can be then appropriately modeled by a compounded conical Radon transform. Under suitable conditions, this transform is invertible and analytic three-dimensional image reconstruction is implementable. As the scattering angle plays the role of the spatial rotation angle in conventional tomography, data can be acquired by a detector operating in a fixed position and no coincidence circuitry is necessary. Thus this novel modality leads to a new detector conception with high energy resolution but without bulky cumbersome spatial rotational mechanism. This is highly attractive for medical imaging, industrial non-destructive evaluation, nuclear waste storage surveillance and home land security monitoring.

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Differential Phase-Contrast Imaging Experimental System Based On Moire Deflectometry with Incoherent X-Rays

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Hard X-ray phase-contrast imaging is a newborn non-destructive testing and diagnostic technology in medicine, biology and materials science. It provides high sensitivity and contrast of weakly absorbing low-Z objects by measuring phase shifts of the X-rays. Since 1990s, several hard X-ray phase-contrast imaging methods have been developed. Interferometer-based methods use an X-ray interferometer to measure phase shift of the X-rays pass through the sample directly. Propagation-based methods apply Fresnel diffraction to provide contrast relative to the second derivative of phase shift. Analyser-based methods yield differential phase shift by use of a perfect crystal according to Bragg diffraction theory. Grating-based methods also obtain differential phase shift by use of a grating interferometer (i.e. Talbot interferometer) according to Talbot theory. Above methods all rely on highly coherence of synchrotron radiations or micro-focus X-ray tubes. In 2006, Pfeiffer et al firstly attempted to measure differential phase shift by use of three gratings with conventional X-ray tubes. Their method derived from grating-based methods with synchrotron radiations. The first grating before the X-ray source acts as a beam splitter to create an array of individually spatial coherent X-rays, then the coherent X-rays irradiate the Talbot interferometer to measure differential phase shift. Thus, a traditional viewpoint is that coherent X-rays and coherent measurements are essential to hard X-ray phase-contrast imaging at all times, but the demand of coherence obviously limits practical applications of phase-contrast imaging. In this paper, we introduce a differential phase-contrast imaging experimental system consisting of a conventional X-ray tube, two absorption gratings and a digital X-ray imager with amorphous silicon. The new system is based on moire deflectometry with incoherent X-rays by use of two gratings according to geometrical optics without any coherent theory. Moire phenomenon is produced when two absorption gratings irradiated by incoherent X-rays directly. In the case of cone beam X-rays generated from conventional X-ray tubes, different distance between two gratings with different periods results in diverse moire effects. Phase stepping method is adopted to obtain differential phase shifts of the X-rays past through the sample. Three model samples and a little white mouse's back claw are done in the experimental system to validate the new method. Furthermore, our system has high energy utilization efficiency by employing the X-rays of all energy spectra from X-ray tubes with large fields of view, but not of certain special energy which has to be elaborately selected in coherent methods. The fabrication of high aspect ratio gratings can also be simplified due to the incoherent condition. Thus, it breaks through the traditional viewpoint on the demand of coherence and realizes hard X-ray phase-contrast imaging with incoherent method revolutionarily. We anticipate that our system would be an effective prototype of phase-contrast imaging with conventional X-ray tubes applied to clinical diagnoses, biologic examinations and material inspections, et al.
Acknowledgements: The work was supported by Program for New Century Excellent Talents in University.

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Improved Characterization of Environmental Samples

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Various types of environmental samples are being routinely collected and analyzed by national and international bodies throughout the world for searching and monitoring of radioactive substances in the environment. Such surveillance becomes even more important in the case of nuclear accidents or malevolent acts. Probably the most common way to study in detail the radiation emitted by a sample is by placing it close to a silicon or germanium detector, which is connected to a multi-channel analyzer. Spectra generated by these detectors are typically analyzed using sophisticated analysis algorithms. If a more complete picture of the sample properties is needed, results of the different measurements will be combined. As is clear, the described approach is reliable and technically simple. Simplicity, however, leads to the fact that only part of the information available is recorded. As an example, a single measurement using a traditional silicon detector is unable to identify the number of particles emitting alphas and/or betas in a sample or their physical location. Obviously, comparisons between particles are impossible and, in addition, coincidence measurements such as beta-gamma or alpha-gamma, and half-life studies are not feasible. Because of such limitations, a program was initiated in Finland aiming to introduce up to date spectroscopy tools for sample analysis. In practice, this means the introduction of Double-Sided Silicon Strip Detectors (DSSSD), special silicon detectors with ultra thin entrance windows, VME-based data acquisition systems, among others, to the field. The work was started by testing the central ideas, briefly mentioned above, at the University of Jyvaskyla, using available detectors in the Accelerator Laboratory. Following the success of the initial tests a design of the first dedicated setup for use with environmental samples was made. Currently this device, known as PANDA, is under construction. When ready, it will be tested in detail using a variety of samples. Since the goal is to bring these techniques to a routine use, a significant effort will also have to be made to automate the analysis of the data. As the detectors, for example DSSSDs, can be used to create a more detailed understanding of the sample properties, this program also includes research and development related to the sample collection. In this presentation we show results from the initial tests made at Jyvaskyla, introduce the design of the PANDA device and generally discuss the whole program. These developments are also applicable to other closely related fields such as nuclear safeguards or nuclear forensics.

