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BOOK OF ABSTRACTS

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ID: 1

Synthesis, processing and EPR response of $Y_{1.98}Eu_{0.02}O_3$ micro rods

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The design and development of new dosimetric materials based on rare earth oxides is the great challenge in innovation of materials. Yttrium oxide (Y_2O_3) is one of the most important sesquioxides and presents crystal characteristics that enable doping with rare earth ions, being a promising material for radiation dosimetry**.** This paper reports the development and Electron Paramagnetic Resonance (EPR) signal response of $Y_{1.98}Eu_{0.02}O_3$ micro rods from a facile-low pressure hydrothermal synthesis and bio-prototyping. As synthesized powders with narrow submicrometer particle size distribution with d_{50} of 584nm exhibited reactive surface, which led the formation of stable aqueous suspensions by controlling surface charge density of particles through alkaline pH adjustment, and as a consequence ceramic samples with dense microstructure as sintering at 1600ºC for 4h in air atmosphere. $Y_{1.98}Eu_{0.02}O_3$ micro rods were irradiated using ^{60}Co source with doses from 1 to 100kGy and EPR spectra were measured at room temperature in X band microwave frequencies. Sintered samples exhibited linearity of the main EPR signal response from 10Gy to 10kGy. Supralinearity was observed for higher doses, which is possibly ascribed to formation of more defects. Using europium as dopant enhanced remarkably EPR signal of yttrium rods due to 4f-4f transitions of Eu^{3+} ion. These innovative findings make europium doped yttrium oxide a promising material for radiation dosimetry.

Keywords: synthesis, yttrium oxide, bio-prototyping, EPR, dosimetry, ceramic processing.

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Measurement of the Enhancement of the Nuclear Interaction Yield with Crystalline Targets at Cyclotron Energies

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Ordered structures such as crystalline materials may help to enhance the nuclear interaction yield [1]. Indeed, the aligned atoms act as a single entity on impinging charged particles causing the trajectory to pass from its random motion to a deterministic one [2]. In fact, Monte Carlo simulations [3] suggested that specific crystal alignments allow for the enhancement of the production rate of nuclear inelastic reactions, because particles are forced to pass on the atomic nuclei more frequently than would happen in an amorphous material.

Recent measurements we carried out at the AN2000 accelerator of the INFN National Laboratories of Legnaro (INFN-LNL) showed the first experimental evidence of such effect. A 643.5 keV collimated proton beam was used to induce the $^{18}O(p,\alpha)\ ^{15}N$ reaction in an Al_2O_3 substrate oriented along the <0001> axis. The capability of manipulating such an effect paves the way to the study of innovative targets for the enhancement of the nuclear interaction yield with a constant density.

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ID: 5

The MegaSPIDER detector system for fission product yield measurements

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Nuclear fission is a highly complex process, and despite many decades of research there are still limitations to our ability to accurately model different aspect of this nuclear reaction. This is a problem for nuclear technology in cases where subtle aspects of the fission process are relevant, such as in fuel burn-up analysis using fission products. The yield of specific fission products is known to change significantly as a function of the incident neutron energy, but there is very little experimental data that describe this for the relevant actinides.

A new detector system, MegaSPIDER, is being developed for studying fission product yields (FPY) at the Los Alamos Neutron Science Center (LANSCE). The system uses fast timing detectors and gas ionization chambers to measure the time-of-flight and kinetic energy of fission fragments in order to determine their mass. A predecessor to the detector system, SPIDER, was used to demonstrate the capability and measured fission product yields from U-235, Pu-239 and U-233 at thermal neutron energies. The new detector system will have a significantly higher efficiency and will enable studies of yields for fast neutron-induced fission.

ID: 7

Development of Trigger and Start Detectors for Experiments with High-Energy Heavy Ions at JINR

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Fast Cherenkov and scintillation detectors based on MCP-PMTs and SiPMs are being developed for application in the MPD (Multi-Purpose Detector) and BM@N (Baryonic Matter at the Nuclotron) experiments with heavy ion beams of the Nuclotron and the NICA collider, which is built at LHEP/JINR [1-3]. The experiments are dedicated to study of the properties of hot and dense nuclear matter created in nucleus–nucleus collisions. The aim of the detectors is fast triggering of nucleus–nucleus collisions with high efficiency and generation of the start signal with picosecond time resolution for TOF measurements. The detectors provide the time resolution of 50 ps and can operate in the strong magnetic field of the experimental facilities.

The Fast Forward Detector is a multichannel Cherenkov detector that is being developed for the MPD experiment. It consists of two identical modular arrays with MCP-PMT readout. For the BM@N experiment, a system of beam and target area detectors is used. The concept and performance of the detectors and the results of simulations and tests are discussed.

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ID: 8

High efficiency and high sensitivity thermal neutron detectors based on hexagonal BN epilayers

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Solid-state thermal neutron detectors with improved detection efficiencies and sensitivities are highly sought after for the detection of special nuclear materials. Due to the inherent nature of low flux of fission neutron emission from a potential fissile material as well as the fact that the neutron flux is inversely proportional to the square of the distance from the source, it is challenging in many cases to detect neutron signals at relatively large distances. Consequently, large size high efficiency detectors are desired to improve the detector performance and to provide a reasonable count rate.

We have successfully synthesized by MOCVD freestanding wafer-scale ^{10}B enriched hexagonal boron nitride (*h*-BN) epilayers with a thickness of about 50 microns [1-5]. We have realized recently vertical photoconductor-like thermal neutron detectors of 1 mm^2 in size with 51.4% detection efficiency [1]. Builds on our previous work, we report here the fabrication and characterization of 3 mm x 3 mm *h*-BN thermal neutron detectors in vertical photoconductor-like geometry with 50% detection efficiency. The effects of resistivity, dark current density, and the carrier mobility-lifetime products on the device performance were monitored and optimized via MOCVD growth parameters. With improved material quality, the noise related dark counts have been significantly reduced. The work laid the groundwork for realizing large area neutron detectors.

The spectroscopic responses of *h*-BN detectors to 5.31 MeV alpha particles from ^{210}Po and gamma photons produced by ^{137}Cs decay at 0.662 MeV have also been characterized. The results revealed that *h*-BN semiconductor detectors are very sensitive in resolving energies of specific reaction products and have a negligible response to gamma photons [1-4]. Our results indicate that *h*-BN are highly promising for realizing sensitive solid-state thermal neutron detectors with expected advantages resulting from semiconductor technologies, including compact size, light weight, low operating voltage, and low cost.

The detector work is support by the DOE NSSA SSAA program (DE-NA0002927). The study of the basic structural properties of *h*-BN is supported by the NSF (ECCS-1402886).

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ID: 9

Surface Element Diagnostics by PIXE Investigation

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Proton (particle) Induced X-ray Emission (PIXE) is a conventional procedure for highly efficient elemental characterization of materials based on ion beam analysis. It is more effective in comparison with electron-based excitation of X-ray characteristic emission due to the small yield of bremsstrahlung photons. Proton or ion-induced X-rays are used to characterize the studied material's elemental composition by exciting X-ray fluorescence through an ion braking process. The fluorescence yield is dependent on absorption factors of the material fluorescence lines. Moreover, the real fluorescence yield is dependent on the bulk material characteristics. As a result, PIXE analytical measurements are characterized by high sensibility, but considered as a quality analytical method for the volume material elemental diagnostics. At the same time, unique possibilities of PIXE measurements can be used for efficient element diagnostic of surface or thin layer materials by including a special design of a planar X-ray waveguide-resonator (PXWR) [1] along with the X-ray fluorescence yield detection. In this scheme, the waveguide-resonance slit clearance is formed by the surface of the studied object and a polished surface of a beryllium reflector. The width of the waveguide-resonance slit clearance is defined by the coherence length of the studied material's fluorescence lines. For the total elemental analysis of the surface, the slit clearance width must be smaller as 60 nm. If the contents of light elements of the target surface area are of interest, the distance between reflectors must be smaller than 150 nm. This paper presents the characteristics of this new method for surface elemental analysis and discusses some limitations of its detection procedure.

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ID: 10

HiRIS – a High-Resolution Upgrade of VACIS Mobile Non-Intrusive Inspection Systems

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DHS S&T is funding Spectral Labs Inc. (SLI) to upgrade the performance and extend the useful life of Mobile VACIS[(1)] gamma-ray non-intrusive inspection (NII) systems used by US and other customs and border protection agencies worldwide. This High-Resolution Imaging System (HiRIS) program will result in significant spatial resolution of state of the art gamma cargo inspection systems by doubling the pixel count. Along with improved contrast sensitivity and potentially greater penetration the resultant system will enable quicker and more effective contraband interdiction by inspectors. This significant enhancement in spatial resolution is achieved by using the latest advancement in photomultiplier technology, solid state silicon photomultipliers (SiPM) coupled with higher-efficiency CsI scintillation crystals (replacing larger NaI detectors used in legacy systems). The improved overall detection efficiency results in better contrast sensitivity while maintaining maximum scan speed and average throughput of 20 cargo conveyances/hour. SLI has developed digital pulse-shape analysis electronics and advanced image processing algorithms to replace legacy analog electronics and analysis tools. These analysis tools provide the potential to minimize cross talk and provide sharper images. The HiRIS detector module and associated data processing, image enhancement software and processed data display are designed to replace these functions in the legacy systems while maintaining the existing ^{60}Co source enclosure/collimator/shutter, mechanical source and detector positioning system and source and vehicle motion control electronics (existing Programmable Logic Controller –PLC). The HiRIS kit will also enable, as shown in the table, operation at greater extremes of operational environment required in many CBP locations.

Results of SLI demonstration of the spatial resolution performance of the CsI/SiPM detector array (~6 mm) will be shown. SLI has qualified three commercial suppliers of the CsI/SiPM detectors which will allow the large number (~600 detectors/system) to be procured in a cost-effective and affordable manner. The HiRIS kit is currently in the process of being retrofitted into an existing Mobile VACIS system and performance of the enhanced and upgraded HiRIS NII system will be shown. After a successful field evaluation of the HiRIS system by CBP, it is anticipated that existing legacy systems, many of which have successfully operated for 10 to 15 years and have reached the end of their useful life, can be upgraded by HiRIS and be used for another 10 to 15 years.

HiRIS and Legacy MME-NII Performance

Upgrade Specifications	HiRIS Performance	Legacy MME-NII Performance
Spatial Resolution	~ 6 mm (.236”) using SiPM	12 mm (.472”) using PMT
Steel Penetration	6” (15.2 cm)	6” (15.2 cm) (GFE measured 4” (10.2 cm)
Contrast Sensitivity	5%-7%	8%-10%
Image Resolution	Advanced Imaging Algorithm	Legacy Tools
Intellectual Property	Full and Unlimited Rights	Limited Rights
Maximum Scan Speed	5 mph	5 mph
Inherent Availability	New Rugged Components, Lower Temp Modules	Obsolete and Aging Components
Operational Environment	-40°C - 55°C (-40°F - 131°F)	-18°C to 49°C (0°F - 120°F)
Average Throughput	20 conveyances per hour	20 conveyances per hour
Radiation Exclusion Zone	No Changes	NRC Registered

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ID: 11

Positron emission particle tracking: a powerful nuclear application for flow studies

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Positron emission particle tracking (PEPT) has been developed into a flexible applied nuclear technique for measuring the trajectory of a single tracer particle moving within a system of granular or liquid flow, or attached to a moving rigid body. The tracer particle is pre-labelled with a radionuclide (such as ^{18}F or ^{68}Ga) which decays via positron emission. The nearly co-linear 511 keV annihilation gamma rays are detected in coincidence by a modified PET camera, which defines their line of response (LOR). The chronologically measured LORs may then be used to triangulate the position of the moving tracer particle. In principle only two LORs are necessary for each measured position. However in practice a larger number of measured LORs are required due to the recording of none-useful LORs resulting from the detection of gamma rays after undergoing Compton scattering between creation and detection and the coincident detection of two gamma rays which were not associated with the same annihilation event. Since many thousands of coincidence events can be processed by a PET camera each second, the possibility of tracking the position of a fast moving particle may be realised. Over the last decade a wide range of PEPT applications have been explored, for example powder mixing, particle and fluid behaviour in granular beds, rotating drums, stirred tanks and flotation cells.

