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BOOK OF ABSTRACTS

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ACCELERATOR DEVELOPMENT/ANALYTICAL METHODS

**Compact Dielectric Wall Accelerator Development for Intensity Modulated
Proton Therapy and Homeland Security Applications***

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Compact dielectric wall (DWA) accelerator technology is being developed at the Lawrence Livermore National Laboratory. The DWA accelerator uses fast switched high voltage transmission lines to generate pulsed electric fields on the inside of a high gradient insulating (HGI) acceleration tube. Its high electric field gradients are achieved by the use of alternating insulators and conductors and short pulse times. The DWA concept can be applied to accelerate charge particle beams with any charge to mass ratio and energy. Based on the DWA system, a novel compact proton therapy accelerator is being developed. This proton therapy system will produce individual pulses that can be varied in intensity, energy and spot width. The system will be capable of being sited in a conventional linac vault and provide intensity modulated rotational therapy. The status of the developmental new technologies that make the compact system possible will be reviewed. These include, high gradient vacuum insulators, solid dielectric materials, SiC photoconductive switches and compact proton sources. Applications of the DWA accelerator to problems in homeland security will also be discussed.

*Patents Pending. Lawrence Livermore National Laboratory is operated by Lawrence Livermore National Security, LLC, for the U.S. Department of Energy, National Nuclear Security Administration under Contract DE-AC52-07NA27344.

Ultra-compact Accelerator Technologies for Nuclear Detection *

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We report on compact accelerator technology development for potential use as a pulsed neutron source quantitative post verifier. The technology is derived from our on-going compact accelerator technology development program for radiography under the US Department of Energy and for clinic sized compact proton therapy systems under an industry sponsored Cooperative Research and Development Agreement. The accelerator technique relies on the synchronous discharge of prompt pulse generating stacked transmission line structures with the beam transit. The goal of this technology is to achieve ~10 MV/m gradients for 10s of nanoseconds pulses and to ~100 MV/m gradients for ~1 ns systems. As a post verifier for supplementing existing x-ray equipment, this system can remain in a charged, stand-by state with little or no energy consumption. We detail the progress of our overall component development effort with the multilayer dielectric wall insulators (i.e., the accelerator wall), compact power supply technology, kHz repetition-rate surface flashover ion sources, and the prompt pulse generation system consisting of wide-bandgap switches and high performance dielectric materials.

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A fast pulse, high intensity neutron source based upon the dense plasma focus*

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Alameda Applied Sciences Corporation (AASC) has built a bench-top source of fast neutrons (~10-40ns, 2.45MeV), that is portable and can be scaled to operate at ~100Hz. The source is a Dense Plasma Focus driven by three different capacitor banks: a 40J/30kA/100Hz driver; a 500J/130kA/2Hz driver and a 3kJ/350kA/0.5Hz driver. At currents of ~130kA, this source producesⁱ ~3x10⁶ (DD) n/pulse. The neutron pulse widths are ~10-40ns and may be controlled by adjusting the DPF electrode geometry and operating parameters. This paper describes scaling of fast neutron output from this Dense Plasma Focus, over a range of currents from 30 kA up to 350 kA. For each current and driver, different DPF head designs are required to match to the current rise-time, as the operating pressure and anode radius/shape are varied. Doping of the pure D₂ gas fill with Ar or Kr was shownⁱⁱ to increase the neutron output. Results are discussed in the light of scaling laws suggested by priorⁱⁱⁱ literature.

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- i A fast pulse, high intensity neutron source based upon the dense plasma focus*, B. L. Bures and M. Krishnan, proceedings of the Crete'08 conference.
- ii Controlling the Neutron Yield from a Small Dense Plasma Focus using Deuterium-Inert Gas Mixtures, B. L. Bures, M. Krishnan, Y. Eshaq, Proceedings of Dense Z-Pinch conference, Arlington, VA, 2008
- iii Current and neutron scaling for megajoule plasma focus machines, S. Lee, Plasma Phys. Control. Fusion 50 (2008) 105005 (14pp)

The mechanism of helium bubble formation in erbium tritide neutron generator films

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Neutron generators, exploiting the fusion reactions $d + T \rightarrow \alpha + n + 17.6\text{MeV}$ and $d + D \rightarrow {}^3\text{He} + n + 3.3\text{MeV}$ to yield 14MeV and 2.2MeV neutrons, respectively, consist of a deuteron accelerator and a deuterium-tritium target. Generator lifetimes are limited by release of helium, generated by the radioactive decay of tritium, into the accelerator envelop. Generator targets typically are films of β -phase tritides and deuterides of erbium, $\text{ErD}_x\text{T}_{2-x}$. Previously we have reported that loading erbium films with tritium or deuterium leads to plate-like defect structures oriented along the erbium hydride 111 crystallographic planes. Our later work showed that the density of the defects increases with time in ErT_2 , but not in ErD_2 . We forwarded the hypothesis that the defects are introduced by processing and that, because of the high solubility of hydrogen in erbium, the defects are initially empty. ${}^3\text{He}$, which is not soluble in the erbium matrix, fills the defects as the tritium decays. The helium pressure causes the defects to grow and collect more He until they percolate, providing a path for the helium to escape through the film surface. This model is in contrast to the standard one, which envisions He bubbles forming in a uniform metal matrix by nucleation and growth. We test whether the plate like defects are initially empty or filled with He or hydrogen—a key factor that can discriminate the two models, using small-angle neutron scattering on H/D-loaded erbium powders with a new, “double contrast” technique to unravel the issues of defect content.

Coupling high-energy radiography and Active Photon Interrogation (IPA) to optimize the characterization of nuclear waste packages

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Radiological characterization of nuclear waste packages is an industrial issue in order to select the best mode of storage. The alpha-activity, mainly due to the presence of actinides (^{235}U , ^{238}U , ^{239}Pu , ...) inside the package, is one of the most important parameter to assess during the characterization. Non-destructive active methods (NDA methods), based on the fission process and on the detection of particles emitted after this reaction, allows to quantify the alpha-activity. Fission can be induced either by neutrons or by high-energy photons delivered by a linear accelerator (LINAC). Both these techniques are respectively designated as Active Neutron and Photon Interrogation (INA and IPA). IPA is well adapted to the characterization of large concrete waste packages. However, this technique requires a simulation step which is necessary to interpret experimental results and to quantify the global mass of actinides. The weak point of this approach is that characteristics of the package are often not well-known and these latter can have a huge impact on the final result of simulations. High-energy radiography, based on the use of a linear accelerator, allows to visualize the content of the package and is also a performing way to tune simulation models and to optimize the characterization process by IPA. In this article, we present high-energy radiography results obtained for two different waste packages (global mass of 1.8 t) in the SAPHIR facility (Système d'Activation PHotonique et d'IRradiation). This latter is a facility built in CEA Saclay and dedicated to the research and development of methods based on IPA. We discuss too possibilities offered by the coupling between high-energy radiography and IPA.

Applications of Nuclear Resonance Fluorescence

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Nuclear resonance fluorescence (NRF) is a photon-based active interrogation approach that provides isotope-specific signatures that can be used to detect and characterize samples. Photon energies are in the range of a few MeV, so that penetration through significant material is possible. Unlike other active interrogation techniques that are based on inducing fission, NRF is sensitive to a wide range of isotopes: for example ^{11}B , ^{12}C , ^{13}C , ^{14}N , ^{16}O , ^{27}Al , ^{208}Pb , ^{235}U , ^{238}U and ^{239}Pu just to name a few. NRF is most likely to outperform existing technologies for applications requiring isotopic information of sealed samples. Pacific Northwest National Laboratory is conducting a review of potential applications that could be addressed by NRF techniques. These applications cover a wide range of topics, from geo-location, to material assay, to safeguarding the nuclear fuel cycle. The objective of the project is to search for potential applications, define technical requirements, identify physical limitations, conduct an initial assessment of the technique and design a research approach for developing the applications. In this talk, our current results for several of the applications will be presented.