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The Application of Forward Scattering in Material Identification

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Dual energy radiation detection technology is widely adopted for the purpose of material identification through non-invasive inspection, especially of large objects like cargo containers. Here we have proposed a new method of dual energy detection. First, a single energy accelerator serves as the source of stable, single energy X-rays, which will serve as the higher energy X-rays of the dual energy radiation. Meanwhile, these single energy X-rays are used to interact with a scattering object. Forward scattering will be produced through the Compton Effect between the radiation and the scattering object. Forward scattering within a fixed small angle, which is obtained through a group of collimators, serves as the other lower energy radiation. In the initial stages of research, we used MCNP4 to simulate the scatter spectrum produced by the interaction between the X-rays from a 9MV accelerator and a graphite scattering object. The simulation further obtained the categorical curves of different materials under the two types of radiation spectrums. The outcome of the simulation shows that by using this method, it is possible to obtain relatively good results in differentiating between organic and inorganic matter. In addition, the presence of a high proportion of low energy X-rays (<300KeV) in the scatter spectrum is useful for identifying relatively thin materials. Building on the foundation of the outcome of the simulation, we used a CWO detector for experimental verification. Initial results have shown that dual energy material identification is feasible through the use of a high energy accelerator and a small degree of forward scattering. We are currently in the process of working on more experiments to further test our theory.

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Fast Neutron Dose Evaluation in BNCT with Fricke Gel Detectors

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The BNCT (Boron Neutron Capture Therapy) is an experimental cancer treatment in which a suitable delivery agent deposits selectively boron inside the malignant cells; afterwards, when the tissue is exposed in a thermal neutron field, the boron capture reactions generate short range and high LET charged particles (7Li and alpha) damaging mainly the cells in which they are produced. Providing an effective boron molecular carrier and a suitable neutron field, the BNCT can be a highly selective method for malignant cells destruction. Adequate thermal neutron flux can be provided by nuclear reactors; up to twenty years ago, thermal neutron fields have been employed for BNCT

for swallow depth tumour treatments, but in the last years a general interest has grown for epithermal (0.5eV to 100 keV) neutron beams that, having a more penetration power, can be used to treat diseases until depths of several centimeters. Dosimetry in an epithermal neutron beams is very complex, because of the presence of different radiation components having different radiobiological effectiveness. The neutron fluence admitted for a treatment is evaluated on the basis of the dose absorbed by healthy tissue. In tissue without boron, the main contributions to the absorbed dose come from photons (due to background and to neutron reactions with hydrogen nuclei in the tissue) and recoil protons (due to elastic scattering of fast neutrons on hydrogen nuclei). The method proposed in this work concerns the evaluation of gamma and fast neutron dose components in a tissue equivalent material and it is based on the optical reading of Fricke gel dosimeters. The Fricke (ferrous sulphate) solution is infused in porcine skin gel layers 3mm thick together with xylenol-orange; these gels, named FriXy gels, are imaged with a CCD camera before and after irradiation; the difference of optical absorbance of visible light at 585nm is proportional to the absorbed dose up to saturation. Therefore, by pixel-to-pixel elaboration of the acquired grey level images it is possible to obtain dose images. This work presents a method that employs a couple of gel dosimeters made of light and heavy water respectively. Thanks to the different recoil energies of protons and deuterons, it is possible to separate gamma and fast neutron doses inside the gel by elaborating the images with proper algorithms. To this aim it is necessary to know the ratio of proton/deuteron released energies that are calculated with a Monte Carlo code (MCNP5). The results obtained with measurements carried out in the BNCT facility at Nuclear Research Institute of Rez (CZ) are presented and compared with data taken with other methods.