The laboratories of PEPT Cape Town, situated at iThemba LABS, South Africa, have been fully operational for a number of years. We provide an overview of the PEPT technique and report on a number of research highlights spanning a wide range of contexts of both single phase and multi-phase systems of flow, as well as advances made on the simultaneous tracking of multiple tracers in the same experiment and the dynamic imaging of flow within packed columns.

For PEPT studies it is important for the shape and composition of the tracer to be as similar as possible to the class of material it is representing. Ideally, the activity of the tracer must be such that sufficient LORs are recorded per second to produce a reliable measurement of the trajectory of the tracer. We thus also report on the state-of-the-art in tracer production for PEPT, including work which aims to produce useable tracers in the 20-50 micron range.

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Characterization and Monte Carlo simulations for a CLYC detector

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The CLYC (Cs_2LiYCl_6:Ce) detector is a scintillator detector that exhibits sensitivity both to neutron and gamma radiation with possibility to separate the two types of radiation by Pulse Shape Discrimination. This feature makes it interesting in view of the development of non-destructive assay for safeguards of nuclear material, nuclear security and fast neutron personal dosimetry. This work is part of a collaboration agreement between SCK•CEN and JRC-Geel.

Within this framework, a 1”×1” CLYC detector highly enriched in ^{6}Li was purchased and tested both with analogue and digital electronics. In this work, we report about the characterization of such a detector in terms of energy resolution and full energy efficiency for gamma rays. This was achieved by means of measurements with calibrated gamma point-sources with an analogue chain in a well-given and reproducible geometry. The experimental data were also used to validate a model of the detection system that was developed with the Monte Carlo code MCNP-CP.

In addition, we also optimized the settings of a data acquisition system based on a CAEN 5730B digitizer. Such a system allows acquiring the waveform of the signal coming from Photo Multiplier Tube with a 2 ns resolution and can also perform a Pulse Shape Discrimination on board. The performances of such a system were investigated with measurements with a ^{252}Cf source and are also presented in this paper.

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Tracking Challenges and Novel Approaches in High Energy and High Track Density Environments

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Intermediate and high energy nuclear collisions create an environment where the number of tracks can reach about five thousand, with a total hit number of about fifty thousand. Tracking in these environments is a great challenge, especially if one would like to do it in an online environment for trigger purposes. Traditional, follow-your-nose tracking algorithms require a reliable "seed" track and a general sense of direction, i.e. where the primary, event vertex occurred. KALMAN This information is typically provided by the user or other software modules. After the initial tracking is done, filtering techniques (like the Kalman filter) are applied for outlier rejection and signal sharpening.

We discuss here the basic elements and performance of a novel technique based on the Cellular Automaton (CA) algorithm[1]. The technique requires no track seeding or event vertex knowledge and can be adapted to various experimental configurations and needs, e.g. fixed target or colliding beams, tracking planes or continuous tracking etc. The technique was applied to online and offline analysis environments of existing and future experiments[2] and it demonstrated superior performance compared to traditional tracking. We present here a sample of performance comparisons and gains in terms of gains of W-boson and heavy flavor (charm mesons) done on data samples at various luminosity environments where significant gains (in the order of 20-30%) were obtained.

1 *http://web-docs.gsi.de/~ikisel/reco/HERA-B/cats_vds.pdf*
2 *http://phys.kent.edu/~smargeti/STAR/HFT/StiCA.pdf*

ID: 14

Ion Optic Design of the Microprobe Beam Line of Sichuan University

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At the end of 2016, the first beam was extracted from the 3.0 MV Tandetron accelerator system at Sichuan University, China. The accelerator was imported from HVEE as a multi-purpose research platform. For one of the main applications, the system will be connected to a micro-beamline to achieve submicron resolution, so the accelerator is designed with energy stability as high as 0.01%. The measured brightness for the 3 MeV proton beam is 5.5 pA/um^{2}mrad^{2}MeV and the energy stability has reached the design goal. The commissioning results of the accelerator and the ion optic design of the microprobe beam line will be presented in this paper.

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Combined Fast-Neutron and γ-ray Computed Tomography: A Single Modality with which to Discern both Nuclear Materials and Contrived Shielding Configurations?

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Neutron tomography is a well-established non-destructive testing technique used to evaluate the properties of the materials, components and systems without causing damage to samples under scrutiny. Several studies have focussed on the use of cold and thermal neutrons for this purpose, however, only few reports emphasise the use of fast neutrons. The key benefits of fast neutrons are that they can penetrate deeper into substances than thermal neutrons and, as a result of moderation in a sample under scrutiny, they can fall below the low-energy threshold of organic scintillation detectors yielding a tomographic response that has a reduced contribution of scatter-derived noise. γ Rays yield signature information on high-Z constituents. This complementarity between γ rays and neutrons can be exploited if they can be detected simultaneously from the same source and sample, and ideally at the same time. The hypothesis behind this study is to explore this possibility and to identify the optimum combinations of materials with which to test a combined γ-ray/fast-neutron tomography system and hence with which to optimise the system geometry and design to achieve competitive image resolution quickly with a relatively small neutron source. This has been done via the simulated computer tomography of a variety of materials combinations with the potential to serve this purpose with Monte Carlo simulations. The samples are scanned under a fan beam with a collimated mixed radiation field; both californium-252 and americium-beryllium have been used in these simulations. The collimator system comprises a combination of two polyethylene blocks and two tungsten blocks separated by a narrow gap to produce a fan beam, which is directed towards a phantom made of different materials. The design is completed by an array of organic scintillator detectors that, via computed algorithms, discriminate and retain neutrons and gamma rays. Experimentally, instead, the simultaneous detection of neutrons and gammas occurs by means of real-time pulse-shape discrimination systems, as shown in previous research for neutrons only. The different behaviour and the complementarity of neutrons and γ rays will be shown. A clear separation is observed for materials such as water, heavy water, concrete, lead, tungsten, aluminium, and other materials used widely for moderation and shielding as well as materials used in the nuclear industry such as uranium and plutonium. The combined γ-ray/neutron method has potential applications in in-situ materials inspection, nuclear safety, nuclear security and possibly in nuclear safeguards inspections.

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Status of the 2D Multi-Wire Proportional Chamber Detector for China Spallation Neutron Source

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The re-designed two dimensional Multi-Wire Proportional Chamber (MWPC)[1] detector based on ^{3}He operation gas has been developed for the multifunctional reflection spectrum detection requirements of the China Spallation Neutron Source (CSNS), which is under construction in Guangdong province, China. This efficient thermal neutron detector, with a large area (200mm×200mm of the active area), two-dimensional position sensitivity (<2mm of the position resolution), high detection efficiency (>65% in the wavelength of 1.8Å) and good n/γ discrimination, would be required to satisfy the demands.

The neutron detector consists of a MWPC detector and a high pressure gas vessel. The wire readout structures of the detector and the gas purity device have been optimized based on the previous design and testing. The re-designed MWPC detector with an absorber thickness of 10 mm, 8.5 atm operation gas mixture of ^{3}He and C_3H_8, anode wire space of 1.5 mm and readout strip pitch of 1.5 mm has been constructed. Using a non-return valve manufactured by Swagelock, the gas purity device has been developed to clean the water and refresh the impurity gas. The effective cycle time can be up to 20 minutes one time.

The performance of the position resolution and the two dimensional imaging accuracy by the traditional center of gravity readout method[2] was studied with an X-ray radiation source. Figure 1 shows the assembled detector photo filled the operation gas, the position resolution (~160 μm), and imaging. In the first half of this year, the detector will be mounted at CSNS and be studied using a neutron source.

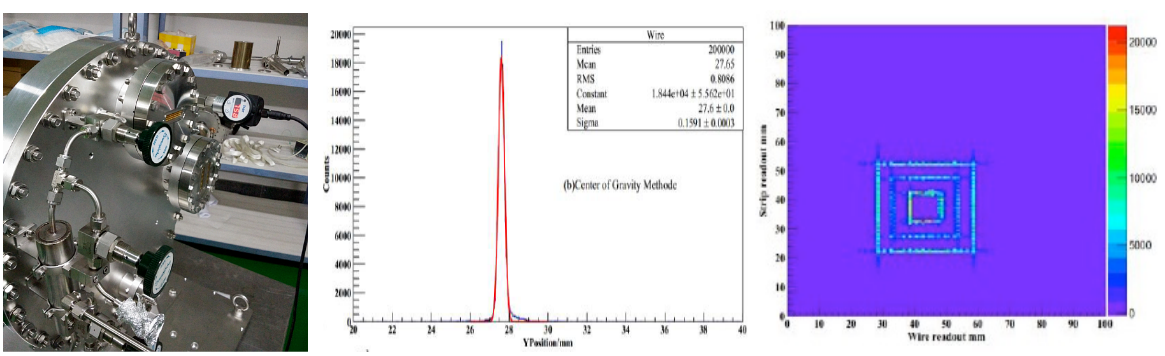

Fig. 1. Photo and resolution of the MWPC detector.

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ID: 20

Position sensitive twin ionization chamber for nuclear fission investigation

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In this work we report recent achievements in design of twin back-to-back ionization chamber (TIC) for fission fragment (FF) mass, kinetic energy and FF orientation. Correlated FF kinetic energies, their masses and the angle of the fission axes in 3D Cartesian coordinates can be determined from analysis of the heights and shapes of the pulses induced by the fission fragments on the anodes of TIC. Anodes of TIC were designed as consisting of isolated Δ-shaped strips each having independent electronic circuitry and special multi-channel pulse digitization apparatus. Mathematical algorithms were provided along with formulae derived for fission axis angles in laboratory reference frame. It was shown how the point of fission fragments origin on the target plane may be determined using the same measured data. The last feature made the TIC a rather powerful tool for prompt fission neutron (PFN) emission investigation in event by event analysis of individual fission reactions from non point fissile source. Position sensitive neutron induced fission detector for neutron imaging applications with both thermal and low energy neutrons was found as another possible implementation of the designed TIC. Preliminary measurements with the thermal neutron induced fission was done and demonstrated in the report.

ID: 21

Control System (CS) and Data Acquisition (DAQ) Architecture for a Personnel Safety System Monitoring the Radiation Background in the ATLAS Cavern

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EDUSAFE is a 4-year Marie Curie ITN project, which focuses on research into the use of Virtual Reality (VR) and Augmented Reality (AR) during planned and emergency maintenance in extreme environments of high radiation background (HEP experiments, nuclear installations, space, deep sea, etc.) The scientific objective of this project is research into advanced VR and AR technologies for a personnel safety system platform, including features, methods and tools. Current technology is not efficient because of significant time-lag in communication and data transmission, missing multi-input interfaces, and simultaneous supervision of multiple workers who are working in the extreme high radiation background environment. The aim is to technically advance and combine several technologies and integrate them as an integral part of a personnel safety system to improve safety, maintain availability, reduce errors and decrease the time needed for scheduled or sudden interventions. The research challenges lie in the development of real-time (time-lags less than human interaction speed) data-transmission, instantaneous analysis of data coming from different inputs (vision, sound, touch, buttons), interaction with multiple on-site users, complex interfaces, portability and wearability. The result is an integrated wearable VR/AR system and Control System which can be implemented and tested as a prototype. The LHC at CERN and its existing Personnel Safety System, requirements and protocols will be used as a test and demonstration platform. In this article the progress of the project will be presented and especially the major contribution of the NTUA team in developing and optimizing the Control System (CS) and the Data Acquisition System (DAQ).