This effort was funded by the U.S. Department of Energy Office of Defense Nuclear Nonproliferation, Office of Nonproliferation Research and Development (NA-22).

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Neutron resonance spectroscopy for the analysis of materials and objects

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The appearance of resonances in neutron induced reaction cross sections is the basis of the Neutron Resonance Capture (NRCA) and Transmission (NRTA) Analysis techniques. Since resonances can be observed at neutron energies which are specific for each nuclide, they can be used as fingerprints to identify and quantify elements in materials and objects. Both NRCA and NRTA are fully non-destructive methods which determine the bulk elemental composition, do not require any sample preparation and result in a negligible residual activation. So far we have preferred to determine weight ratios of elements of the object under study by comparing with standard samples. Most of the applications were related to archaeological objects such as copper-alloy artefacts.

In this paper we review the technique, present an improved analysis procedure, which is based on a more methodological approach, and discuss the applicability of the technique in the biomedical field, for material science and nuclear applications. The improved procedure relies on a full Resonance Shape Analysis (RSA) and accounts directly for the neutron self-shielding, multiple scattering, Doppler broadening and instrumental resolution. Therefore, calibration requirements are significantly reduced and the implementation of RSA makes the method applicable to difficult samples with strongly overlapping resonances. We also discuss the applicability of the technique in the nuclear field, notably the detection of neutron poison in nuclear materials and the quantification of impurities in reference materials.

DETECTORS/DATA ANALYSIS-VALIDATION

New detectors for pulsed fast-neutron resonance radiography

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Pulsed Fast-Neutron Resonance Radiography (PFNRR) is a radiographic imaging method that exploits the characteristic resonances in total neutron cross-sections of different isotopes in the energy-range $E_n=2-10$ MeV. In PFNRR the inspected object is irradiated with pulsed neutrons of a broad spectral distribution. The spectral analysis of the transmitted image will allow a reconstruction of the elemental composition of an object. PFNRR holds promise for fully-automatic detection of conventional and improvised explosives concealed in luggage and cargo, by determining the density distribution of light elements such as C, N and O within an inspected object.

A PFNRR system requires a large area imaging neutron detector with fast timing capability for Time-of-Flight (TOF) spectroscopy. Previously we have presented results of our Time-Resolved Integrative Optical Neutron detector (**TRION**), a high-spatial-resolution fast-neutron imaging system with TOF capability. This 1st generation **TRION** has already demonstrated that high-resolution fast neutron imaging, suitable for detecting small quantities of thin-sheet explosives, is feasible. The previous design permitted capturing an image only in a single energy-bin, thus using only a small fraction of the broad neutron spectrum.

Here we present results of a new detector system, which can capture simultaneously up to 4 images at different neutron energies. This detector uses an ultra-fast optical preamplifier and four independent intensified CCD cameras. We show also the concept of the next system presently being assembled, capable of capturing 8 independent energy frames. This new camera uses a much simpler design with only one single, specially designed intensified CCD camera.

Operational characteristics of SiC diodes as ionizing radiation detectors

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SiC Schottky diodes of different doping concentrations have been used to detect alpha particles, ^{12}C and ^{16}O ions at energies between 5 and 37.6 MeV [1,2]. The diode depletion-thickness, the linearity of the response, the energy resolution, the signal rise-time and the Charge Collection Efficiency (CCE) were measured for different values of the applied reverse bias. In some diodes minority charge carriers, generated by the incoming ion in the neutral region, diffuse to the depleted layer and are finally collected. From a best fit procedure, the minority carriers diffusion length and lifetimes are extracted. Finally, the radiation damage produced by ^{16}O ions was evaluated by measuring the degradation of both the signal pulse-height and the energy resolution as a function of the ions fluence. The data show that SiC material is radiation harder than silicon but diodes having a factor 20 lower doping concentration exhibit a radiation hardness reduced by 60%.

[1] M. De Napoli et al. NIM A 572 (2007) 831

[2] M. De Napoli et al. NIM A 600 (2009) 618

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Radiation Detection Using Graphene-Based Sensors

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We are developing radiation sensors and detector architectures based on graphene, a novel electronic material with many exceptional properties of potential use for radiation detection. Unlike the established detector technologies based on charge collection in semiconductors, the graphene-based detector instead utilizes a sharp dependence of graphene electrical conductivity on a local electric field, which can be abruptly changed by charge carriers produced by ionizing radiation in an absorber material. The use of electric field instead of charge collection eliminates the requirement for high carrier mobility and lifetime that is a characteristic of conventional charge collection-based detectors. This novel detection method offers a unique opportunity to deploy narrow-bandgap absorber materials such as InSb without temperature, purity, carrier mobility, or lifetime constraints. Our approach is potentially applicable to special nuclear material detection, medical applications, monitoring of nuclear fuel cycles, and high-sensitivity detectors for particle and nuclear physics. We will present our progress on the device modeling, design and fabrication, and initial validation experiments in conjunction with laser-based and ionizing radiation sources. This technology has the potential to significantly outperform current detectors, such as the gamma-ray detectors based on high purity germanium, in terms of the energy and spatial resolution, speed and functionality.

Digital Pulse Processing Techniques for Time Variant Pulse Shape Analysis

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In many applications of radiation detection and measurement, radiation detectors exhibit time variant responses to incoming radiation events.

Frequently when scintillation based detectors are used, radiation detection may occur within a flux of both neutrons and gamma-rays. In such applications, accurate pulse shape discrimination is important to distinguish neutrons and gamma-rays. Often the separation of neutron and gamma-ray spectra will significantly improve the detection and classification of illicit materials.

Alternatively, in large area semi-conductor detectors (such as SD, Si(Li) and HPGe detectors) “ballistic deficit” is caused by a significant difference in the collection velocities of electrons and holes. The particular shape (or form) of each radiation event in the digitised detector data depends on the exact site of the radiation-detector interaction.

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Traditional digital pulse processing methods seek to overcome the challenges of ballistic deficit by either using rise-time detectors to identify and discard malformed pulses or gated integrators are used to force the various pulse shapes towards a standard pulse form. When pulse shape discrimination is required to distinguish between gamma-ray and neutron fluxes traditionally various ratios of rise-times, pulse duration and decay-times have been used.

While such approaches overcome some of the issues associated with time-variant detector responses, the resolution and throughput of the radiation measurement system can be significantly degraded particularly at elevated count-rates.

Previously the authors have presented a real-time nonlinear digital pulse processing algorithm which uses model-base signal processing techniques to accurately recover data corrupted by pulse pile-up. This paper extends the application of this technique to the applications described above. That is, the accurate detection and measurement of multiple forms arising either from ballistic deficit or as a result of multiple radiation types impacting on the detector. The performance of the multiple form digital pulse processing algorithm is evaluated on both semiconductor and scintillation based radiation detectors.

A Framework for the Relative and Absolute Performance Evaluation of Automated Spectroscopy Systems

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The development of high-speed, high-performance gamma-ray spectroscopy algorithms is critical to the success of many automated weapons detection systems. In response to this need a proliferation of such algorithms has taken place. With this proliferation comes the necessary and non-trivial task of validation. There is (and always will be) insufficient experimental data to determine performance of spectroscopy algorithms over the relevant factor space at any reasonable precision. In the case of gamma-ray spectroscopy, there are hundreds of radioisotopes of interest, which may come in arbitrary admixtures, there are many materials of unknown quantity, which may be found in the intervening space between the source and the detection system, and there are also irregular variations in the detector systems themselves. All of these factors and more should be explored to determine algorithm/system performance. This paper describes a statistical framework for the performance estimation and comparison of gamma-ray spectroscopy algorithms. The framework relies heavily on data of increasing levels of artificiality to sufficiently cover the factor space. At each level rigorous statistical methods are employed to validate performance estimates.