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Gamma Cube: An Ultrahigh Resolution and Ultrahigh Sensitivity SPECT System for Tracking Radiolabeled Immune Cells in Mouse Brain

Geng Fu, University of Illinois

In this paper, we present the design and feasibility of a novel ultrahigh resolution and high sensitivity single photon emission microscope (SPEM) system for in vivo imaging of immune cells in mouse brain. This system consists of six intensified EMCCD detectors. Each detector has an active area of 7 cm in diameter and is capable of providing an intrinsic resolution of ~100 um for detecting 27-200 keV gamma rays. An excellent imaging resolution (of around 100 um in 3D) has been demonstrated with a prototype dual-headed SPECT system that is based on the I-EMCCD sensor. In order to achieve a reasonable detection efficiency for in vivo studies, we proposed a novel SPECT system that consists of 6 detectors arranged in a cubic configuration. This system will be coupled to a truncated spherical collimator that incorporates 216 micro-openings (such as pinholes or ring-holes) distributed on the spherical shell. This system offers an very high detection efficiency of 0.2-1% and provides multiple orthogonal views around the object. In our previous study, we have demonstrated the capability of visualizing ~750 radiolabeled T cells in mouse brain, using a dual-headed SPECT system with a measured detection efficiency of 0.025%. Given the greatly improved detection efficiency offered by the Gamma Cube detector, it is possible to image a much smaller number of cells in mouse brain at an ultrahigh imaging resolution (100-200 um). This development would offer an enormously powerful tool for noninvasive monitoring of the homing behavior and recruitment of T cells related to T cell mediated immunotherapy. In this study, we will use three I-EMCCD detectors to form half of the cubic structure as proposed for the Gamma Cube system. A spherical ring-hole collimator will be fabricated using tungsten powder deposited on a rapid-prototyping mode that is made with laser machining. Imaging studies based on both phantom and small animals will be presented. In addition, we will perform Monte Carlo simulation to optimize the design of apertures and to predict the performance of a fully assembled Gamma Cube system for in vivo SPECT imaging based on I-125, I-123 and Tc-99m labeled cells. These results will be presented.

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Radiometric Meteorology

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Gamma radiation from naturally occurring radon progeny may be used as a tracer for meteorological processes: 1) In-situ measurement of atmospheric gamma radiation from radon progeny enables the determination of rain and snow rates to much better accuracy than standard rain gauges and gives a handle on how droplets are formed and 2) Time dependent ratios of gamma radiation from 214Pb and 214Bi which are chemically concentrated and filtered from collected rainwater enable determination of the age of rain drops or the elapsed time since activity adhered to the droplet was removed from secular equilibrium. 1) Gamma ray rates measured with a portable high resolution Ge detector are found to be proportional to a power of radiometric precipitation rates. A highly successful model explains the physics of this relationship and enables one to distinguish the extent to which radon progeny are surface adsorbed or volume absorbed [MG1]. During electrical storms excess activity from lightning has been observed [MG2]. 2) Positive and negative ion exchange resins are used to concentrate and subsequently extract 214Pb and 214Bi ions from 10s of liters of collected rainwater or snowmelt. Gamma radiation from these radio-nuclides, measured with a high-resolution, portable gamma ray detector is integrated over 5-10 min intervals. The measured evolution of these two activities from secular equilibrium to transient equilibrium has meteorological applications enabling both the determination of average elapsed times between the formation of raindrops and the time they reach the ground, as well as an estimate of the initial activity at the source of droplet formation.

[MG1] M. B. Greenfield et al., J. Appl. Phys. 93, pp. 5733-5741, and references therein.
[MG2] M. B. Greenfield et al., J. Appl. Phys. 93, pp. 1839-1844, and references therein

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Special Light-Insensitive Development-Free Radiographic Film for Beam-profile Imaging
Fred Becchetti, University of Michigan
R.S. Raymond, Hao Jiang, M. Ojaruega, A. Villano, presenting (U. Michigan); J.J. Kolata, A. Roberts (U. Notre Dame)
We have tested a special uncoated version of light-insensitive and development-free radiographic film (ISP Gafchromic EBT) for beam-profile imaging of low energy primary and secondary nuclear acceerator beams and radioactive sources. Other possible applications of this material as a nuclear particle and radiation detector also are being investigated.