Keywords: augmented reality, radiation, control system, data acquisition, wireless supervision system

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Antineutrino Detection based on ^{6}Li-doped Pulse Shape Sensitive Plastic Scintillator

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Reactor antineutrino detectors filled with liquid organic scintillator have been successfully demonstrated over many years [1,2,3]. They work by identifying the correlated positron and neutron pair that result from inverse beta decay (IBD). Similar correlated event signatures, however, can be produced by fast cosmogenic neutrons, which deposit kinetic energy in the scintillator before thermalizing and capturing. To control these backgrounds, detectors are situated deep underground and surrounded by thick layers of hydrogenous material. Another (so far unexploited) approach is to identify topological and scintillator specific clues to identify neutron induced backgrounds in the data. We propose three possible ways of achieving this. First, individual neutron/proton scatters deposit energy over a small volume relative to minimum ionizing particle tracks caused by positrons or gamma rays. A detector sensitive to particle track length might identify the neutron-like backgrounds. Second, pulse shape sensitive organic scintillators may be able to identify neutron scatters on the basis of the intrinsic signal response time. Third, assuming conservation of momentum, genuine IBD interactions should on average have a directional component between the positron and the subsequent neutron capture, that should point along the direction of antineutrino travel. Neutron backgrounds will have no such component. With the recent advent of pulse shape sensitive plastic scintillator doped with ^{6}Li [4], fine-grained detectors sensitive to particle track length, position and pulse shape might now be realizable from machined thin segments, or rods coupled with multi-channel photomultipliers. Our group aims to test this concept by building and deploying a detector at a nuclear reactor. Additionally, we will test the techniques developed for antineutrino detection for utility as a neutron imager. We will report on some of the challenges involved and early progress towards these two goals.

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ID: 24

Analysis of Uranium by Using HyperGam-U

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A code HyperGam-U has been developed for analyzing uranium gammas and X-rays in the Kα-region.[1] Eight certified reference material (CRM) samples were measured by a planar Ge detector. Each sample contains a gram of highly pure U_3O_8 powder sealed in a glass vial. The enrichment of the samples ranges from about 1% - 99%. Measurement and analysis were performed at the Nuclear Chemistry Research Division of the Korea Atomic Energy Research Institute. The strongly overlapping 13 peaks emitted from ^{235}U and ^{238}U in the Kα-region are decomposed by using peak shape functions for gamma and X-ray, respectively. In addition, calibration relations of channel, widths and efficiency vs. energy are used. The spectrum display, analysis and automatic fitting of the region are done by a new code HyperGam-U. Correction on the attenuation in the finite sample-container was accessed in a simple parallel beam geometry. The true coincidence effects were corrected in full detail by using the code KORSUM[2] after a suitable modification. The enrichment biases are within 2% of the certified values. A further analysis method will be discussed on the content of ^{234}U, ^{236}U and the age of the sample.

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ID: 25

The Influence of the "New" CRP on Monitor Reactions for Charged Particle Beams

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In 2012, a new CRP entitled "Nuclear Data for Charged-particle Monitor Reactions and Medical Isotope Production" was launched by the IAEA (CRP-F41029) with the aim to complement, broaden and upgrade the database that was constructed as outcome of a similar CRP that ended in 2011. These earlier results are available as hardcopy in IAEA TECDOC-1211 and on-line in the medical portal under https://www-nds.iaea.org/medical/monitor_reactions.html.

An important goal was the improvement on accuracy and reliability of cross-sections for monitoring reactions of proton, deuteron, alpha and ^{3}He particle beams.

Through a new systematic compilation of the literature (especially for recent, well documented published data) and by performing dedicated experiments, the excitation functions for the existing reactions covering the different particles could be confirmed and extended to a wider energy range. During the compilation, special attention was given to correction of outdated nuclear data, and the latest values for γ-ray abundances and half-lives provided by the subgroup of evaluators for nuclear data were used. For proton and deuteron beams, several new reactions were added (formation of ^{46}Sc on Ti complementing the ^{48}V formation, reactions on Cu and Ni for deuterons, reactions on Cu for ^{3}He), and previous ambiguities between reactions leading to the activation products ^{62}Zn and ^{63}Zn were solved.

The most important progress, however, is in the introduction of uncertainties on the recommended cross-sections for all monitor reactions. The compilers provided, based on what was published by the original authors or on their experience with experimental techniques, total uncertainties on all experimental cross-section values. The statistical fit by the Obninsk group, using PADE approximation, on the selected data series, resulted in recommended excitation functions with a confidence interval reflecting reduced uncertainties compared to the original separate experimental data sets. Even after adding a correction for systematic effects and correlations, overall uncertainties of the order of 5% on the individual recommended cross sections are obtained for 33 monitor reactions.

Examples of the procedure and results for selected reactions will be shown together with some interesting facts:

- the presence of the strongly discussed bump in the Al(p,x)^{22}Na excitation function around 120 MeV was confirmed by TALYS calculations as results of the onset of the reactions with separate nucleons;
- the correction factor for the ^{nat}Mo(p,x)^{96}Tc reaction, used as monitor in the systematic Levkovkij study, was established as 18% ;
- no corrections are needed for the ^{nat}Mo(α,x)^{97}Ru monitor reaction (Levkovskij study).

ID: 26

Research and Development Undertaking at DTRA

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The Defense Threat Reduction Agency goal is aimed at developing and providing a very specific answer to a very specific question. Our focus is on solving key problems faced by our warfighters, military leaders, and others that deal directly with combating weapons of mass destruction. This presentation will cover the Defense Threat Reduction Agency Nuclear Technologies mission space and highlight a few success stories from technologies supported by DTRA. The presentation will equally highlights DTRA NTD current priorities and goals for new technology developments and engagements.

ID: 27

Performance of an Advanced Silicon Drift Detector with Ultra-Fast Pulse Processing

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We have developed several versions of multi-element Silicon Drift Detectors (SDDs) that when combined with advanced Digital Pulse Processors (DPPs) produce spectroscopic systems for high-flux chemical analysis and high quality x-ray mapping. These systems have good energy resolution at very high count rates and are capable of collecting quality spectra and x-ray images in a short time.[1]

Several kinds of multi-element SDDs were developed: a 3-element focal design ("Vortex ME-3"), a 4-element SDD ("Vortex ME-4"), and a 7-element SDD ("Vortex ME-7"). This work presents the high count-rate capability of the Vortex ME-4 SDD equipped with ASIC electronics and combined with an advanced DPP.

The spectrometer was evaluated at the Advanced Photon Source (APS) at the Argonne National Laboratory by collecting a wide range of data using mapping and tomography techniques. Figure 1 presents a spectrum of a $PbMoO_4$ sample collected with the Vortex ME-4 and the Xspress3 DPP. Even at 3 MHz, the spectra are useful. At 1 MHz, peaks are very well resolved.

Several high quality images collected at GSECARS, APS 13-ID-E, by Dr. Matt Newville will also be presented. We will present several images, including images of a polished thin section of garnet with zoning in yttrium, and an XRF image extracted from a zircon grain (574 pixels). Total count rate (throughput) was around 5.5 Mcps, with iron K_α contributing around 1.1 Mcps and zirconium K_α around 2.2 Mcps.

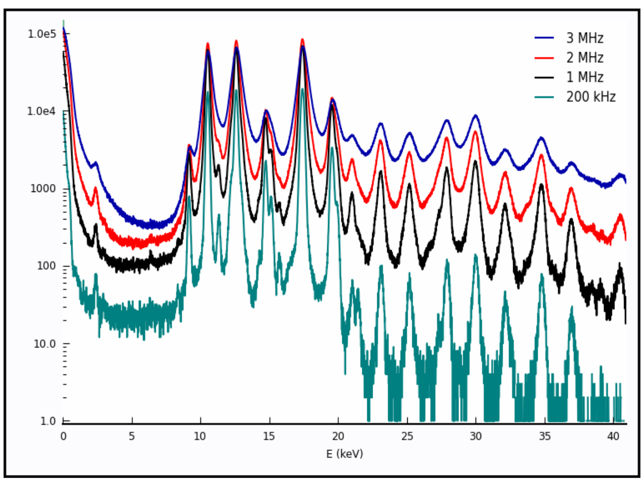

Fig. 1. Spectra of $PbMoO_4$ sample, at 3 MHz, 2 MHz, 1 MHz and 200 kHz.

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ID: 28

Using PIGE to Screen for an Environmental Toxin

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Ion beam analysis techniques have been a widely used in a variety of environmental fields, and with great impact in certain cases, such as the study of particulate matter in aerosols. The next "large impact" application has emerged with the discovery of the widespread environmental contamination of per- and polyfluorinated alkyl substances (PFAS) in groundwater, and its ubiquity in consumer products. PFAS are a class of chemical surfactants that use the carbon-fluorine bond chemistry to impart water- and stain-resistance to all manner of papers and textiles and personal care products, but also have found widespread use as a primary ingredient in aqueous film-forming foams (AFFF) used as fire-fighting foams at more than 41,000 military and civilian airports around the world for the past ~60 years. Since the carbon-fluorine bond is so persistent, PFAS chemicals bioaccumulate in the environment and have been observed worldwide in environmental samples – even far from their original application. Recently, two particular PFAS chemicals have been linked to six diseases and there are thousands of ongoing studies measuring the ecotoxicity and the human health effects of these compounds. Simultaneously, preliminary data suggest that more than 15% of the US drinking water supply may be contaminated with PFAS which would lead to an unprecedented cleanup estimated to cost more than $1 billion in the US alone.

The traditional method for measuring PFAS has been the wet chemical technique of liquid chromatography-tandem mass spectrometry, but because each of these molecules is characterized by many ^{19}F atoms, a Particle Induced Gamma-ray Emission (PIGE) spectroscopic method has been developed to measure total fluorine as a surrogate for PFAS treatments of papers and textiles[1-3], and a related method developed to screen for the presence of PFAS in water[4,5], sediment and biota. This classic application of nuclear physics is both sensitive and rapid, and can be used to screen large numbers of samples *ex vacuo*. Examples of its application to broad surveys of consumer products will be given, together with preliminary work from the site characterization studies of AFFF-contaminated military airbases. Implications from these preliminary studies are that there will be an increased need worldwide for PIGE analyses that has been previously unseen in ion beam analysis since the early aerosol studies. Interlaboratory standards and method development is needed to meet this challenge in a coordinated effort to have the most environmental impact.

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ID: 30

Nondestructive Material Inspections Using Brilliant Quasi-monoenergetic Gamma Beams at ELI-NP

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The Extreme Light Infrastructure – Nuclear Physics (ELI-NP) facility will provide laser and gamma beams with unprecedented characteristics for nuclear physics research and applications.[1] The ELI-NP gamma beam system (GBS) will deliver monochromatic gamma-ray beams (bandwidth < 0.5%) of high spectral density (~10^4 photons/s/eV) and high degree of linear polarization (> 95%) in the range of 0.2–19.5 MeV produced by the laser-Compton backscattering technique (LCS).[2] These beams are promising tools for probing the structural and elemental composition of industrial objects with high resolution and high precision. The nondestructive and noninvasive inspections planned at ELI-NP use nuclear resonance fluorescence (NRF) and computed tomography to perform quantitative assays of objects of various nature and composition.[3] The NRF-based assays will be performed in two ways, backscattering and transmission, and can be successfully applied for detection of nuclear material, assay of spent nuclear fuel or elemental analyses of work of arts. The high sensitivity of these measurements is guaranteed by the high spectral density of the gamma beam and the availability of an advanced gamma-ray detection system based on segmented clover HPGe detectors.[4] In addition, two experimental setups specialized in nondestructive analyses based on transmission images or reconstructed tomograms will also be available at ELI-NP to analyze objects up to 150 kg using either pencil or cone beams. Here we discuss the implementation of the experimental setups, which is currently underway at ELI-NP. We also present the status of the gamma beam system, discuss the performance of nondestructive inspections foreseen at ELI-NP, and comment on the superiority of the LCS gamma-ray beams to other available gamma-ray sources.