MEDICAL IMAGING/DOSIMETRY/ION BEAM ANALYSIS

Design considerations of a Compton camera for low energy medical imaging

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Development of a Compton camera for low energy medical imaging applications is currently underway. The ProSPECTus project aims to utilise position sensitive semiconductor detectors to generate high quality images using electronic collimation. This method has the potential to increase the imaging efficiency of conventional mechanically collimated SPECT systems by a factor up to 100, a highly desirable improvement on clinical systems.

The geometry of the ProSPECTus system has been optimised for 99mTc 141keV gamma-rays using a validated Geant4 package to maximise the number of useful events required for imaging. Images have been produced for the optimum geometry using Geant4 data of point and line sources processed by cone beam reconstruction techniques. The use of simulated data has allowed a quantitative assessment of the effects of experimental contributions such as detector energy and position resolution on the resultant image quality. Design considerations for the new ProSPECTus system encompass the results of the optimisation and image quality assessment. The results presented will include optimisation analysis and images from the proposed ProSPECTus system which is to be built and assessed.

A semiconductor-based approach to Small Animal PET imaging

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Semiconductor small animal Positron Emission Tomography is a field of global research interest. The SmartPET system [1] combines the application of high-purity germanium (HPGe) planar detectors with high speed digital electronics and pulse shape analysis (PSA) [2] for nuclear medical imaging. The detectors are orthogonally segmented strip detectors which are mounted in a rotating gantry to perform PET [3] imaging. PSA enables the improvement of spatial resolution beyond the physical segment size to 1mm x 1mm x 2mm. This system has shown promising developments in image resolution for both PET [3] and Compton camera imaging [4]. Data of increasingly complex phantom geometries were acquired, experimentally and in simulation, and

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reconstructed. The simulated data were exploited to systematically quantify the sources of image distortion. Specifically, the effect of the positron range was quantified to add at worst 0.9mm +/- 0.2mm blurring to the reconstructed image for a Na-22 source. The lateral position resolution is shown to relate linearly to image resolution. Image sensitivity is increased with γ -ray tracking techniques to include photons which scatter within the detector. This novel approach to PET imaging and its potential impact on the field shall be discussed.

- [1] H.C.Boston et al., Nucl. Instr. and Meth.A (2007)
- [2] K. Vetter et al. Nucl. Instr. and Meth. A 452 (2000) 223
- [3] R.J. Cooper et al. submitted (2008)
- [4] J.E.Gillam et al. Nucl. Instr. and Meth. A Vol 579 (2007) 76

Integral Dose Measurements from an Accelerator-based Source

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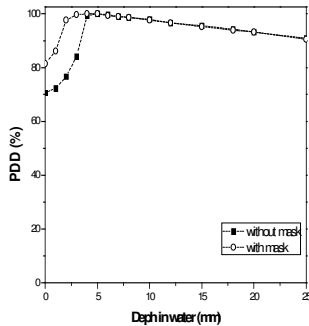
Several integral benchmark measurements of both photon and neutron dose from a nominal 25 MeV accelerator-based bremsstrahlung source were conducted on an outdoor test range. These data were collected using various instruments including thermoluminescent dosimeters (TLD), optically stimulated luminescent (OSL) dosimeters, and ionization chambers (both gas-filled and air-filled). Dose is considered from two principal sources, dose from the accelerator system and dose from the photon beam. With this consideration, measurements were performed at various locations and include on-axis beam measurements, off-axis measurements and around the accelerator system. In addition to the measurements, several Monte Carlo (MCNP Version 5) calculations were performed. Calculations were based on using the photon ambient dose equivalent as it is a useful quantity from which to compare instrument response. Detailed results of both the MCNP calculations as well as the measurements are discussed.

Measurements of the influence of thermoplastic mask in high energy photon beams: GEL dosimeter or ionizing chamber?

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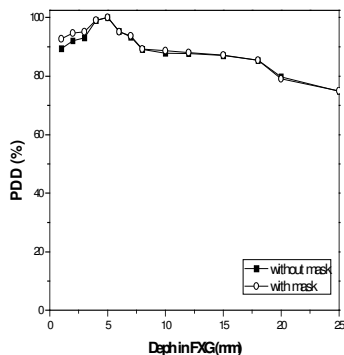
This article investigates the influence of the immobilization mask material in the absorbed dose distribution in patients submitted to photon beams in radiotherapeutic treatment, inferring the values at different depths, in build-up region, to ⁶⁰Cobalt and 6 MV Linac photons. The measures of Fricke Xylenol Gel (FXG) are compared to cylindrical ionizing micro-chamber PTW-Freiburg TM 31016 – 0.016 cc. The measurements showed different responses for incident photon beams, such as that FXG measures can suffer a minor influence of backscatter when compared with ionizing chamber PTW which has higher atomic numbers since it is made with graphite, PMMA and aluminum components.

is made with graphite, PMMA and aluminum components.

Conclusions

When the physical characteristics of the dosimeter gel FXG [3] are known we observe its skill to characterize the measures of the linear attenuation coefficients as well as to minimize the influence of the backscattering in the measures of absorbed dose on medium. This skill makes possible a bigger precision of measures in the thresholds of the surface of the patients, which is benefic to the radiotherapy [1]. The use of ionization chambers with materials of graphite and aluminum types provides to observe this influence, as can be seen in the graphics of PDD% x Depth (*Figure 1*). It shows that there is a bigger variation of dose absorbed regarding the energy, observed at measurements with and without mask (**wi-wo**) relations (*Table I*). The influence of the use of the immobilization mask lessens with the approximation of the depths of electronic balance (build-up) for the investigated energies [2], the values met showed that the use of the material in the mask contributes to bigger doses near to the surface of the human tissue.

Table I: (wi-wo) of ⁶⁰Co and 6MV photons, measured with FXG and IC-PTW



Depth (mm)	FXG	PTW/0.016cc	FXG	PTW/0.016
	Δ%	Δ%	Δ%	cc Δ%
	⁶⁰ Co (wi-wo)		6 MV (wi-wo)	
1	04.47	14.22	16.06	22.07
2	03.49	20.96	17.59	25.45
3	01.62	15.72	15.34	21.34
4	01.13	1.12	15.72	16.84
5	0.00	0.56	07.60	11.23
10	-	-	03.10	01.13
15	-	-	00.12	00.26

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References

- [1] Bentel G.C., L.B. Marks, K. Hendren and D.M. Brizel. **Comparison of two head and neck immobilization systems.** *Int J Radiat Oncol Biol Phys* **38**, pp. 867–873.1997.
- [2] Lamb A. and S. Blake. **Investigation and modelling of the surface dose from linear accelerator produced 6 and 10 MV photon beams.** *Phys Med Biol* **43**, pp. 1133–1146.1998.
- [3] Moreira MV, de Almeida A, Costa R and Perles L. **FXG mass attenuation coefficient evaluation for radiotherapeutic routine.** Institute of Physics Publishing Journal of Physics: Conference Series **3**, 146–149 doi:10.1088/1742-6596/3/1/014. Third International Conference on Radiotherapy Gel Dosimetry.2004.

Materials Science and Engineering Research and Education at the Center for Irradiation of Materials of Alabama A&M University

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The Center for Irradiation of Materials @ AAMU (<http://cim.aamu.edu>) established in 1990 to serve the University in its research, Education and services the need of the local community and Industry. CIM irradiation capabilities oriented around two tandem type ion accelerators with seven beam lines providing high resolution Rutherford backscattering spectrometry (RBS), MeV focus ion beam, high energy ion implantation and irradiation damage studies, particle induced x-ray emission (PIXE), particle induced gamma emission (PIGE), and ion induced nuclear reaction analysis in addition to fully automated ion channeling. One of the two tandem ion accelerators designed to produce high flux ion beam for high fluence MeV ion implantation and high fluence ion irradiation damage study. The facility is well equipped with variety of surface analysis systems, such as SEM, ESCA, as well as scanning micro-Raman analysis, UV-VIS Spectrometry, luminescence spectroscopy, Thermal conductivity, electrical conductivity, IV/CV systems, Mechanical test systems, AFM, FTIR, Voltmetry analysis as well as low energy implanters, Ion Beam Assisted Deposition and MBE systems. In this presentation we will demonstrate how the facility provides services to schools, industries and how CIM has contributed to the recent invention of fabrication of highly efficient thermoelectric materials.