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An Extended Solenoid-based Time-of-flight Beam Line for Low-energy Radioactive-Beam Research
Fred Becchetti, University of Michigan
Hao Jiang, presenting, A. Villano, M. Ojaruega, R.S. Raymond (University of Michigan); J.J.Kolata, A. Roberts (University of Notre Dame)

The existing UM-UND dual-solenoid low-energy radioactive nuclear beam (RNB) apparatus TwinSol (www.physics.lsa.umich.edu/twinsol) located at the University of Notre Dame FN tandem accelerator is being extended into a well-shielded low-background experimental room to permit improved time-of-flight (ToF) measurements. As part of this project a new, large ISO-250 scattering chamber has been constructed and is being installed. Ray tracing calculations indicate that the extended ToF beam path together with the larger scattering chamber, a new position-sensitive detector array and new beam -timing detectors will allow for significant energy spread compensation in addition to improved angular resolution and identification of the secondary RNB beam reaction products. In-beam tests and initial experiments will be undertaken shortly and the initial results presented.

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Luminosity Measurement Calorimeters and Tracking Detectors for Crabbed Waist Collisions at DAFNE
Paolo Valente, INFN Roma
Nicolas Arnaud, presenting

The Frascati e+e- collider DAFNE, running at sqrt(s) 1.02 GeV is testing the crabbed waist scheme, aiming to reach a large improvement of the specific and integrated luminosity of the accelerator. In order to have a reliable, fast and accurate measurement of the absolute luminosity a number of dedicated detectors have been designed, built, tested, calibrated and put into operation. In particular, three different monitors have been realized: a Bhabha calorimeter, realized with lead/scintillator tiles read by WLS fibers subdivided in 10+10 phi sectors, a Bhabha GEM tracker, of annular shape, with a 4x16 pads per side, covering the same angular region between 18 and 27 degrees in theta, and a Bremsstrahlung proportional counters realized by a couple of 4 PbWO4 crystals at small angle. Results from the beam tests and from the preliminary run of DAFNE are presented.

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Non-Destructive Imaging Materials Investigation by Microfocus 3D X-Ray Computed Tomography

Ricardo Tadeu Lopes, Federal University of Rio de Janeiro (UFRJ)

Inaya Lima, Ricardo Lopes (UFRJ); Carlos Appoloni (Laboratory of Applied Nuclear Physics, Physics Department, UEL, Brazil), Eugenia Duarte (Histological and Embryology Department, UFRJ; Joaquim de Assis (State University of Rio de Janeiro / IPRJ/ UERJ), Gabriela Pereira (Nuclear Instrumentation Laboratory / UFRJ)

Since the X-ray was discovered by Roentgen in 1878 this kind of radiation has been used to inspect the inside of many materials in a non destructive way. A well established method for inspecting the internal structure of materials is 3D X-ray Transmission Computed Microtomography (microCT). MicroCT is a non-invasive imaging technique that provides an internal inspection of a material by its cross section with a resolution typically of the order of several microns. The parameters usually studied in medical research and in industrial fields are porosity and its distribution throughout the material. The main goal of this research is to carry out a high-resolution in vitro analysis of biomedical samples (bones) as well as nondestructive testing of industrial components (SiC components) by microCT in order to obtain the porosity and its distribution. It was used two quantification process. One of them is based on stereologic terminology. Another one is through image processing analysis using Matlab program. The system that was used is a microfocus Fein Focus with an electromagnetic device which allows five degrees of freedom, in relation to the movement and position of the specimen as well as the adjustment of the magnification factor of the captured image. The results show that microCT offers an opportunity for intense investigation in different areas of science and an improvement in providing new information in a non destructive way for different compositions, size and structure.

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A Study of the Performance of the ALICE Zero Degree Calorimeters

Corrado Cicalo', INFN Sezione di Cagliari

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The Zero Degree Calorimeters (ZDCs) for the ALICE experiment will estimate the centrality of the ion-ion collision by measuring the energy carried away by the non-interacting nucleons (spectators). The spectator protons and neutrons will be separated from the ion beams by the separator magnets of the LHC beam optics and respectively detected by the proton (ZP) and the neutron (ZN) calorimeters. ZDCs are spaghetti calorimeters, which detect the Cherenkov light produced by the shower particles in silica optical fibres embedded in a dense absorber. The technical characteristics of ZP and ZN detectors are described. The calorimeters have been tested at the CERN SPS using hadron and electron/positron beams with momenta ranging from 50 to 200 GeV/c; the ZN detector's behaviour has also been studied with an Indium beam of 158 A GeV/c. The beam test results are presented: the calorimeters' response, the energy resolution and the localizing capability. Also the signal uniformity and a comparison between the transverse profile of the hadronic and electromagnetic shower are discussed. Moreover the differences between the ZP detector's responses to protons and pions of the same energy have been investigated. The procedure for monitoring of PM stability and their calibration will also be presented.