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ID: 32

Neutron Detectors for the Gamma Beam Intensity and Polarization Monitoring at ELI-NP

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The high brilliance Gamma Beam System at ELI–NP will generate quasi–monochromatic gamma-ray beams, continuously tunable between 200 keV and 19.5 MeV, with a high spectral density ($>10^4$ photons/s/eV) and a high degree of linear polarization (> 99%). Several instruments are proposed for measuring the intensity and polarization of the gamma beam.[1] One method to determine the polarization of the gamma-ray beams is based on measuring the angular distribution of the neutrons from the d(γ,n)p reaction. For energies above 4 MeV, we use three NE213-type neutron detectors placed around the D_2O target, while for gamma beams below 4 MeV, the choice of detectors is based on ^{6}Li-glass. The photodisintegration of the deuteron will also be used to monitor the intensity of the gamma beam but only after a thorough characterization of the neutron detectors. An extensive campaign to measure the response functions of our neutron detectors is underway with mono-energetic neutrons and a Cf-252 time-tagged ionization chamber.

In this paper, we present the method for beam polarization and intensity calculations, the recent experimental data from the prototype test[2] at the High Intensity Gamma Source, and the results of the MCNP simulations and experiments for characterizing NE213-type and Li-glass detectors.

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ID: 35

Dosimetry for Radiological Protection at the New Research Facility, ELI-NP

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The Extreme Light Infrastructure (ELI) will be the only European and International Center for high-level research on ultra-high intensity lasers and laser-matter interactions, and briefness will go beyond the current state-of-art by several orders of magnitude. The third pillar of this project, ELI-NP (ELI-Nuclear Physics), is going to be finalized in Magurele (near Bucharest, Romania) and will focus on laser-based nuclear physics. The radiation beams and fields that will be produced in the ELI-NP are extremely different from all the applications of dosimetry developed in Romania up to now. The main types of radiation are given in the ELI-NP White Book along with their characteristics (of these beams/fields).

In order to identify the adequate technical solutions for the dosimetric and radiometric instruments for radioprotection in different areas of the ELI-NP facility, different calculations based on simulations were performed. These estimations of the source-terms were necessary to establish the main technical and metrological characteristics of the different classes of instrumentation to be used for the dosimetry for radioprotection. These instruments must cover the main three areas of dosimetry for ELI-NP:

1. Personnel dosimetry
2. Area dosimetry (monitoring)
3. Environment dosimetry (monitoring)

The devices dedicated to the first three items must fulfill the regular requirements for radiological protection of personnel and the environment and will serve to obtain the licenses required by the Romanian Nuclear Authority (CNCAN). According to the regulations and practices, the following kinds of measurements are needed for radiation protection dosimetry:

1. Area measurements, including fixed instruments (monitors), mobile instruments (monitors), and portable instruments.
2. Personnel dosimetry, including dosimetric films, TLDs and personnel electronic dose/dose rate meters.

This paper will present the specific requirements for the dosimeters to be used at ELI-NP and the solutions established at this moment for the individual monitoring.

ID: 36

Spectroscopic Multi-modal Material Identification using a Nuclear Reaction-Based Quasi-Monoenergetic Source

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Transmission radiography using MeV-class radiation provides a powerful method for identifying the content of dense objects, where methods utilizing low-energy radiation may fall short. Fast neutron and gamma ray probes have proved their usefulness in imaging in the past, but neither probe by itself is universally applicable due its poor penetrability for objects dominated by low- and high-atomic number contents, respectively. One method to overcome this limitation and increase the effectiveness of the material probe is dual-particle (gamma and neutron) transmission imaging. Material identification can be enhanced by combining complementary information that can be gained by using both photon and neutron transmission radiography. It is especially convenient if the nature of the probe is such that it produces both photons and neutrons. Further reducing the complexity of the imaging approach, one could employ a single type of detector capable of performing spectroscopic measurements for multiple particle types (neutrons and gammas). We present radiography of dense objects through a broad range of effective atomic numbers based on the $^{11}B(d,n\gamma)^{12}C$ reaction and an array of eight EJ-309 liquid scintillators. The deuteron-induced stripping reaction on ^{11}B, produces two prominent gamma energies at 4.4 and 15.1 MeV from the excited product nucleus, ^{12}C. Additionally, quasi-monoenergetic neutrons are produced, with their energies governed by the reaction kinematics, including the incident deuteron energy and angle. We demonstrate a method that integrates both neutron and gamma transmission spectroscopic signatures to deduce specific material properties that is practical and applicable to a wide range of nuclear nonproliferation and security applications.

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ID: 37

Prompt and Delayed Fission Neutrons in Active Interrogation by Monoenergetic and Multimodal Radiation Sources

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Detection and quantification of fissionable materials, including special nuclear material (SNM), is of significant interest in a range of applications, including the search for clandestine material, cargo scanning, safeguards, and treaty verification. While every application has its own unique set of requirements, they can all take advantage of the unique signatures of fission. Active interrogation (AI) using an external radiation source can make those signatures more intense and impose a characteristic time structure that can aid their detection. One major challenge in AI is discerning the characteristic fission signatures of SNM from the source radiation. One way this can be accomplished is by observing the delayed radiation signature (neutrons or gammas). An alternative method can be applied when monoenergetic or quasi-monoenergetic AI sources are used, where the background from the source may be rejected by spectroscopy.

We describe our recent progress in the use of nuclear reaction AI sources, including $^{11}B(d,n)^{12}C$ and $D(d,n)^{3}He$, to induce, detect, and interpret the characteristic neutron signatures from fission. First, we have measured the $^{11}B(d,n)^{12}C$ delayed neutron emission using scintillation detectors based on both neutron capture and proton recoil, focusing on the long (up to tens of seconds) lived neutron groups. We found an excellent agreement of the detected delayed neutron profile with calculation in which the time evolution of the delayed neutron spectrum and energy dependence of detector efficiency have been taken into account [1]. We present the preliminary results of modeling of the detectability of this delayed neutron signature over background in a system scaled up to large size, resembling a cargo scanning scenario. In a related analysis we also describe the potential for discrimination between fission of ^{235}U and ^{238}U by use of the time evolution of delayed neutron emission from long-lived neutron precursors. Finally, we discuss the preliminary results of AI of large (>10 kg) quantities of ^{235}U at the Device Assembly Facility (Nevada Test Site), using $D(d,n)^{3}He$ neutrons, where we detected >2.5 MeV prompt neutrons from fission concurrently with transmission imaging using liquid scintillators. Modeling has been performed to correlate the magnitude of the detected prompt neutron rate with the quantity of ^{235}U and will be presented.

This work has been supported by the National Science Foundation under Grant No. ECCS-1348366 and ECCS-1348328, by the U.S. Department of Homeland Security under Grant Award Number 2014-DN-077-ARI079-02 and 2014-DN-077-ARI078-02, and by the Consortium for Verification Technology under Department of Energy National Nuclear Security Administration award number DE-NA0002534.

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ID: 38

Fast Neutron and Gamma Ray Detection and Multiplicity Counting with LLNL Liquid Scintillator Array – LLNL-ABS-720019

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For many years at LLNL we have been developing time-correlated neutron detection techniques and algorithms for many applications including Arms Control, Nuclear Material Assaying and Nuclear Threat Detection. For much of our recent development we have taken advantage of fast neutron detection with liquid scintillator which preserves the inherent nanosecond production time-scales of fission and neutron induced fission are preserved instead of being lost in neutron moderation time of thermal neutron detectors.

We have been developing simple robust algorithms that can be used to determine critical material characteristics such as mass, multiplication, moderation and reflection. Some of our new methods have included taking advantage of both neutron and gamma ray correlations (and cross correlations) and we have also found that for much of our work we require a better working knowledge of how effective our Pulse Shape discrimination is working as a knowledge of neutron (and gamma ray) purity are often critical to our understanding our data. So we have found it necessary to rethink how we are performing our PSD and ways of adjusting such parameters in real time in order to obtain the best data possible for a given measurement, so naturally this have become some of our recent focus. We will report on recent developments in both understanding and applying neutron and gamma ray correlations in fissionable material, progress in our understanding and developing a better dynamic way to employ PSD and if there is time show some more recent developments we are working on for new methods and capabilities which employ active neutron interrogation.

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ID: 39

ESS Accelerator Installation Strategy and Non-Destructive Testing Implementation

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The proton accelerator will be the sole driver for neutron production at the European Spallation Source – ESS in the forthcoming years. The ESS accelerator is designed to be the brightest accelerator ever built for neutron research. The facility is currently undergoing its installation phase, where Area Supervisors (AS) manage the physical plant of the machine, whereas the accelerator components are assembled, installed and tested by the System Leaders (SL). Following the accelerator project goals, preventive and regular maintenance is explicit on the machine to serve the nominal ESS operations scheme. The program of Non-Destructive Testing for Accelerators (NDTA) at ESS is a measurements and testing program, based on the development and implementation of the Resonant Ultrasound Spectroscopy (RUS) on the machine structural materials. The first testing set-up of NDTA is under fabrication and based on ultrasound (UT) pinducers, that will allow for measurements of spectra from samples of various structural materials (Nb, SSt, Alu, etc.). Materials considered for measurement and validation come from the material batches that accelerator modules are manufactured from, with the aim to create a database of modal responses of the different subassemblies of the ESS accelerator. A later implementation of the testing set-up in the tunnel, for online measurements during operations, is under evaluation.

ID: 40

A reactor-status effect on the β^+ decay rate of ^{22}Na

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In the search for an electron antineutrino detection method with sensitivity below the 1.8 MeV threshold for the inverse beta decay reaction on a free proton, β-decay counting experiments with ca. 3 kBq ^{22}Na and ^{60}Co sources were conducted at unit #1 (2.775 GW_{th}) of the Koeberg Nuclear Power Station in South Africa. The goal was to determine if the rate of decay is measurably influenced by a change between the ON–OFF status of such a reactor.

The experimental setup consisted of a single NaI crystal to measure de-excitation and annihilation photons associated with β-decay. Its volume and well shape were purposely chosen to use coincidence summing in the interval 170–2452 keV to differentiate between electron capture and β^+ emission in ^{22}Na. The Pb-shielded setup was placed in the seismic vault underneath the containment building, thereby shielded from the reactor core by 8 m of uninterrupted concrete. Background radiation, responsible for ca. 1% of the total countrate with either source placed in the NaI well, increased by merely 3% when the reactor status changed from OFF to ON. This small increase is semi-quantitatively explained by fast neutrons exciting ^{208}Pb nuclei throughout the Pb castle.

Offline analysis of measured pulseheight spectra comprised background subtraction, correction for natural decay, grouping into daily averages, energy calibration, and integration over three energy regions-of-interest (TOT, MED, HI). Subsequently, normalized countrates were parameterized to jointly describe the time dependence of two instrumental effects and a reactor-status step function in a least-squares regression analysis. For ^{22}Na two measurement series were made, each covering an ON–OFF–ON cycle of the reactor. The following fractional countrate (activity) changes in the step from reactor OFF to ON were obtained: $(\Delta A/A)_{TOT}$= [3.06±0.13(*stat*)±0.07(*syst*)]*10^{-4}, $(\Delta A/A)_{MED}$= [+1.34±0.37(*stat*)±0.22(*syst*)]*10^{-4}, and $(\Delta A/A)_{HI}$= [-2.73±0.22(stat)±0.13(*syst*)]*10^{-4}. The systematic errors are governed by uncertainty in the difference between background spectra during reactor ON and OFF. For TOT and HI, the reactor status effect corresponds to a decrease relative to the natural decay rate while the opposite is observed for MED.