Sponsors: Supported in part by AAMU Research Institute, NASA, DOE, NSF and industries.

Applications of high energy focused ion beams: from 2D mapping toward 3D microtomography

Primož Pelicon, Nataša Grlj, Primož Vavpetič

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Implementation of standard techniques of Ion Beam Analysis with high-energy focused ion beams results in a high lateral resolution, defined by the size of the focused beam. Raster-scanning of the beam leads to two-dimensional maps of elements or isotopes in the sample.

At Jožef Stefan Institute tandemron laboratory, high-energy focused ion beams are used for several types of nuclear spectroscopy. Micro-ERDA with ^7Li beam is used to detect depth and lateral distribution of hydrogen isotopes in surfaces and thin layers. Micro-NRA with focused ^3He beam employing nuclear reaction $\text{D}(^3\text{He},\text{p})^4\text{He}$ is used to measure lateral distribution of deuterium in materials for fusion research. The most demanded application by the users is micro-Proton Induced X-ray Emission (micro-PIXE) for biomedical research. A 3 MeV proton beam with a dimension of $1.5 \times 1.5 \mu\text{m}^2$ is scanned over selected area of the tissue slice to reveal a two-dimensional elemental distribution on the tissue or cellular level [1]. Success of the method is strongly dependent on the tissue treatment in the sample preparation stage, consisting of shock-freezing and freeze-drying. Important step further in the elemental mapping on the cellular and sub-cellular level will be a construction of setup for measurements on frozen hydrated tissue, currently ongoing in the laboratory. The frozen tissue will be kept on low temperatures during the shock-freezing, sectioning, transfer and micro-PIXE analysis. In this way, the tissue will be better preserved for 2D mapping on sub-cellular level.

X-ray optical devices, such as polycapillary lenses or polycapillary conic collimators, attached to the X-ray detector and aligned in the confocal set-up, enable 3D micro-PIXE tomography [2]. In combination with the frozen tissue technology, the method will significantly enhance the abilities of the micro-PIXE analysis in biomedicine.

[1] K. Vogel-Mikuš et al, *Plant Cell Environ.* **31**, 1484 (2008).

[2] M. Žitnik et al, *Appl. Phys. Lett.* **93**, 094104-1 (2008).

ION BEAM MODIFICATION OF MATERIALS

Formation of magnetic nanoclusters by ion implantation into suitable substrates

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Ion beams are finding increasing applications in the synthesis and modifications of materials on the nanometer scale, with strict control of ions species, energy and fluence allowing one to tailor the ion irradiation conditions to specific applications. The accelerated ions circumvent restrictions set to ion solid interactions by thermodynamic effects such as diffusion, solubility, desorption and alloy formation.

We have conducted Mössbauer spectroscopy measurements on a series of substrates implanted with low fluence Fe ions accelerated to 60 – 80 keV energy in a search for the formation of magnetic nanoclusters in the substrates. Mass separated ⁵⁷Fe ions were implanted to fluences of 5×10^{15} , 1×10^{16} and 2×10^{16} cm⁻², into ZnO, 3C-SiC and SiO₂ substrates. The search for cluster formation was conducted as functions of thermal treatment of the substrates and implantation dose. The Mössbauer studies were complemented with Rutherford Backscattering spectrometry, and MOKE and VSM measurements.

The Mössbauer spectra of the Fe implanted ZnO and SiC single crystals, annealed up to 1073 K and 973 K, respectively, show that the Fe³⁺ ions remain fairly constant in the crystals, while the Fe²⁺ show some reordering. Evidence of magnetic cluster formation is observed in the SiO₂ substrate. These results will be presented and discussed.

MeV Ion Beam Assisted formation of pseudo-crystals

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For the past fifteen years, we have formed nanostructure in the MeV ion beam track in order to fabricate pseudo-crystals consisting of nanostructures. The focus of our work is based on the energy deposited due to ionization in order to produce quantum dots or nano-structures resulting to production of pseudo-crystal consisting of nano-crystals with applications in optical devices as well as with applications in highly efficient thermoelectric Materials. The interacting nanocrystals enhance the electrical conductivity, reduce thermal conductivity and increase the Seebeck coefficient, in order to produce highly efficient thermoelectric materials. Theoretically, the regimented quantum dot superlattice/ pseudo-crystals consisting of nanostructures of any materials produces new physical properties such as new electrical band structure, phonon mini-bands, as well as improved mechanical. A proper choice of nanocrystals, host and buffer layer result in production of highly efficient thermoelectric generator (TEG)* with efficiencies as high as 30% which correspond to figure of merit above 4.0. In addition to above such systems are in a unique position to be used both as electrical generation from heat and/or other forms of radiation as well as cooling the structures, thus enhance the applicability of hybrid systems.

The interaction of nanostructures results in phonon mini-bands formation reducing the thermal conductivity, while increasing the electrical conductivity resulted in synthesis of TEG with much

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higher efficiency than reported to this date. We will review a series of materials selected for investigation some operating at temperatures around 300K and some at about 1000K.

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Patent filed/Patent Pending.

Lattice site location of Ni and Co ions implanted in SiC epilayers

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Silicon carbide is a promising wide-bandgap semiconducting material suited for potential applications in spin-based electronics, and to induce ferromagnetism, ion implantation is the only realistic way to dope SiC with magnetic ions at high enough fluences. For this work, SiC epilayers grown on 4H-SiC single crystals were implanted at 450°C with 850 keV Ni⁺ or Co⁺ ions with fluences in the 1-9×10¹⁶ Ni/cm² and 0.5-2×10¹⁶ Co/cm² ranges, respectively. A post-implantation annealing was performed in N₂ at 1100°C in order to recover the implantation-induced structural damage. After the annealing, the remaining structural disorder and the lattice site location of Ni and Co ions have been studied by Backscattering Spectrometry in channeling geometry (BS/C) with a 3.45 MeV He²⁺ beam along the <0001> and <11-23> axes. These measurements have been correlated with the magnetic behavior of the samples determined by SQUID magnetometry.

Nanoscale Cascades in Diamond under Cluster Ion Irradiations

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Diamond electronics is attractive for high power - high frequency applications due to unique set of properties: high mobility of electrons and holes, low noise and leakage current, extremely high thermal conductivity. But diamond is the most hard material with very low diffusivity and solubility of impurity atoms. Instead of doping metastable inclusions with other phases of carbon may be used to form conductive layers or even quantum dots for devices. The goal of the present work is a formation of nanoscale amorphous carbon or graphite nanodots with sp³ or sp² hybridization in diamond lattice.

The synthetic diamond samples were implanted by keV-energy Ar_n⁺ cluster ions using facilities PUCLUS and CIDA [1]. The cluster-bombarded surfaces were studied by AFM in tapping mode. Cluster-surface impact leads to formation of nanosize radiation-damaged areas (craters) that were theoretically predicted elsewhere [2]. Covalently bonded phases with sp² or sp³ hybridization were identified by Raman spectroscopy and MW adsorption. Detailed study of radiation-damage formation depending on the cluster size and impact energy is under progress. The following chemical etching allows to remove the amorphised material and leads to pits formation. By studying depth of the pits the information on the development of radiation cascades depending on the conditions of cluster impact can be obtained. These nanopits can also be used for following fictionalisation of the diamond surface.