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The ALICE Dimuon Forward Spectrometer

Elisabetta Siddi, INFN Sezione di Cagliari

The ALICE Muon Spectrometer is mainly dedicated to the measurement of the production of J/Psi, Psi', Upsilon', Upsilon", through their decay into muon pairs, in different reactions like Pb-Pb, Ca-Ca, p-Pb, p-p. This is a possible signal to identify the formation of the Quark-Gluon Plasma. The Spectrometer, installed on one side of the interaction point, is composed by: - three absorber sections to shield the detectors from the large particle flux: a front absorber in the acceptance region 2 < eta < 9, a beam shield which surrounds the beam pipe and a muon filter, just before the trigger chambers; - a dipole magnet, which will deflect muons according to their charge and allow their momentum measurement. It is 5 m long, 6.6 m wide and 8.6 m high. The central field will be 0.7 T and the integral one > 3 T m; - a tracking system of 10 planes of Cathode Strip Chamber. The tracking CSCs are grouped into five stations, two located before the magnet, one inside and two after it. The shape of each detector is circular with an angular acceptance from 2 to 9. The total surface is around 100 square meters with one million channels equipped; - a trigger system of 4 planes of Resistive Plate Chamber, to select, amongst the background sources, the events of interest, i.e., the muon pairs coming from a J/Psi or Upsilon decay. Different detector prototypes were assembled and tested so far. After more than 10 years of design, R&D and production, all the muon spectrometer infrastructures are in place in the ALICE experimental hall, while all detector modules and their electronics have been assembled and installed. In this presentation the main characteristics of the system, its performance and the physics program will be discussed.

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A Silicon Beam Tracker

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H. S. Ahn (IPST); J. B. Bae, D. H. Kah (Kyungpook National University); C. H. Kim (IPST), H. J. Kim (Kyungpook National University), K. C. Kim, Moo Hyun Lee, presenting, L. Lutz, O. Ganel (IPST); H. J. Hyun, S. W. Jung (Kyungpook National University); A. Malinin (IPST); H. Park, S. Ryu (Kyungpook National University); E. S. Seo, P. Walpole, J. Wu, J. H. Yoo, Y. S. Yoon, S. Y. Zinn (IPST)

A general purpose Silicon Beam Tracker (SBT) was constructed with an active area of 32.0 x 32.0 mm^2 to provide beam tracking. The tracker consists of two modules, each comprised of two orthogonal layers of 380 micro-m thick silicon strip sensors. In one module each layer is a 64-channel AC-coupled single-sided silicon strip detector (SSD) with 0.5 mm pitch. In the other, each layer is a 32-channel DC-coupled single-sided SSD with 1.0 mm pitch. The signals from the 4 layers are read out using modified CREAM hodoscope front-end electronics with a USB 2.0 interface board to a Linux DAQ PC. In this paper we present the construction of the SBT, along with its performance in radioactive source tests and in a beam test at CERN, the European high energy physics lab.

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Comparative Simulation Study of I-124 and F-18 on the Three MicroPET Series Systems: Measurement of Sensitivity and Scatter Fraction

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I-124 is an isotope suitable for development of new radiopharmaceutical and immuno-PET. The physical characteristics of I-124 induce the degradation of image quality. In previous study, we have presented the results of Monte Carlo simulation for the R4, F120, and newly released Inveon PET systems. In this study, we simulated and compared the count characteristics including sensitivity, scatter fraction of I-124 with those of F-18 on the R4, F120 and Inveon systems. PET geometry and physical component such as photoelectric effect, Compton and Rayleigh interactions were simulated. Simulation for sensitivity and scatter fraction were repeated under two different conditions (energy window: 250~750 keV or 350~650 keV). NEMA-like rat and mouse phantoms were simulated for calculating scatter fraction. Sensitivity of I-124 on R4, F120 and Inveon were 1.3, 1.6, and 2.6% within an energy window of 250~750 keV. Scatter fraction of mouse simulating phantom of R4, F120, and Inveon were 22.0, 21.4 and 21.3% within the same energy windows. This paper presents the comparative results of Monte Carlo simulation for I-124 and F-18 on the R4, F120 and Inveon PET scanner. Only 23% of

decays of I-124 are pure positron emission, which lead to lower sensitivity compared with that of F-18. The results show that scatter fractions of I-124 were similar on the R4, F120 and Inveon scanner.