Considering the spectral shape generated by our coincidence summing approach, this result is explained by reduction of the β^+ emission branch of the ^{22}Na and nil change in the electron capture branch. No reactor status dependence was observed with the ^{60}Co source in the counter. The negative sign for TOT and HI activity changes in ^{22}Na points to an antineutrino related interference effect on the β^+ decay of ^{22}Na and rules out reactor neutron induced reactions. The corresponding cross section for the effect of with their statistical uncertainty becomes (1.59 ± 0.08) x 10^{-25}, with a systematic uncertainty of 30%, mainly due to the estimate of the antineutrino flux. This value is 18 orders of magnitude larger than for the reaction on a free proton.

Although we have tried to exclude systematic effects as an explanation for our findings, we realise that a hidden instrumental effect may still be present. However, the present result, if confirmed, has considerable consequences for both fundamental physics and reactor monitoring.

ID: 42

Identifying the C*haîne Opératoire* of Prehistoric Pottery Using Imaging Methods and Experimental Archeology

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This presentation reports the use of imaging methods - radiography and X-ray computed tomography (CT) - and experimental archaeology to reveal the manufacturing techniques of Eneolithic pottery. This approach recommends itself as an excellent non-invasive way of studying prehistoric pottery, being especially meaningful for investigating unbroken pots. The combination of imaging analysis and experimental archaeology has the potential to confirm or refute some of the current hypotheses regarding Eneolithic pottery.

Inspired by the archaeological research in the Sultana-Malu Roșu (southeastern Romania) tell settlement belonging to Kodjadermen-Gumelniţa-Karanovo VI culture (c. 4500-3800 BC), in 2010 we started a project on experimental archaeology. One of the main goals of this project was to re-create Eneolithic pottery. In order to reach it, a complex approach involving the use of archaeometric methods, was employed.

The reconstruction of the *chaîne opératoire* of archaeological pottery started with the information obtained through macroscopic observations. The next step was the development of experimental and demonstrative models. In this process, several types of clay, tempering, modeling, burnishing, decorating, drying and firing procedures were tested. Different hand-making techniques, such as shaping the vessels from one lump of clay, coiling and molding were also tried.

The experimental archaeology procedures were backed up by the petrographic (optical microscopy on thin sections) and chemical (X-ray fluorescence and X-ray diffraction) analyses on ceramic samples from two Eneolithic dwellings excavated on the tell settlement from Sultana-Malu Roșu. These analyses not only helped the identification of the clay source used as raw material by the prehistoric potters, a source that turned out to be located in the proximity of the tell settlement, but also provided a more refined recipe for the mixture clay - temper.

Radiography and CT were employed to study the structure of the vessels produced during the experimental workshops, as well as the one of genuine Eneolithic pottery excavated from the tell settlement. The set of images obtained from both experimental and archaeological pottery turned out to be comparable with each other and they helped reveal the manufacturing techniques. The most promising results are the ones on vessels resulting from coiling techniques.

The data reported in this study will be used in the future research of archaeological pottery assemblages; in the long run, they will lead to a better understanding of ancient pottery and of the people who manufactured it.

Work supported by a CNCS – UEFISCDI grant - project number PN-III-P2-2.1-PED-2016-0742.

ID: 43

Large Scale Imaging Simulations for Active Interrogation

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The threat of nuclear terrorism and proliferation of special nuclear materials (SNM) is of growing public concern. The ability to scan cargo moving across borders is paramount to ensuring that SNM will not fall into the wrong hands. Detecting shielded SNM specifically has been named as one of the grand engineering challenges of the 21st century.

The current industry standard for photon-based active interrogation beams is bremsstrahlung x-rays. While it is simple to produce a bremsstrahlung beam at high fluxes, the continuous energy spectrum inherent to bremsstrahlung is non-ideal, and leads to large doses to cargo without aiding in detection of SNM. In this research, we propose the use of a quasi-monochromatic interrogation beam generated by the nuclear reaction $^{11}B(d,n\gamma)^{12}C$. This reaction produces prominent gamma-rays at 4.4 and 15.1 MeV. In addition to being mono-energetic, the use of two distinct energies allow for simultaneous dual-energy imaging if spectroscopic detectors are employed.

Using Geant4, we model an imaging system using the gamma-ray spectrum of $^{11}B(d,n\gamma)^{12}C$ as the interrogation beam and custom-made quartz Cherenkov-based spectroscopic detectors. This imaging system is tested on a full-scale simulation of an ISO cargo container (40' x 8' x 8'). The container is loaded with various cargo, including cars and oil barrels, to simulate a real-world scenario (the Geant4 rendering of the container can be seen in Fig. 1). In addition to cargo in the container, several items are incorporated to characterize the spatial resolution of the system as well as the contrast-to-noise ratio. Transmission images and reconstructed Z_{eff} maps are compared between the mono-energetic source and a bremsstrahlung (15 MV) image.

To properly characterize the trade-off between dose and image quality, the imaging dose from each beam was calculated in Geant4. To perform the calculation, a block of water was placed inside a container, and the density of materials inside the container were varied. This allows for dose to be calculated as a function of cargo density.

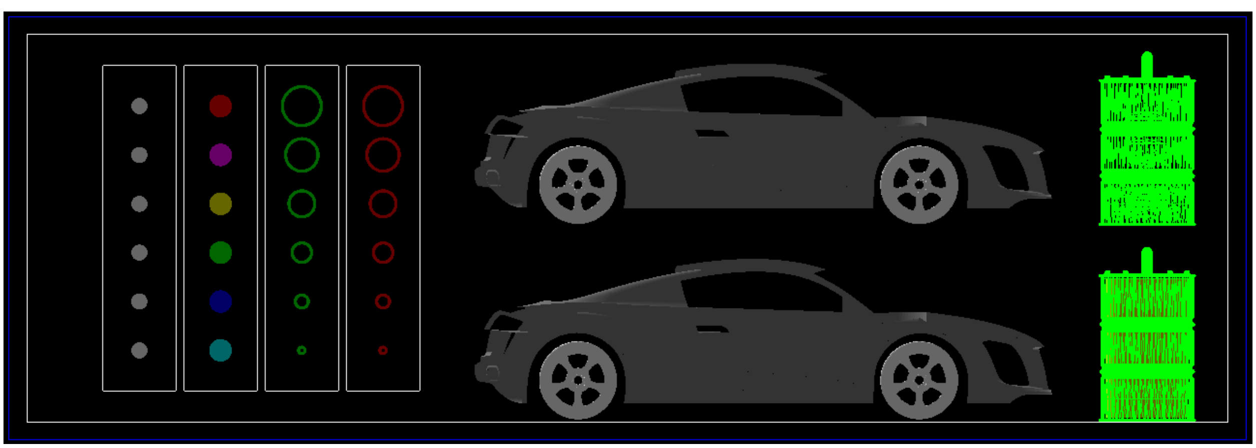

Fig. 1. Geant4 representation of the cargo container to be imaged. One of the cars is concealing a uranium block where an engine should be. The disks on the left side of the image are used to characterize the effectiveness of the Z_{eff} calculation and the spatial resolution of the system.

ID: 44

Fingerprinting of the commercial nuclear reactor forensics using Origen-S modeling code

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Nuclear forensics is the technical means by which nuclear materials, whether intercepted, intact or retrieved from post-explosion debris, are characterized and interpreted. In this work, a focus was made on characterizing a Pressurized Water Reactor (PWR), with emphasis on the output electrical power between 900 and 1200 MWe. The reactor was assumed to complete a standard cycle with no unplanned outages. Plutonium isotopic concentration data were calculated for a range of nuclear power reactors using the Origen-S modelling code based on typical Westinghouse fuel assembly with fuel type of W17 X 17, and individual operating histories. Isotopic ratios of plutonium in nuclear reactors during the fuel cycle period provide information on how the plutonium grows into the fuel as a function of burnup as well as its attractiveness to proliferators. Using the acquired results from uranium and plutonium isotopic ratios, the origin of each spent fuel assembly for a particular reactor can be predicted and documented for a future reference database.

ID: 45

Searching for Special Nuclear Material with Discrete Energy Nuclear Reaction Based Sources and Cherenkov Detector Array

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Searching for shielded special nuclear material, SSNM, in transit is an arduous task in both complexity and scope. Millions of cargo containers are shipped around the world and travel through various ports of entry such as border crossings, railroads, and shipping ports making physical inspection unfeasible. Active interrogation leveraging highly penetrating, monoenergetic gamma rays can uncover the illicit material when coupled to a uniquely designed array of ultra-fast Cherenkov detectors capable of crude spectroscopy. Cherenkov detectors capable of crude spectroscopy provide a means of detecting the transmitted high energy gamma rays with unrivaled speed, dead-time, crosstalk, and ruggedness. Energy resolution is not a top priority when using well separated discrete energy photons such as the 4.4 and 15.1-MeV gamma rays available from the $^{11}B(d,n\text{-}\gamma)^{12}C$ or $^{12}C(p,p')^{12}C$ reactions. The array of detectors interprets the high energy photon transmission through the cargo container leveraging the differential transmission which is used to produce high contrast planar images of the cargo contents while scanning along the container. Attenuation of the discrete energy source through the container can be calculated based on the spectroscopic information from the Cherenkov detectors leading to a means of coarse atomic number, Z_{eff}, identification as the interaction probability of two main gamma rays scales differently as a function of atomic number, Z.

We present a novel active interrogation system leveraging highly penetrating, discrete energy photon sources and custom designed Cherenkov detectors. The investigation starts with a detailed investigation of the $^{11}B(d,n\text{-}\gamma)^{12}C$ source to characterize the exact energies of the observed gamma rays and probable origins. Once the source is understood, we are able to employ an array of custom designed Cherenkov detectors to measure the differential attenuation of the most prominent reaction products and relate the relative transmission of the two main energies to an approximate Z_{eff}. We demonstrate imaging using the source – detector combination to evaluate the spatial resolution and material discrimination capabilities of this novel active interrogation system.

ID: 46

The New Inner Tracker Based on Cylindrical GEM Detectors for the BESIII Experiment

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A new inner tracker based on a Cylindrical GEM detector is under development to replace the current inner drift chamber of the BESIII Spectrometer. The BESIII experiment,[1] carried out at the BEPCII double-ring e^+e^- collider at IHEP in Beijing (PRC), running at c.m. energies in the tau-charm region and a luminosity of $1.0\text{x}10^{33}$ $cm^{-2}s^{-1}$, allows the study of a rich physics program, such as meson spectroscopy, including XYZ states, baryon spectroscopy, hadron form factors and tau physics. BESIII is foreseen to run up to 2022 and beyond.

A replacement of the current inner drift chamber has been proposed,[2] because of the aging under the effect of radiation after many years of operation. The new inner tracker will consist of three cylindrical layers of triple GEM, surrounding the interaction point, covering 93% of the solid angle, with a spatial resolution better than 130 μm. A first prototype has been already built and tests of performance are ongoing.

A custom ASIC in UMC 110 nm technology, to provide both charge and time measurements, allowing the readout of the detector in μTPC mode, has been designed starting from an existing chip developed for medical PET application[3] and the first prototype is under test.

This talk will cover the notable and innovative aspects of the new inner tracker and review the results of the first cylindrical GEM prototype and of the readout chip prototype.