1. V.N. Popok, S.V. Prasalovich, M. Samuelsson, E.E.B. Campbell. Rev. Sci. Instrum. 73 (2002) 4283-4287.
2. Y. Yamaguchi, J. Gspann. Eur. Phys. J. D 34 (2005) 247-249.

Extra-thin SiGe layers in SGOI structure measured by low angle RBS/channeling and electron Auger spectroscopy with ion sputtering

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Using bulk silicon can be ended at 22 nm technological node due to silicon mobility limitation. New types of substrates need for further scaling in CMOS microelectronics. Dual Silicon-Germanium-On-Insulator (SGOI) structures based on SiGe alloy are characterized with high hole and electron mobility and compatible with current silicon planar CMOS technology. But high Ge content at the interface with SiO₂ deteriorates the electrical properties. It is extremely important to know exact content and Ge atom location at this interface.

The profile and lattice position of Ge atoms in few nm thick SGOI film were determine by two techniques at Si/SiO₂ bonded interface. Joint semiconductor material stack was obtained by implanted hydrogen transfer of one layer material (silicon as a matrix) and syntheses of the second one (germanium), which was grown between upper Si matrix and bonded amorphous SiO₂ film on Si substrate due to thermal (800÷1100 oC) segregation of Ge atoms from SiO₂ to Si/SiO₂ interface. It was shown by both methods that maximum Ge content is near 5% and total

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SiGe layer thickness is less than 5 nm. All Ge atoms at the Si/SiO₂ interface are in the Si lattice position according to channeling with low angle (10°) exit of He ion beam.

Enhancement of ammonia (NH₃) sensitivity in Swift Heavy Ion (SHI) irradiated nanocrystalline SnO₂ thin films

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Swift heavy ion irradiation is an effective technique to induce changes in the microstructure and electronic energy levels of materials leading to significant modification of properties. Here we report enhancement of ammonia (NH₃) sensitivity of SnO₂ thin films subjected to high-energy Ni⁺ ion irradiation. Sol-gel-derived SnO₂ thin films (100nm thickness) were exposed to 75MeV Ni⁺ ion irradiation, and the gas response characteristics of irradiated films were studied as a function of ion fluence. The irradiated films showed *p*-type conductivity with a much higher response to NH₃ compared to other gases such as ethanol. The observed enhancement of NH₃ sensitivity is discussed in context of ion beam generated electronic states in the SnO₂ thin films.

Radiation hardened silicon-on-insulator structures with N⁺ ion modified buried SiO₂ layer

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The buried oxide (BOX) limits the total-dose radiation hardness of SOI materials by building up radiation-induced charge as result of ionizing radiation. In this paper the radiation-resistant SOI structures were performed by N⁺ ion implantation into thermally grown silicon dioxide film and subsequent hydrogen transfer of silicon layer to the nitrogen ion-implanted substrate under conditions of wafer bonding. Accumulation of the carriers in the BOX was investigated as a function of fluence of nitrogen ions in the range (1-6)×10¹⁵ cm⁻² and as a function of total radiation dose ranged from 10⁴ to 10⁷ rad (Si). The accumulation of the carriers was characterized by the measurements of the capacitance-voltage and conductance-voltage characteristics in the frequency range 100 Hz to 1 MHz. It was obtained that in the case of the samples implanted with nitrogen ions to fluence of 6×10¹⁵ cm⁻², the voltage shift corresponding to the charge accumulation near the bonding interface was one order of magnitude lower than that corresponding to the charges near the thermal SiO₂/Si interface. Under conditions of the

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subsequent ionizing radiation, charge accumulation rate near the nitrogen ion-implanted interface was less than that obtained from the nitrogen-free interface by a factor of five.

Growth of nanocrystals in the In⁺ and Sb⁺ ion implanted SOI structures

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The formation of heterostructures-on-insulator seems as a way to increase the carrier mobility in the nanometer-scale layers. The formation of Si/InSb-on-insulator structures would provide an increase in the effective electron mobility of the nanometer scale silicon-on-insulator (SOI) films. Growth of InSb nanocrystals at the Si/SiO₂ bonding interface of SOI structures has been studied as a function of the annealing temperature. SOI structures with the ion-implanted regions above and below the bonding interface were produced as a result of the hydrogen transfer of the Sb⁺ ion implanted silicon layer from first silicon substrate to the In⁺ ion implanted SiO₂ layer thermally-grown on the second silicon substrate. Rutherford backscattering spectrometry and high-resolution transmission electron microscopy (XTEM) were used to study the properties of the prepared structures. Up-hill diffusion of In and Sb atoms from the implantation regions toward the bonding interface as well as subsequent interface-mediated growth of InSb nanocrystals were observed as the annealing temperature achieved 1100° C. The strain minimizing orientations of the Si and InSb lattice heteropairs were obtained from XTEM analysis of the grown nanocrystals. It was suggested that the formation of InSb nanocrystals occurs as the Sb atoms segregated at the interface capturing there the In atoms.

Surface processing for cell adhesion

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We have studied the interaction of MeV ion in its track with large number of polymer types and few metals in order to tailor their properties for aerospace applications, and medical applications, control cell adhesion, improved surfaces for heart-valve, for hip-joint implants, for fabrication of nano-pours used for DNA-sequencing and for filtration, as well as change in the surface properties of bio-compatible polymers for control drug/medication delivery.

Chemical changes are produced in plastics by the ionizing radiation interacting with the material resulting in the liberation of electrons from the atoms. For polymers, the radiation induces modifying processes in the polymer chains that produce chemical changes in the materials' properties. These processes can occur separately or in combination with one another and,

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depending on the nature of the material, one or more can occur simultaneously. Molecular excitations may be transmitted through the material as phonons or excitons which may cause bonds to break and produce scission, and cross-linking of the polymer chains. In many cases, dissociated hydrogen atoms and other small molecules move through the material and diffuse out as volatile species are formed. Dehydrogenation or the liberation of hydrogen atoms produces dangling bonds which eventually saturate and results in cross-linking. Other molecular emission processes, double bond formation, triple bond formation, dipole formation and precipitate formation by self clustering of the injected species can also occur. Our studies have revealed the effects on the polymers by radiation using energetic ion beams and have allowed us to modify the polymers as a result. This is a review paper of this work at the Center for Irradiation of Materials of AAMU and resulting applications.

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DEMINING / DETECTION OF EXPLOSIVES

Cameras vs. Computer simulation in Mine Protection

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For more than twenty years explosive blasts have been successfully simulated by software that had its origin out of supersonic wind tunnel analyses. The first program I was made aware of was the Autodyne program used by scientists of General Dynamics at a presentation at Fort Belvoir VA. Subsequently a series of better programs appeared; at this point a program called LS Dyna enjoys common support.

From 1965 the Government R&D organization CSIR in South Africa designed Mine Protected Vehicles for their insurgency wars that only stopped in 1989. All was done using mostly high speed cameras, electronic and mechanical measuring devices to develop the safety principals.

Since going to the US the author continued using his video and mechanical measuring rigs to improve the product of the company he worked for.

Finally enough evidence in favor of pictures has been collected to challenge the use of programs based on gas expansion formulae like those mentioned. The lecture will show these films and the effect on design. Examples will be used by the author to show what likely is really happening in those critical milliseconds of destruction caused in a buried charge explosion under a vehicle or human foot.

**DEVELOPMENT OF DECISION MAKING ALGORITHM FOR
CONTROL OF SEA CARGO CONTAINERS BY TAGGED NEUTRON
METHOD**

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Nowadays in Russia and abroad there are several groups of scientists, engaged in development of systems based on tagged neutron method (API method) and intended for detection of dangerous materials, including high explosives (HE). Particular attention is paid to possibility of detection of dangerous object inside a sea cargo container. Energy gamma-spectrum, registered from object under inspection is used for determination of oxygen/carbon and nitrogen/carbon chemical ratios, according to which dangerous object is distinguished from not dangerous one. Material of filled container, however, gives rise to additional effects of rescattering and moderation of 14 MeV primary neutrons of generator, attenuation of secondary gamma-radiation from reactions of inelastic neutron scattering on objects under inspection. These effects lead to distortion of energy gamma-response from examined object and therefore prevent correct recognition of chemical ratios. These difficulties are taken into account in analytical method, presented in the paper. Method has been validated against experimental data, obtained by the system for HE detection in sea cargo, based on API method and developed in VNIIA. Influence of shielding materials on results of HE detection and identification is considered. Wood and iron were used as shielding materials.