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Development of a Near Real-Time Photon Dose Monitor

Michael Shannon, Georgia Tech

Work is underway at Georgia Tech to develop an instrument to monitor, in near real-time, the dose from a pulsed bremsstrahlung field operated in an outdoor environment. The radiation field of interest is generated by a high-energy (20-30 MeV) electron accelerator used for national defense applications. Doses in the primary beam can be quite high and are relatively simple to detect. On the other hand, doses in the scattered beam approach background, which provides a significant detection challenge. Coupled with these challenges, is the requirement for the detector to operate in austere conditions ranging from high temperatures to rain and snow conditions. The proposed system utilizes a near-tissue equivalent plastic scintillator coupled to a photomultiplier tube and associated electronics package. This detection scheme is used to determine the electron energy deposition spectrum in tissue which results from gamma-ray interactions. From these data, a dose estimate can be made. Currently, the proposed system is undergoing a series of Monte Carlo modeling studies to optimize the best configuration to account for secondary particle equilibrium as well as pulsed source effects. Since secondary particle equilibrium is a concern for photon energies in excess of 1.5 MeV, additional tissue equivalent material is being used to account for build-up. In addition to modifications to the detector, an electronics package is being developed to process the pulse data in near real-time. This paper will discuss the scoping studies performed to best optimize the detector's design as well as report on a summary of work to date. Results from initial testing will be presented.

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A Preliminary Study on Dual-Energy Computed Tomography for Small Animals

Sungho Chang, KAIST

Dual-energy CT (Computed Tomography) is used for clinical human scans. Dual-energy CT has several advantages, including a faster scan time and higher contrast, while giving less radiation dose in comparison to conventional CT. Dual-energy CT has been adopted for small animal studies. X-rays of energies lower than those for human scan, typically 80 kVp and 140 kVp, were used. A simplified phantom made from materials with compositions and densities similar to those of mouse tissues was made, and Dual-energy images were reconstructed from CT data acquired with a cone-beam micro CT. Dual-energy CT images of the phantom and a mouse will be presented.

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Environmental Radiation Monitor Ion Chamber for Low Energy Pulsed X-Ray Background

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Ion chamber sensitive to low energy pulsed X-rays has been developed for area monitoring at the electron accelerators of R. R. Centre for Advanced Technology, Indore. Pulsed X-ray background is produced in the vicinity of these machines due to scattering of electrons by the molecules of the residual gas in the accelerators. This radiation needs to be monitored in the working areas for personnel safety. The X-rays suffer multiple scattering from the wall and ground and in the working area the energy can be well below 100keV. Conventional monitors are insensitive to X-rays below 100keV and can severely underestimate the exposure levels. For this purpose a special high pressure ion chamber with aluminium wall was developed and tested for performance in pulsed X-ray background. The chamber has all welded construction, which imparts long life to the detector. The all welded configuration became feasible with the use of special SS to Al explosion welded composite plates. All the weld joints have been subjected to pneumatic pressure tests and helium leak tests up to 10-9std. cc/sec to ensure the soundness of construction. The chamber has 25 litre sensitive volume, is filled with nitrogen at 85 psi and current sensitivity is 12 nA/R/h. The chamber can measure exposure levels from 20 uR/h-100 mR/h in working areas and has uniform energy response within 12% from 35 keV to 1.25 MeV of gamma energy. The chamber shows more than 86% collection efficiency at 100mR/h average pulsed x-ray background for 500V operating voltage. Theoretically evaluated collection efficiency values closely match with the experimentally observed values. The chamber was subjected to long term tests to ensure stability of response.