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ID: 47

Radioxenon Imprinting

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Imprinting is the process by which an atmospheric gas plume transports into the subsurface environment. It is important to understand this process as it introduces radioactive gas background when sampling for radioactive gases resulting from an underground nuclear explosion. The mechanism may also be utilized to acquire samples of radioactive gas plumes that have passed over a geology.

Two sampling campaigns were carried out near the Chalk River Laboratory in Canada where medical isotope production resulted in the release of radioxenon plumes. The first sampling campaign was in September 2014 and the second sampling campaign was conducted in July 2016. A system was developed and deployed to collect subsurface gas samples. Atmospheric air samples were simultaneously collected along with subsurface air samples. Sample collection times were 24 hours. Radioxenon analysis on both subsurface and atmospheric air samples were conducted at Pacific Northwest National Laboratory. Surface atmospheric activity concentrations were also available from a NaI detection system operated by Health Canada. The results of these experiments verified the magnitude of the imprinting process and were utilized to compare against subsurface gas transport models.

Figure 1 shows the results of the July 2016 measurement campaign. Subsurface gas samples were taken at a depth of 1 m for the first part of the experiment and then at 1.9 m for the second part of the experiment. Atmospheric activity concentrations show that multiple ^{133}Xe (5.243 day half-life) plumes passed over the experimental site during the measurement campaign. Of interest is the significant increase in subsurface ^{133}Xe activity concentrations at the 1.9 m depth following the plume passage on 19 July. ^{133}Xe subsurface activity concentration had a delay in reaching the maximum value due to transport time. Maximum subsurface activity concentrations were within two orders of magnitude of atmospheric activity concentrations during plume passage. These results show that the magnitude of subsurface activity concentrations could potentially serve as interference in monitoring for underground nuclear explosions. In addition, imprinting of ^{133}Xe remains detectable more than a week after plume passage.

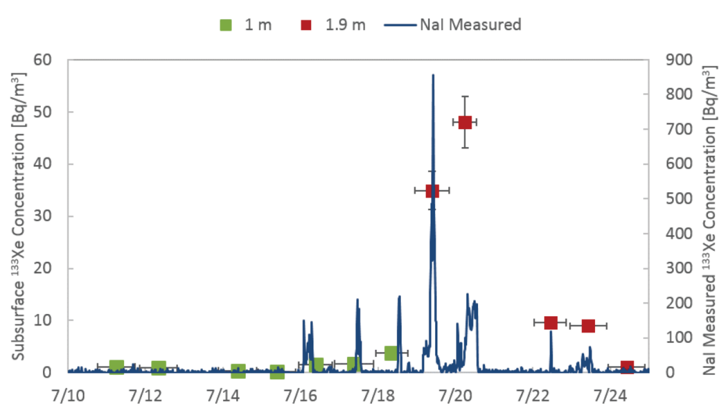

Figure 1. Subsurface and atmospheric ^{133}Xe concentrations resulting from July 2016 measurement campaign.

ID: 48

Response Assessment of a New Albedo Neutron Dosimeter for Health Personnel

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The use of TLD's by health personnel who work in clinical radiation environments is required by law. However, many professionals prefer to use Electronic Personal Dosimeters (EPDs) that provide dose estimation in real time. This preference may lead to a generalized use of the EPD dosimeters in detriment of using the required TLD, as using both types can be uncomfortable and unpractical. In an effort to avoid this scenario, a gamma/neutron dosimeter composed of a TLD and an EPD are being developed. In this paper, the results obtained from the studies performed in order to develop the neutron albedo dosimeter to be incorporated in the TLD+EPD dosimeter are shown. Monte Carlo simulations using the state of the art MCNP6 code were used to obtain the response of the albedo dosimeter. The original dosimeter consists of a PMMA light pipe sandwiched between two neutron 6LiF: ZnS(Ag) scintilators. The reference man GOLEM voxel phantom was used in the simulations in order to calculate the fraction of radiation backscatered by a human body in different radiation field conditions. At the same time, this allows one to calculate the dose delivered to several organs and relate it to the response of the dosimeter. From these results, it was possible to decide on the materials and dimensions of the extra layers that are necessary to include in the original neutron dosimeter in order to achieve the performance requirements.

ID: 49

Adsorptive Transport of Noble Gas Tracers in Porous Media

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The transport of noble gas radionuclides in porous media is relevant to the detection of underground nuclear detonations as well as the sequestration of reprocessing off-gases. However, in field tests releasing radioxenon underground, the quantity of radioxenon observed at the surface has fallen well below expectations[1]. This study examined the diffusivity of noble gases (Kr and Xe) and the inert molecular gas sulfur hexafluoride (SF_6) in porous media to observe any unexpected behavior.

To replicate the transport of radiogenic noble gases in underground media, a two-bulb gaseous diffusion apparatus was constructed. The two bulbs are connected with a column of 10-30 Ottawa sand and ordinary atmosphere filled both the bulbs and pore spaces. The tracer gases were diluted in an isolated bulb to approximately 1000 ppm. Once released, the gases were allowed to diffuse through the column. Aliquots were withdrawn at regular time intervals from both bulbs and concentrations were quantified using a Shimadzu QP2010 SE gas chromatograph-mass spectrometer. The effective diffusivity was then calculated using a maximum likelihood estimate on the quasi-steady state model.

The effective diffusivity of Xe in the silica sand was observed to be 135.2% that of SF6 whereas the effective diffusivity of Kr observed to be 161.4% that of sulfur hexafluoride. These findings are consistent with the binary diffusivities in N_2: 132.6% and 161.7% respectively. However, the apparent volume of the system was inconsistent amongst the species, with Xe converging at slightly lower gas phase concentration than Kr or SF6. This apparent reduction in gas phase concentration occurred within the first few measurements and is consistent with transient accumulation of an adsorbed phase.

As the effective diffusivities in the silica sand were shown to be consistent with the binary diffusivities in N_2, a porosity-tortuosity model is appears sufficient when considering similar geological materials. However, with the observation of significant gas adsorption, consideration of adsorbed phase accumulation is necessary when scaling to larger geological systems. This work supported by HDTRA1-12-1-0009.

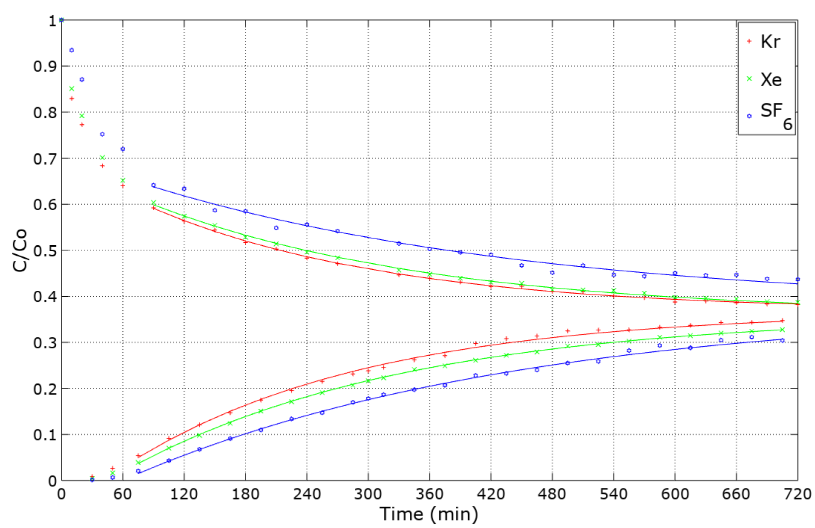

Figure 1: Differential Diffusion and Adsorption of Tracer Gases

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ID: 51

Rotating Scatter Mask Assembly for Gamma Source Imaging

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Current gamma imaging systems are limited in utility due to their cost, size, narrow field of view, and low image formation efficiency. This effort constitutes a critical step in the development of an imaging system that is limited by none of these factors. This gamma imaging system consists of a routine NaI(Tl) scintillation detector coupled with a rotating scatter mask, the geometry of which is specifically chosen such that the detected signal obtained from one complete mask rotation provides sufficient information to uniquely determine the relative direction of the source position. This mask encases the detector and can be completely encapsulated with a 0.045 m^3 cube (side length of 35.56 cm). A GEANT4 simulation was developed to model the functionality of this system and obtain a library of detector response curves. This simulation was validated via statistical comparisons with experimental and MCNP data. Using the results of the simulation, an algorithm was developed that was shown to predict experimental source direction over a nearly 4π field of view with average errors that were smaller than the resolution in the library of curves employed to image, with an average error in azimuthal angle θ of 4.12° and an average error in polar angle φ of 2.94°.

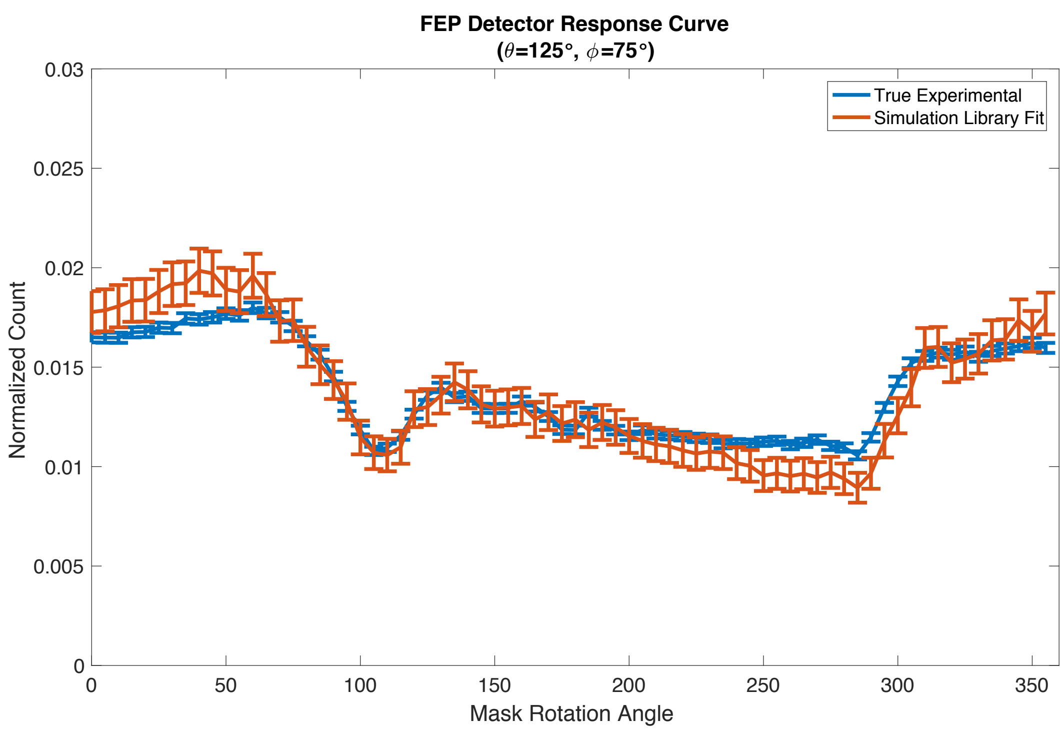

Figure 1. Normalized experimental FEP detector response curve graphed with the simulation library detector response curve, which represents the nearest match, indicating the source direction of the experimental radioactive source predicted by the imagining algorithm.

ID: 52

Dosimetric Evaluation Employing the Techniques of TL and OSL with Different Thermoluminescent Materials for Clinical Evaluation of Extremities Doses using Electrons Beams Applied to Total Irradiation of Skin Treatments

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One of the modalities of radiotherapy is the total irradiation of the skin (TSI),which aims to deliver a homogeneous dose distribution over the entire skin surface of the patient. In some anatomical regions, the dose may vary widely due to the angle of treatment or even the skin surface itself, which is often significantly curved and oblique to this plane. Thermoluminescent (TL) dosimeters have demonstrated great efficiency in electron beam dosimetry, as well as in the detection of several types of errors related to the application of the dose to the patient. In radiotherapy, most measurements using TL dosimeters have been made using LiF:Mg,Ti (TLD-100). More recently, LiF micro-dosimeters with dimensions of 1x1x1 mm^3, which are similar to the TLD-100, have been used. The minimal dimensions allow their use with some advantages, especially in *in vivo* monitoring.