Results of method application for analysis of experimental data on HE simulator measurements (Tetryl, TNT, RDX) are presented.

**Device for Detection of Explosives, Nuclear and Other Hazardous Materials in
Luggage and Cargo Containers**

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Device for detection of explosives, radioactive and heavily shielded nuclear materials in luggage and cargo containers based on Nanosecond Neutron Analysis / Associated Particles Technique (NNA/APT) is under construction. Detection module consists of a small neutron generator with built-in position-sensitive detector of associated alpha-particles, and several scintillator-based gamma-ray detectors. Explosives and other hazardous chemicals are detected by analyzing secondary high-energy gamma-rays from reactions of fast neutrons with materials inside a container. The same gamma-ray detectors are used to detect unshielded radioactive and nuclear materials. An array of several neutron detectors is used to detect fast neutrons from induced

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fission of nuclear materials. Coincidence and timing analysis allows one to discriminate between fission neutrons and scattered probing neutrons. Calculations with MCNP5 and MCNP-PoliMi codes, as well as experiments with cosmic rays, lead us to the idea of a position-sensitive spectroscopic neutron detector consisting of an array of thermal neutron detectors surrounded by blocks of plastic-based (or liquid-based) fast neutron detectors that simultaneously serve as neutron moderators.

Mathematical modeling by MCNP5 and MCNP-PoliMi codes was also used to estimate the sensitivity of the device and its optimal configuration. Comparison of the features of three gamma detector types – based on BGO, NaI and LaBr₃ crystals will be presented.

The detection module can be used as a confirmation sensor for detection of hazardous substances in cargo and luggage within the suspicious regions defined during pre-screening with the high energy X-ray screening equipment.

Creation of the detection module is partly funded by ISTC through project #3534
<http://tech-db.istc.ru/ISTC/sc.nsf/html/projects.htm?open&id=3534>

Pulsed Thermal Neutron Delayed Gamma Spectrometry (PTNDGS) for Explosives Detection

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Gregory Pekarsky
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The US DHS is developing PTNDGS technology to non-intrusively probe cargo as a method for discriminating the absence or presence of a concealed explosive mass. This technology will measure secondary gamma ray emission spectra as a consequence of the pulsed neutron interrogation of a cargo object. Specifically, radiative capture interactions associated with thermal neutrons, resulting from the moderation of the primary pulsed fast neutron flux, will be exploited as the primary means for producing desired gamma ray spectra. Thus, maximizing thermal neutron flux relative to fast neutron flux, as well as sufficiently separating their time dependent distributions by delaying the generation of thermal neutrons will be primary objectives of the optimization process. These objectives will be accomplished by optimizing the shape and position of moderating materials external to the inspection object, as well as spatial relationships between the neutron source, object under inspection, and respective gamma ray detectors. In parallel, to most effectively measure the gamma rays emitted from thermal neutron capture interactions, optimized parameters for a measurement time gate in between fast neutron pulses will be established. Suspect explosive materials will be distinguished from benign materials by examining gamma ray spectral measurements for the existence of characteristic peaks corresponding to explosive elements of interest. Most notably, the technology's ability to discern the 10.8 MeV signature peak of nitrogen from background noise will be used to determine the overall success of the experimental effort.

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**Detection of Improvised Explosive Devices at Long-Range Using Coded
Aperture Imaging of Backscattered X-Rays with Dynamic Reconstruction**

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Anatoli Arodzero, Omar al Kofahi, Cristian Dinca and Peter Rothschild

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Detection of improvised explosive devices at a distance has been and remains a pressing problem. One approach to this problem which has been proposed is to use backscattered x-rays to detect the low-Z materials of explosives. Backscatter has been used previously to detect contraband and explosives in vehicles or carried on individuals. However, the conventional approach, generally based on a variant of pencil-beam scanning, degrades with distances much greater than ~5 meters, and is not at all practical for source-to-target distances of 50 to 100 meters. Further, almost all of the work to date has assumed a fixed geometrical relationship between the interrogating source and the detector rather than the practical case where the source and the detector are moving relative to the target object. Our approach illuminates the entire field of view with x-rays and images the backscatter using a coded aperture. Since the source-detector is in constant motion relative to the target, a new approach to coded aperture imaging, *dynamic reconstruction* has been developed in which events are reconstructed on an event by event basis while in motion. Examples of backscatter images using this technique will be shown as well as a larger discussion of the applicability of dynamic reconstruction to other problems such as long range passive detection of radioactive sources.

NUCLEAR REACTIONS/TEST BAN TREATY STATUS

Neutron and nuclei exotic production in SPIRAL2

Manssour FADIL

GANIL, Bd Henri Becquerel, 14076 Caen cedex 5

Now in the phase of construction in GANIL, SPIRAL2 facility will be in few years a world leader in the production of exotic nuclei. With an incident beam of 40 MeV deuteron and 5 mA , 200 kW power will be dissipated on a graphite converter. This converter (carbon thick target) converts the deuteron with the stripping reaction on high fast spectrum neutron of about 10^{15} n.s⁻¹. With a natural uranium target, this neutron flux will induce a fission rate of about 10^{14}

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fissions.s⁻¹. Rich neutron nuclei, produced by fission, will be extracted and accelerated in the existing cyclotrons of GANIL.

The talk will describe the SPIRAL2 facility, the production mechanism and some radioactive aspects as it is calculated with Monte Carlo codes. Results of experiments estimating neutron production with possible solid and liquid converters (respectively graphite and heavy water) will also be presented.

D+D and D+T Exothermic Nuclear Reactions

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The exothermic reactions $3\text{H}(d,n)4\text{He}$ and $2\text{H}(d,n)3\text{He}$ are commonly used as major sources to investigate monoenergetic neutrons for energies above 2MeV. We have used the aforementioned reactions to deduce neutron spectra from a specially designed deuterated (C6D6) liquid scintillator. Major features of the detector and its response to high-energy neutrons and gammas from recent experiments will be presented. The present results indicate unique characteristics that should make these detectors useful in many nuclear reaction studies to detect high-energy neutrons.

Overview of the current status of the radionuclide network of the Comprehensive Nuclear Test Ban Treaty Organization and the challenges of its sustainment

Luis Cella

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The Comprehensive Nuclear-Test Ban Treaty (CTBT) bans all kinds of nuclear explosions. In order to monitor its compliance a verification regime composed of, among others, an International Monitoring System (IMS) is being built. The IMS consist of 321 stations of four different technologies and 16 radionuclide laboratories that support the radionuclide network. This in turn consists, in addition to the labs, of 80 stations distributed worldwide, in different environments ranging from tropical forest, to polar sites and sand-covered deserts.

As of February 2009, 55 radionuclide stations have been certified to comply with stringent technical requirements. Radionuclide stations monitor airborne radioactivity by using high-volume air samplers and gamma-ray spectrometry systems equipped with High-purity

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Germanium detectors. Authenticated data is transmitted by means of a dedicated VSAT antenna to the International data Centre in Vienna. Additionally, 40 of the 80 stations are equipped with automatic radionuclide monitoring systems.

An overview of the current status of the radionuclide network is presented, together with a description of the current equipment being deployed on the field both for particulate and xenon monitoring. The challenges of maintaining such huge number of state-of-the-art stations are also discussed.