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Study of the Radiation Hardness of VCSEL and PIN Arrays

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The silicon trackers of the ATLAS experiment at the Large Hadron Collider (LHC) at CERN (Geneva) use optical links for data transmission. VCSEL arrays operating at 850 nm are used to transmit optical signals while PIN arrays are used to convert the optical signals into electrical signals. The optical devices will be exposed to intense radiation produced in the proton-proton collisions at a center-of-mass energy of 14 TeV. We investigate the feasibility of using the devices at the Super LHC (SLHC), a planned upgrade of the LHC with ten times higher collision rate. We irradiated VCSEL and PIN arrays with 24 GeV/c protons at CERN up to a fluence of 4.3 x 10^15 p/cm^2. The GaAs VCSEL arrays were fabricated by three vendors, Optowell, Advanced Optical Components (three varieties, 2.5, 5.0, and 10 Gb/s), and ULM Photonics (two varieties, 5 and 10 Gb/s). The GaAs PIN arrays were also fabricated by the same vendors but there was only one variety from each vendor. The silicon PIN arrays were fabricated by Truelight. The responsivities of the GaAs PIN arrays decrease by 90% after irradiation and hence are not suitable for the SLHC application. The responsivities of the sillicon

PIN arrays decrease by 65%, an acceptable degradation. The optical power of VCSEL arrays decreases significantly but can be partially annealed, except those of ULM 5 Gb/s, with high drive currents and hence are acceptable for the SLHC application.

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Investigation of the GSO Based Detection System for Continuous Blood Sampling - Simulation Study

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Minimal dispersion and high sensitivity with background rejection are important for quantitative measurement of radioactivity concentration in blood sampling system. We proposed GSO based detection system, which has been newly designed for continuous blood sampling with high sensitivity. This detection system consists of four GSO scintillation crystals, photomultiplier tubes assembly with lead shield. Two paralleled GSO detectors with photomultiplier tubes are facing to another two paralleled detectors, and polyethylene tube line of a continuous blood flowing is introduced to unique designed acryl guide at the detection position. The two paired GSO detectors providing a sensitivity in single photon based simulation were ~94 % for Tc-99m, ~ 60 % for Flourin-18 respectively. The relation between thickness and detection efficiency of the BGO for annihilation photons were also studied. We estimated the sensitivity from 20mm square GSOs of various depths. In addition, the geometrical effect and efficiency of crystal, and absolute sensitivity were also investigated using GATE simulation code (Geant4 Application for Tomographic Emission). In near future, the GSO based detection system for continuous blood sampling will be used in clinical as well as in small animal studies for PET tracers.

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Registration Method for the Detection of Tumor in the Lungs and Liver Using a Multimodality Small Animal Imaging

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Small animal PET scanning with 18F-FDG is increasingly used in murine tumor model. The aim of this study was to obtain multimodality images with small animal PET and CT tumor image by using hardware guide and registration method. PET imaging studies was performed with a dedicated small animal PET scanner (R4). The liver and lung tumor model mice were scanned for 20 min static image using hardware guide with 1% activity of injection dose in small animal. The CT images obtained with a clinical Symbia can be used to improve the anatomical localization of uptake in the PET images. CT imaging was performed with helical scan type of 1.25 mm axial sampling, 80 kV, 120 mA. 124I-FIAU-PET was obtained in the orthotopic HCC. Contrast enhanced CT image was obtained at 3 h postinjection of Fenestra LC. The small animal PET and CT images were fused using the hardware fiducial markers were manually identified in both data sets. The PET and CT images were registered using the small animal contour point in both data

sets to perform a point-based rigid registration. Registered image in HCC model and lung metastasis tumor model showed a good correlation of images from both PET and CT. PET and contrast enhanced CT allows a precise and improved detection of tumor in liver and lung model. Multimodality imaging with small animal PET and CT image could be useful for the detection of metastatic tumor. This method improves the quantitative accuracy and interpretation of the tracer.

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Multivariate Data Analysis for Drug Identification using Energy-Dispersive X-ray Diffraction