New dosimetric materials have been evaluated for application in the area of clinical dosimetry, such as $CaSO_4$:Dy, which has been extensively used in dose measurements at the level of radioprotection due to its high sensitivity. Another type of material that has gained importance is the Optically Stimulated Luminescence (OSL) dosimeter where it differs only in stimulation. Aluminum Oxide (Al_2O_3:C) dosimeters, in general, have provided good results as luminescent detectors. These dosimeters have advantages over TLDs due to their high sensitivity, faster readout, possibility of multiple re-readings and no need perform heat treatment.

TSI dosimetry is quite complex when evaluating and measuring absorbed dose in the cutaneous region. TL dosimeters have been demonstrating excellent results in assessing dose uniformity on the skin. The cutaneous extremities are regions that are always exposed at practically all treatment positions, resulting in an overdose that may vary up to 20% over the dose in the abdomen, which is the reference point for this treatment.

Thegoal of this work isto evaluate the performance of different dosimetric materials in the analysis of extremities, allowing the verification of overdose in TSI treatments. TL dosimeters showed good results —the percentage difference between the TL dosimeter response was within the expected range — although there was a variation of the results obtained in the study of the extremities that can be explained due to errors of positioning, movement and positions of the respective dosimeters. OSL (Al_2O_3:C) dosimeters presented higher uncertainties but showed results close to the TL dosimeters.

ID: 53

Investigating Artifacts Associated with β Particle Interactions in Charge Coupled Devices

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Charge couple devices (CCDs) have been shown in literature and previous research to have potential for detecting charged particles and ionising radiation. In particular, the clusters in the pixel images produced are distinctive for α and β radiation, with α particles causing large, symmetrical clusters or long vertical tracks called blooming, and β particles causing long, curved tracks. The size and shape of these tracks are also related to the energy of the incoming particle, giving the potential for spectroscopy of these types of radiation. This could be used to create a hand-held, portable device for in-situ detection and identification of radioactive contamination.

However, γ radiation produces small clusters of only 1 or 2 pixels, which is difficult to separate from smaller β tracks. Therefore, investigations into the tracks associated with β particle interactions in CCDs have been carried out. Simulation work has been carried out using CASINO (Monte Carlo simulation of electron trajectory in solids) to predict the size of the pixel clusters that β particles will produce. This has been done considering the maximum β particle energy of two sources: 512 keV for ^{137}Cs and 310 keV for ^{60}Co, as these sources are available to make experimental comparisons. In each case 10,000 electrons were simulated passing through a pixel grid, and the number of pixels each electron passed through was recorded in a histogram. It was found that the higher energy electrons peaked at a cluster size of 3 pixels, and the lower energy electrons had a smaller peak at 4 pixels with a higher proportion of larger cluster sizes. This is to be expected due to the higher scattering cross section for lower energy β particles. Experimental data show instead a peak at 1 pixel for both sources, due to the addition of the smaller γ clusters. However, the ^{60}Co source with the lower energy β particles showed a higher proportion of larger cluster sizes than the ^{137}Cs, as was seen in the simulation. This gives further evidence of the γ clusters consisting of only a small number of pixels. The simulations and experimental data will be used to further process the CCD images in an attempt to distinguish between β and γ radiation.

ID: 54

Identification of Microscopic Uranium Particles Using Fission Tracks in Nuclear Solid State Detectors

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The isotopic analysis of individual micrometer- and submicrometer-size particles containing fission isotopes of uranium is a challenging analytical activity. Electron microscopy or mass spectrometry methods may not be sufficiently fast or reliable for the measurement of cotton swipes containing low concentrations of particles of interest, especially if the particles are of submicrometer size. Therefore, improvement of the established analytical procedures is needed. The advantage of the fission track [1, 2, 3] method consists in extraordinary sensitivity and statistical validity of the evaluation of the tested nuclear material.

In this contribution, a method of fission track sample preparation and uranium particle analysis using a combination of scanning electron microscopy (SEM) and secondary ion mass spectrometry (SIMS) is described. High-energy fission products passing through the insulating material of nuclear solid state detector leave narrow trails of damage along their trajectories [4], which are known as the latent tracks. The tracks can be made easily optically visible after chemical etching and their positions relative to one or more fiducial marks can be recorded using the optical microscope. Transfer of the fission track coordinates measured with the optical microscope to the SEM is followed by the assignment of the tracks to individual uranium particles on the silicon substrate. The synchronization of the coordinate system of the detector containing the radiation tracks with that of the silicon substrate carrying uranium particles has been achieved using a set of laser-drilled holes in the detector that coincided with a set of fiducial marks made in silicon by the focused ion beam (FIB). The FIB-milled marks also allowed for the transfer of the uranium particle coordinates from SEM to the coordinate system of the SIMS. Once the position of the uranium particle of interest is known in the SIMS coordinate system the isotopic ratio measurement can follow. The efficiency of the procedure is discussed.

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ID: 55

Inhibition of Proliferation of Gastric Carcinoma Cells *in vitro* with Deuterium Depleted Water Treatment

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Previous studies have demonstrated that low deuterium concentrations into conventional cancer therapy can significantly decrease the growth rate of various tumor cells. In this study, it was found that deuterium depleted water (DDW) significantly decreased the proliferation of MIAPACA-2 cells and the ability of MIAPACA-2 tumor cells to form colonies as well as migration by experiments, which revealed that DDW suppresses cell growth, migration, invasion, and cell cycle progression in MIAPACA-2 cells but does not affect the growth of normal cells. Furthermore, DDW-mediated suppression of growth and invasion may be partially attributed to the stimulation of GAPDH and the down-regulation of expression.

ID: 56

Generation and Detection of Neutrons and Monoenergetic Gamma Rays for Inspection for Nuclear Threats

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Practical methods for the detection of shielded nuclear materials remain a challenge for the inspection of large containers. We describe here an approach to this problem based on the use of high energy gamma rays generated not by bremsstrahlung but through the use of nuclear reaction based sources of gamma rays. The use of high-energy, intrinsically monoenergetic, gamma rays for transmission imaging provides both a means for high contrast imaging of shielded objects and also confirmation of the fissile nature of the material. Radiographic contrast relies on the large difference between the pair production cross section of mid- and low-Z materials and SNM (U and Pu) and, subsequently, the large difference in absorption at high energies. Nuclear reaction based sources can produce both monoenergetic gammas and fast neutrons. SNM may be detected in three ways: imaging through shielded material (Z-dependent), detection of photofission neutrons and gammas, and detection of neutron-induced fission products. The multi-particle approach is particularly flexible with respect to the types of shielding that can be penetrated.

The use of multiple monoenergetic gamma rays of sufficient energy enables transmission radiography at lower dose (factors of 10 or more) than conventional bremsstrahlung based systems and the ability to provide contrast for high-Z materials characteristic of nuclear materials. The system we have implemented uses a combination of monoenergetic gammas and neutrons to probe materials and thus to separate materials by transmission radiography[1,2] and, through the use of delayed neutrons, to identify nuclear materials.[2] Since the incident spectrum itself is monoenergetic, the requirements for energy resolution are considerably relaxed and, although the gamma transmission experiments to date have used NaI detectors, Cherenkov detectors are also a viable alternative, particularly if large arrays are to be considered.[3]

Our initial work is based on the reaction $^{11}B(d,n\gamma)^{12}C$ which produces two characteristic gamma lines at 4.4 and 15.1 MeV as well as fast neutrons with energies of up to ~8 MeV, all of which are used in the interrogation process. The source of deuterons is a 3 MeV RFQ with a solid ^{11}B target. We have also investigated other reactions which provide alternative gamma and neutron spectra and will discuss their advantages and disadvantages.

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ID: 57

The groundbreaking activities of the European Spallation Source – ESS ERIC

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The European Spallation Source (ESS) is under construction in Lund in Sweden. ESS is a European project with 15 founding member and observer countries. The construction of buildings and infrastructure started in 2013. Today the first buildings are being completed and installation of equipment is starting. The accelerator is first concerned with essential infrastructure already being mounted, the cryoplants arriving in spring and summer 2017 and the ion source arriving in autumn 2017. 22 European research institutes and universities contribute with in-kind and will deliver all of the accelerator and most of the RF equipment. Design has been completed for all systems, prototyping is under way, and for the first systems to be installed, manufacturing has already been launched. Integration, coordination of the installation and commissioning are very challenging tasks given the in-kind nature of the project. I will in my talk give an overview of ESS and its accelerator with a focus on the installation phase.

ID: 58

A new Proton Recoil Telescope for the nTOF@CERN facility

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The neutron-induced fission of ^{235}U is currently adopted as a cross section standard for scientific and technological needs, in the thermal region and in the energy range 0.15 MeV - 200 MeV. The International Atomic Energy Agency (IAEA) is seeking to extend this range at higher energies, but up to now no cross-section data are available for energies above 200 MeV and moreover the most reliable theoretical calculations disagree with each other. At the neutron facility n_TOF at CERN we are planning to perform high quality cross section measurements up to 1 GeV, taking advantage of the intense neutron beam in a wide energy spectrum available in the first experimental area. The ^{235}U (n, f) cross section measurement will be performed relatively to the H (n, n) reaction, whose cross section is used as a reference. The fission fragments will be detected by means of Parallel Plate Avalanche Counters (PPAC) equipped with samples of ^{235}U. At the same time two Proton Recoil Telescopes (PRT) will be used to measure the incident neutron flux up to 1 GeV, by detecting the recoil protons emitted in the (n,p) elastic scattering on a polyetilene target. A prototype of the PRT has already been built and tested at n_TOF. It is composed of four plastic scintillators, with thickness from 0.5 to 6 cm and of two thin silicon detectors mounted in front of the scintillators, in order to make the PRT sensitive to energies below 10 MeV. The main aim of the telescope is the discrimination of the recoil protons from the scattered neutrons and from other light charged particles, e.g. deuterons and tritons, emitted in particular from neutron-induced reactions on Carbon. The pulse width of less than 20 ns at n_TOF allows the clear detection of the faster neutrons up to 1GeV.

The PRT has been tested in real conditions at n_TOF, where it was mounted 12 cm far from the polyethylene target at 20 and 30° to respect the beam axis. The results of the test will be presented in this talk, compared with Monte Carlo simulations. Based on these, promising data, a final version of the telescope is now being constructed, It will be installed and tested at n_TOF in 2017, with the aim of performing the final measurement of the ^{235}U (n, f) cross section up to 1 GeV.