DETECTION OF ILLICIT NUCLEAR MATERIALS

Muon tomography with a large-volume prototype

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The muon tomography technique, based on the multiple Coulomb scattering of cosmic ray muons, has been proposed as a tool to perform non-destructive assays of large volume objects for applications in civil security such as cargo container inspection in seaports. A large-volume prototype of about 10 cubic meters has been built at the INFN Legnaro National Laboratories using two large area CMS Muon Barrel drift chambers. The prototype has been used to measure impact point and direction of the cosmic rays at the entrance and at the exit of the volume under inspection with two large area detectors, placed above and below such volume. Several studies with different materials in the prototype volume and different reconstruction algorithms have been performed demonstrating the detection capability of the system. Experimental results on density-based material classification will be presented and discussed.

Improved Method for SNM Inspection

Bernard Harris, Brandon Blackburn

Raytheon Integrated Defense Systems

Conventional active inspection for special nuclear material (SNM) utilizes high-energy photons produced in a solid material convertor. MCNPX simulations indicate superior inspection performance over a wide energy range when electrons convert directly in the air in its

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path to the interrogation zone. This is in stark contrast with the more conventional approach such as a closely located high-z bremsstrahlung converter that generates photons directly at the LINAC beam exit port. MCNPX computer simulations indicate that induced fissions using air conversion is over an order of magnitude greater than conventional inspection. For high-energy applications such as 15-60 MeV, MCNPX simulations indicate direct conversion of electrons in air generated the highest number of fissions in threat objects placed 100 m from the accelerator. This phenomenon occurs for three main reasons. Electrons at energies greater than 30 MeV have considerable air penetration, with a mean free path of around 300 meters at 60 MeV. Because of this range, high energy photons are simply generated at a distance much closer to the target than producing them in a converter near the accelerator. Secondly, air is a low-Z converter of low density. It requires long distances for effective conversion, but because of its effective Z of approximately 7, it preferentially generates high energy photons in the forward direction. Finally, any surviving electrons which make it to the object under inspection will generate bremsstrahlung radiation essentially at the threat object and thus provide a much larger effective solid angle of photon interrogation.

Muon Tomography for Detecting High-Z Nuclear Material in Cargo

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Radiation detection techniques currently employed by standard portal monitors at international borders and ports are not very sensitive to high-Z radioactive nuclear material if the material is well shielded to absorb emanating radiation. Muon Tomography (MT) based on passively probing cargo or vehicles by measuring the multiple scattering of traversing atmospheric cosmic ray muons is currently being pursued by several research groups world-wide to address this problem. Using detailed GEANT4 Monte Carlo simulations, we compare the expected performance of our proposed MT imaging system, which employs compact Micro Pattern Gas Detectors for tracking muons, with the performance of MT systems which use traditional drift tubes. We present results for realistic scenarios of nuclear contraband hidden in cargo using a basic Point-Of-Closest-Approach scattering reconstruction algorithm and a more advanced Estimation Maximization algorithm based on a maximum-likelihood method. A full-scale MT station will require large-area tracking detectors. We report on efforts by the CERN-based RD51 collaboration to develop large-area Gas Electron Multiplier (GEM) detectors with high spatial resolution that could be used for MT. We describe the construction of a small-scale MT prototype with 30cm × 30cm triple-GEM detectors and report first experimental results obtained with the prototype.

**10th International Conference on
Applications of Nuclear Techniques**

The SORDS Trimodal Imager

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The Raytheon Trimodal Imager (TMI) uses coded aperture and Compton imaging technologies as well as the non-imaging shadow technology to locate an SNM or radiological threat in the presence of background. The coded aperture imaging is useful for locating and identifying radiological threats as these threats generally emit lower energy gammas whereas the Compton imaging is useful for SNM threats as in addition to low energy gammas which can be shielded, SNM threats emit higher energy gammas as well. The shadow imaging technology utilizes the structure of the instrument and its vehicle as shadow masks for the individual detectors which shadow changes as the vehicle moves through the environment. Before a radioactive source comes into the fields of view of the imagers it will appear as a shadow cast on the individual detectors themselves. This gives the operator advanced notice that the instrument is approaching something that is radiological and on which side of the vehicle it is located. The two nuclear images will be fused into a combined nuclear image along with isotope ID. This combined image will be further fused with a real-time image of the locale where the vehicle is passing. A satellite image of the locale will also be made available. This instrument is being developed for the Standoff Radiation Detection System (SORDS) program being conducted by Domestic Nuclear Detection Office (DNDO) of the Department of Homeland Security (DHS).

**Bremsstrahlung versus Monoenergetic Dose and Photonuclear Stimulation
Comparisons At Long Standoff Distances**

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Energetic photon sources with energies greater than 6 MeV continue to be recognized as viable source for various types of inspection applications, especially those related to nuclear and/or explosive material detection. These energetic photons can be produced as a continuum of energies (i.e., bremsstrahlung distribution) or as a set of one or more discrete photon energies (i.e., monoenergetic distribution). This paper will provide a follow-on extension of the photon dose comparison presented at the 9th International Conference on Applications of Nuclear Techniques (June 2008). The latter paper showed the comparative advantages and disadvantages

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of the photon doses provided by these two energetic interrogation sources and highlighted the higher energy advantage of the bremsstrahlung source, especially at long standoff distances (i.e., distance from source to the inspected object). Specifically, this paper will pursue this higher energy photon inspection advantage (up to 100 MeV) by providing dose and stimulated photonuclear interaction predictions for air and an infinitely dilute structural material (used for maximum interaction rate assessments since it excludes material self-shielding) as the interrogation object positioned forward on the inspection beam axis at increasing standoff distances. In addition to the direct energetic photon-induced stimulation, the predictions will identify and characterize the importance of any secondary downscattered/attenuated source-term effects arising from the photon transport in the intervening atmosphere.

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Pulsed Photonuclear Measurements of Shielded HEU Oxide Fuel Pins and DU Metal

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Pulsed photonuclear measurements have been performed on HEU oxide fuel pins and DU metal with a 2-12 MeV Varitron electron accelerator at the Idaho National Laboratory Power Burst Facility. The HEU sample (46 wt%) consisted of 8 kg of ²³⁵U and was surrounded by Borobond4 neutron absorber in an ES-3100 container. These measurements investigated the characteristic neutron response in various polyethylene, lead, and iron shielding configurations. The accelerator was operated at an endpoint photon energy of 10 MeV, a 3 μs pulse width, and a repetition rate of 125 Hz. An array of He-3 detectors was used to detect neutrons emitted from each sample. These neutrons were counted during and after the pulse with the Nuclear Material Identification System (NMIS) and used to measure the differential die-way and coincidence distributions. This paper presents results from the measurements.

Radiation control and monitoring at Industrial Group of Enterprises “UZMETKOMBINAT”

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10th International Conference on Applications of Nuclear Techniques

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“Uzmetkombinat” is the biggest metallurgical group of enterprises in Uzbekistan which is producing different types of steels and some non-ferrous metals. Some technological processes at the enterprises are using nuclear methods and devices, in particular, gamma and beta spectrometers for determination of NORM (naturally occurring radioactive materials) and TENORM (technologically enhanced naturally occurring radioactive materials, radioisotope loading level meters and others. Radiation control and monitoring at the enterprises is performed by its special division radiation control service. This service is equipped with various radiation detectors and dosimeters. Special laboratory determines NORM and TENORM contents in raw materials for ferroalloys production. Radiation control is also performed at all railway and vehicle entrance points of the enterprises. Presently the problem contaminated scrap metals is becoming extremely important, that’s why “Uzmetkombinat’ is planning in collaboration with Institute of nuclear physics of Uzbekistan Academy of Sciences to manufacture and install radiation portal monitors at main entry points of enterprises. Special attention of radiation control service is paid to radioactive wastes storage at “Uzmetkombinat” territory. The cases of detection of radioactivity in raw material and metal scrap are presented.