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Preliminary studies have shown the effectiveness of multivariate analysis (MVA) for drug identification from energy-dispersive X-ray diffraction patterns. A statistical model to predict drug content from the diffraction profile of a sample of mixed composition is required. This was developed by applying MVA to both experimental and simulated data. The MVA and Principal Component Analysis (PCA) package Unscrambler (CAMO Software AS) has been used on both experimental and simulated data. Separate data-sets were used for building and testing the models. Experimental data included diffraction patterns from small (5 mm diameter) drug samples with various cutting agents, acquired with a HPGe detector; simulated data included diffraction patterns of samples of different thicknesses (up to 20 cm) including materials simulating drugs (i.e., materials featuring sharp diffraction peaks in the relevant momentum transfer range) and typical packaging materials. Both a HPGe detector (energy resolution 0.7 keV) and a CZT detector (energy resolution 4 keV) were simulated. PCA was used to visualize any correlation between the data and MVA was used to predict the actual drug content. In all cases different statistics were applied to assess the detection limits of the models. Multivariate analysis has proved effective in both identifying the presence of a drug and its concentration. The accuracy of the models, assessed by considering the detection rate and the false positive rate, depends upon the detection threshold applied. Due to the large contribution to peak broadening given by angular resolution, no significant decrease in accuracy has been found when using CZT with respect to HPGe data.

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Time-Resolved Extended X-Ray Absorption Fine Structure Using a Pixel Array Detector

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Time-Resolved Extended X-Ray Absorption Fine Structure (TR-EXAFS) is a powerful technique to study the atomic structure around short-lived atomic species. In this paper,

we investigate the use of digital pixel array detector (Pilatus100K) for TR-EXAFS in fluorescence geometry. The synchrotron provides tunable x-ray pulses with duration of ~80 ps and a repetition period of 153 ns (24 bunch mode). The Pilatus100K is direct x-ray detector where each 172 micron pixel counts individual x-ray pulses above a lower threshold. It consists of ~100K pixels which is each capable of count rates of 1MHz. In addition, the Pilatus100K is electronically gateable detector. We present data showing that the Pilatus100K is capable of isolating a single x-ray bunch at the APS in 24 bunch mode. We also present EXAFS data using the Pilatus100K at the 7ID laser pump - x-ray probe beamline of the Advanced Photon Source. In addition, we also investigate the possibility of removing the elastic scattering contribution using the fact that Pilatus100K is a pixilated detector without using a Z-1 filter.

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Advances in Optical CT Reconstruction Imaging for FXG Dosimetry

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Cancer treatment requires a precisely ionizing radiation absorbed dose determination in an established tissue volume. Although the absorbed dose evaluation is usually obtained using an ionization chamber, the alternative Fricke Xylenol Gel (FXG) dosimeter has shown unique features for the development of more accurate treatment planning. The gel irradiation induces absorbance changes proportional to the absorbed dose in the material, with the advantage of tree-dimensional measures of the irradiated volume. Fricke gel chemical changes are commonly measured using a spectrophotometer or by Magnetic Resonance Image (MRI). In this work we present a new photometric system constructed with a light emission diode (LED) and a digital video camera, which is useful to determine the absorbed dose distribution in the gel dosimeter. The dose calibration curve and the 3-D volume reconstruction were obtained by computational processing from the sample images. The reconstructed images did not present the rings artifacts normally showed in this type of image and were obtained with reduced time.

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Paterson Parker Distribution Dose Method Evaluation through the Fricke Xylenol Gel Chemical Dosimeter

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Low dose Braquitherapy is still used for some cancer treatments in some countries, with the radioactive sources in a pattern suitable to achieve the dose distribution adequate for the treatment and a method to evaluate the dose pattern for the irradiation time is that of Paterson-Parker (PP) [1]. In this work 8 137Cs sources were used to irradiate a group of 25 acrilic cuvettes, filled with the Fricke Xylenol Gel (FXG) in a selected pattern, given from the PP method, to achieve the expected dose in a selected depth. Absorbance measurements were done in each cuvette to reconstruct the 3D absorbed dose distribution

and comparisons were done with that expected by the method. From the results obtained, one could infer a difference lower than 10%, expected by the method once they do not take into account the attenuation of the irradiation in the source material. With these results we could realize that the FXG is also adequate to evaluate a dose distribution calculation method, such as the Paterson-Parker.

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137Cs Absorbed Dose Distribution through Fricke Xylenol Gel Dosimeter Measurements

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Braquitherapy is technique that uses radioactive sources near to a target volume to be treated. Its advantage, comparing to the teletherapy, is the high dose deposition in a small target volume with the radiation reduction dose in the surroundings tissues. This work permits to evaluate the absorbed dose distribution from a 137Cs braquitherapic source, through the [Fe+3] absorbance measurements produced by the gamma radiation in the Fricke Xylenol Gel chemical dosimeter. From the results obtained and compared to those presented in the literature [1,2], one can infer that use of the referred dosimeter for dose distribution verification is adequate absorbed dose distribution control.

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