Radiation Control on Uzbekistan borders – Results and Perspectives

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Three factors place Central Asia and Uzbekistan as its part in a key global nonproliferation position: the proximity of nuclear neighbors, the proximity of states and other groups seeking nuclear/radioactive material and know-how, and indigenous sources of nuclear/radioactive material. The geographical location of Uzbekistan is convenient for illicit trafficking of nuclear materials. To prevent it is possible by installing stationary portal radiation monitors at main customs border crossings or entry points. Their high sensitivity permits to detect signals exceeding background level on several percents in moving objects with recording these signals in computer and the object itself (vehicle, train or pedestrians) on video-camera. Up to date in Uzbekistan 27 checkpoints were equipped with 175 monitors. Cases of radioactivity detection are analyzed. The Institute of nuclear physics of Uzbekistan Academy of Sciences provides stable operation of these radiation monitors, technical assistance and consultancy in case of alarm signals, regular technical maintenance. Besides, in Institute of nuclear physics were elaborated and manufactured radiation monitors working on different basis than traditional ones. These radiation monitors are based on multi-detector system comprising scintillation detectors. The detection of radioactivity is based on difference counting method without connection to natural background level thus providing much lower level of false alarms: 1:10000. For detection of fissile materials the method of gamma-gamma coincidences of prompt gammas produced in fission is used. In these radiation monitors there is no need for special neutron detectors. The perspectives of future development of radiation monitoring on the borders are discussed.

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**Neutron flux from a 14-MeV neutron generator with tungsten filter
for research in NDA methods for nuclear safeguards and security**

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The Joint Research Centre has taken into operation a new experimental device designed for research in the fields of nuclear safeguards and security applications. The research projects currently undertaken include detection of shielded contraband materials, detection of fissile materials, and mass determination of small fissile materials in shielded containers. The device, called the Pulsed Neutron Interrogation Test Assembly (PUNITA), incorporates a pulsed 14-MeV (D-T) neutron generator and a large graphite mantle surrounding the sample cavity. By pulsing the neutron generator with a frequency in the range of 10 to 150 Hz, a sample may be interrogated first by fast neutrons and a few hundred micro-seconds later by a pure thermal neutron flux. The permanent detection systems incorporated in PUNITA include ³He neutrons detectors, HPGe gamma detectors, and lanthanum bromide scintillation detectors.

We have studied the effects of placing a tungsten liner around the neutron generator target. The 14-MeV neutrons induce (n, 2n) and (n, 3n) reactions. In addition the mean neutron energy emitted from generator/tungsten assembly is reduced to about 1 MeV. Both of these effects increase the thermal neutron flux in the sample cavity. The paper describes the observed advantages of the tungsten liner with respect to increase in thermal flux, and better shielding capabilities of the nearby gamma and neutron detectors.

The SORDS Trimodal Imager Detector Arrays

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10th International Conference on Applications of Nuclear Techniques

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The Raytheon Trimodal Imager (TMI) uses coded aperture and Compton imaging technologies as well as the non-imaging shadow technology to locate an SNM or radiological threat in the presence of background. The heart of the Trimodal Imager is the two arrays of NaI crystals. The front array serves as both a coded aperture and the first scatterer for Compton imaging. It is made of 35 5x5x2" crystals with specially designed low profile PMTs. The back array is made of 30 2.5x3x24" position-sensitive crystals which are read out at both ends. These crystals are specially treated to provide the required position resolution at the best possible energy resolution. Both arrays of detectors are supported by aluminum superstructures. These have been efficiently designed to allow a wide field of view and to provide adequate support to the crystals to permit use of the TMI as a vehicle-mounted, field-deployable system. Each PMT has a locally mounted high-voltage supply that is remotely controlled. Each detector is connected to a dedicated FPGA which performs automated gain alignment and energy calibration, event timing and diagnostic health checking. Data are streamed, event-by-event, from each of the 65 detector FPGAs to one master FPGA. The master FPGA acts both as a synchronization clock, and as an event sorting unit. Event sorting involves stamping events as singles or as coincidences, based on the approximately instantaneous detector hit pattern. Coincidence determination by the master FPGA provides a pre-sorting for the events that will ultimately be used in the Compton imaging and coded aperture imaging algorithms. All data acquisition electronics have been custom designed for the TMI. This instrument is being developed for the Standoff Radiation Detection System (SORDS) program being conducted by Domestic Nuclear Detection Office (DNDO) of the Department of Homeland Security (DHS).

Active Mask Compton/Coded Aperture Imaging for the SORDS Trimodal Imager

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In this paper we develop and demonstrate methods for combining Compton and coded aperture imaging modalities in an active mask gamma ray imaging system. Using an active mask, wherein the mask elements are active detectors rather than passive absorbers, one can identify Compton events as those events which deposit energy in both a mask element and the absorbing detector. These events are, of course, suppressed from the coded aperture dataset. To test the system we developed a GEANT4 simulation of an active imager and developed a background model with rate and energy spectrum validated against experimentation data. We then assessed the detect ability of various point sources placed within this background. Maximum likelihood image reconstruction methods were developed for both the Compton and coded aperture imaging modalities. We also produced a hybrid maximum likelihood method for simultaneous imaging of the combined Compton / coded aperture dataset. We show that the detectability of sources from 600 - 2200 MeV is significantly improved by using combined imaging relative to either Compton or coded aperture imaging alone. We conclude with a demonstration of application of combined imaging to experimental results obtained from a real active mask imaging system.

Detection of nuclear materials via cosmic ray muon scattering

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The smuggling of illicit RN material into Canada and allied countries is a major security concern. While radiation detection systems for cargo exist that are sensitive to low levels of gamma or neutron radiation, special nuclear material (U, Pu) and well-shielded radiation sources are difficult to detect by conventional means. A solution to this problem might be provided by highly-penetrating, cosmic ray muons. Dense, high-Z materials like U, Pu and Pb scatter muons at larger angles than "normal" material. Charged particle tracking detectors placed above and below an object of interest (e.g. shipping container) can be used to measure the deflection of the muon trajectories. Defence R&D Canada, in partnership with several other Canadian government departments, private companies and universities has started to study the effectiveness of this technique for detecting smuggled nuclear materials. The main goal of our project is to build a prototype muon tracking system that will be rigorously tested under realistic conditions. This talk will present the results of preliminary simulation studies and an operational analysis of the scanning procedures currently used in Canadian ports.

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**Radiation monitoring of Amu-Darya and Syr-Darya rivers
in Central Asia**

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The study of waterborne radionuclides and metals concentration in Central Asia is of particular interest in the region because of the history of nuclear materials mining, fabrication, transport and storage. This development left a legacy of radionuclides and metals contamination in some Central Asian regions, which poses a clear health hazard to population who rely heavily upon surface water for cropland irrigation and direct domestic consumption. Fifteen sampling locations have been identified in each of the four Central Asian republics for a total of 60 sampling locations. Sampling was occurred in different media. The four different media were water (dissolved); bottom sediment; aquatic vegetation; soils. Measured parameters were: - basic water quality parameters - discharge (m³/s), water temperature (deg C), dissolved oxygen (mg/l), specific conductivity (uS/cm), salinity (g/l), TDS(dissolved solids) (g/l), depth (m), pH, redox potential (mV); - radionuclides parameters - alpha activity, beta activity, radionuclides(⁴⁰K, ²⁰⁸Tl, ²¹²Bi, ²¹⁴Bi, ²¹²Pb, ²¹⁴Pb, ²²⁶Ra, ²³²Th, ²³⁵U, ²³⁸U); - metals - Al, Ag, As, Ba, Ca, Co, Cr, Cu, Fe, Hg, Mg, Mn, Zn etc.). Thus, estimation of radio-ecological situation was made and peculiarities of distribution of radionuclides and metals in the rivers Amu-Darya and Syr-Darya were shown.