ID: 61

Production of Medical Isotopes with a Driven Subcritical Assembly

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Phoenix Nuclear Labs (PNL) has designed and built a high yield neutron generator that will drive a subcritical assembly developed by SHINE Medical Technologies to produce the medical radioisotope molybdenum-99, which is used in tens of thousands of medical imaging procedures daily around the globe. The isotope production system employs an accelerator-driven, low-enriched uranium (LEU) solution in a sub-critical geometry optimized for high-efficiency isotope production (including iodine-131 and xenon-133). Neutrons produced by deuterium-tritium fusion reactions in the PNL accelerator target drive fission in the subcritical LEU solution. Hydrogen and oxygen from radiolysis of water in the solution are continuously recombined during operation. DT neutrons from the PNL device are created in the center of the subcritical assembly. The chamber itself is a cylinder with a height of 100 cm and radius of 5 cm. The chamber is surrounded by cylinders of U-10Mo fuel enriched to 19.5 wt% U-235/U, and copper. The U-10Mo is centered on the DT chamber and has a height of 35cm with an outer radius of 22.7 cm. The copper shields also have an outer radius of 22.7 cm and have heights of 42.5 cm, extending 10cm above and below the DT chamber. The copper acts as a shield and reflector, forcing the neutrons back into the fuel to increase the multiplication and ensure that the flux is being delivered to the testing region. MCNP was used to predict a k_{eff} of approximately 0.98 and a fission power of nearly 25 kW for this configuration. Finally, there are eight cylindrical water pipes with radius of 1.75cm which travel through the height of the system in order to provide cooling. The PNL neutron generator has demonstrated neutron yields greater than $3x10^{11}$ n/s using the DD fusion reaction. PNL is targeting delivery of 6 neutron generators with yields of $5x10^{13}$ DT n/s each in 2018 to SHINE's molybdenum-99 production facility. Target solution chemistry has been selected; target geometry has been optimized and prototyped. ^{99}Mo separation at >97% efficiency has been demonstrated, and commercially viable doses of Tc-99m have been produced. A construction permit for the isotope production facility was issued by the US Nuclear Regulatory Commission in February 2016, the first of its kind since 1960. Construction of the facility is anticipated to begin in 2017, and commercial production of Mo-99 is anticipated to commence in late 2019.

ID: 62

Explosive Hazard Detection with a High Yield DD Neutron Generator

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Explosive hazards (IEDs, mines, and UXO) pose one of the greatest threats to the American warfighter today. Successful defense against these hazards requires the capability to rapidly detect and classify the hazard at safe standoff ranges. Neutron-based detection systems have previously been proven to be viable technology solution, but only at very small standoff distance with long detection times, thus limiting practical application of this technique. Modeling and experimental results of a detection system utilizing a high yield, solid target, DD neutron generator will be presented. When neutrons interact with matter, gamma radiation is emitted with characteristic energy levels that provide signature information about the elemental composition of the object being interrogated. This radiation can be detected and rapidly analyzed via a computer algorithm to generate an alert that an explosive threat is nearby and further analyzed to identify the composition of the explosive material. The speed and standoff distance of detection is directly tied to the neutron source strength, and PNL's very intense neutron generator allows neutron-based explosive detection to be achievable at substantially increased standoff distance in comparison to previously tested systems. PNL is currently under contract with the US Army to test a static, neutron-based explosives detection system. The system utilizes a DD neutron source with neutron yield up to 3×10^{11} n/s in conjunction with a multi-detector array utilizing both NaI and LaBr crystals coupled with PMT's and high speed digitizers. Data is being collected during the spring of 2017 and will be compared to modeling results to validate model-based predictions of the performance of fielded systems. A follow-on, 2-year effort to implement the system onto a mobile platform and test it in a simulated operational environment is being funded by the US Army and will begin in late spring of 2017. Data from the current effort will be presented along with plans for the subsequent mobile platform development and testing.

ID: 64

Determination of Radioxenon Emanation Coefficient in U_3O_8 by Neutron Activation Analysis

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Radioxenon is a relatively inert gas that is indicative of a ^{235}U fission reaction. Atmospheric detection systems across the globe are continually monitoring radioxenon for evidence of nuclear detonation. The ratio of gas that is able to escape its media of origin and enter atmosphere is defined as an emanation coefficient and is not well known for radioxenon. Quantifying the emanation coefficient of ^{135}Xe will have useful applications in nuclear forensics and post detonation verification methods. This study set out to measure this value.

Radioxenon was produced and measured by means of Neutron Activation Analysis (NAA). Samples containing 0.1 g of naturally enriched U_3O_8 powder (New Brunswick Laboratory SRM 129-A) were encapsulated in quartz vials and irradiated in the University of Texas at Austin TRIGA pneumatic transfer facility at 100 kW for 10 s in a thermal flux of approximately 10^{11} n cm^{-2} s^{-1}. Half of the quartz encapsulated samples were broken after irradiation and left open to vent in a fume hood, while the other half remained vacuum sealed to prevent gas from escaping. Each sample was measured for ^{135}Xe concentration with a shielded HPGe detector. ^{135}Xe was measured by spectral analysis of the 249.794 keV photon peak. The intensity was normalized by the number of fissions in each sample. This was achieved by measuring the initial concentration of ^{239}U in each sample and using it to indicate the number of fissions. Normalizing by the number of fissions instead of mass eliminated the largest contributors to uncertainty; sample mass and flux variability. The percent difference in ^{135}Xe concentration between the sealed and open samples is proportional to the emanation coefficient in U_3O_8 powder. The escape of radioxenon was observable in each trial and emanation coefficients were measured to be in the range of 0.7 and 0.4.

It is generally assumed that the radioxenon emanation coefficient is comparable to that of ^{222}Rn. In this study, the range of measured values for the emanation coefficient of ^{135}Xe was found to be within the accepted limits of the emanation coefficient for ^{222}Rn. However, further experimentation will be necessary for more precise measurements. Future work includes extracting and measuring escaped ^{135}Xe by means of cryogenic capture in a gas manifold. The system required for this process is currently being constructed.

ID: 66

Recent Advances In Laser-Based Neutron Sources

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Short-pulse laser-driven neutron sources have become a topic of interest since their brightness and yield have recently increased by orders of magnitude. Using novel target designs, high contrast - high power lasers and compact converter/moderator setups, these neutron sources have finally reached intensities that suits interesting applications.

We present the results of two experimental campaigns on the GSI PHELIX and the LANL Trident lasers. We have produced an unprecedented neutron flux, mapped the spatial distribution of the neutron production as well as its energy spectra and ultimately used the beam for first applications to show the prospect of these new compact sources. We also made measurements for the conversion of energetic neutrons into short epithermal and thermal neutron pulses in order to evaluate applications for non-destructive testing, radiography and nuclear safeguard applications.

The results address a large community as it paves the way to use short pulse lasers as a neutron and hard x-ray source. This can open up neutron research to a broad area of applications as those potentially compact and mobile sources could lead to testing and inspection systems. We already demonstrated the use in active interrogation of sensitive nuclear material and Isotope identification by neutron resonance spectroscopy. Future laser systems with high average power could complement or even replace large scale facilities like reactors or particle accelerators.

ID: 67

Near-monoenergetic Photon Sources for Nonproliferation Applications

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Near-monoenergetic photon sources have the potential to provide significant performance enhancements or enable new capabilities in nonproliferation applications. Their advantages lie in the ability to control energy, energy spread, flux, and in some cases angular divergence and pulse structures to deliver the photons needed for signature generation while suppressing extraneous dose and background that is associated with current bremsstrahlung sources.

To guide the development of monoenergetic sources in the nonproliferation space, assessment of a broad range of applications where near-monoenergetic photon sources may have a high-impact will be discussed. Detailed evaluation was conducted of: cargo screening and interdiction, single-sided inspection to detect hidden SNM, treaty/dismantlement verification, nuclear safeguards, and emergency response. Results of a quantitative assessment of system performance, source requirements, and capability enhancement will be presented. Simulations indicate that dose reductions due to control of source energy spread alone range from about 2x to 4x for radiography applications to above a factor of 50 for photofission depending on the energy that is used. Contrast in Z can be enhanced by use of multiple energies. Additional benefit is available from sources with low beam divergence. Scanning with a narrow beam allows the scatter component in the radiograph of a thick object to be largely eliminated and thus enables further dose reduction and/or increase in contrast. Divergence of ~mrad also makes it possible to deliver a high photon flux onto a area of interest and/or to adapt dose to different thicknesses of material that may be present. Overall reduction in dose could be more than an order of magnitude. For both radiography and photofission, modest energy spreads at the 20% level are appropriate. At energy spreads of or below the percent level, nuclear resonance fluorescence measurements could be performed at several orders of magnitude lower doses than with a bremsstrahlung beam.

Development is in progress of compact MeV photon sources based on Thomson scattering that have the potential to address the needs of nonproliferation applications. Photon energies could be produced from below 1 MeV to greater than 20 MeV, energy spreads as low as ~1%, mrad divergences, and ~10^8 photon/pulse at eventual repetition rates up to 10s of kHz. A brief update on the development of such a source, based on compact laser-plasma accelerators together with techniques to mitigate the size of scattering/photon production and beam disposal systems, will be presented. The path from near term experiments towards applications requirements will be discussed.

ID: 68

PIXE-PIGE Analysis of Merovingian and Carolingian Glass Artefacts

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Knowledge of the elemental compositions of ancient glass artefacts provides clues on the production techniques and material chosen. Numerous archaeometric studies, namely by means of Ion Beam Analysis techniques, have already demonstrated the suitability of these non invasive techniques to provide accurate chemical signatures and to assess the important changes occurring in glass manufacturing techniques. Together with the changes in commercial roads following the fall of the Roman Empire, the growing need for architectural glass certainly contributed to innovations in glass crafts and, in Northern Europe, the transition from soda to potash glass may even be linked to it. At the end of VIIth century, churches had real stained glass windows and, walls as well as floors could be covered with mosaics.

In order to illustrate the current role played by PIXE-PIGE analysis in Cultural Heritage glass studies, we will present results obtained on the external beam line set up of the CEA-IPNAS facility of Liège and thus, on different kinds of glass artefacts within the framework of two distinct projects.

The first one is an on-going project led on Merovingian glass vessels provided by different Belgian museums. Analyzed objects presented in this paper, were excavated from three Merovingian period sites: Harmegnies, Viesville and Rebaix. The second studied corpus is part of a project recently initiated in the territory of the Carolingian Empire and carried out in Belgium, France, Italy and Germany. It focuses on architectural glass artefacts and more precisely on mosaic's glass tesserae. The problematics, questions raised and results obtained on tesserae selected from among the 755 items found during the excavation of Nevers baptistery in Burgundy region (France) will be presented.

ID: 70

Testing of Materials under Space Radiation Environment Using Particle Accelerators of IPNAS

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These last years, IPNAS laboratory has started several collaborations with space science departments to develop set-ups suitable to test space-dedicated materials and components behavior under space environment conditions. During long flights in space, expected interactions and damage in exposed materials are mostly due to energetic electrons and protons. Since the IPNAS irradiation facility hosts several accelerators covering a broad range of particle/energy combinations (0.3–20 MeV for protons), it represents an ideal set of irradiation tools for materials testing.

This paper reports the development and recent uses of two new irradiation set-ups especially installed on two dedicated beam lines on a 30° beam line of the 2.5 MV van de Graaff (0.1–2.5 MeV) and on a 40° beam line of our variable energy CGRMEV 520 cyclotron (2.5–20 MeV). Goals, radiation test plans applied, and typical results obtained in the framework of two projects will be presented to highlight both specific needs and features developed on these vacuum chambers, in order to perform adequate tests.

As space electronic systems employ enclosures to shield sensitive components from space radiation, the first example will present the set-up used for the tests and a few results obtained within the SIDER project aimed at the improvement of the radiation shielding behaviour of composite materials investigated and developed as an alternative to state-of-the-art aluminum.

The second example is an optical coating qualification radiation test campaign led on both chambers in the framework of the Sentinel-4 program of the COPERNICUS Initiative. The Sentinel-4 payload is a high-resolution spectrometer system operating with 3 designated bands in the solar reflectance spectrum, covering the ultraviolet (305–400 nm), visible (400–500 nm) and near infrared (750–775 nm) bands. The optical coating deposited on NiP coated Be mirrors has been tested under various beam conditions, and the radiation test plan applied will be detailed to emphasize specific care taken for the design of a suitable and safe set-up.

ID: 74

Collimation and Characterization of ELI-NP Gamma Beam

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The ELI-NP facility,[1,2] currently being built in Bucharest, Romania, will deliver an intense and almost monochromatic gamma beam with tunable energy between 0.2 and 20 MeV. The challenging energy bandwidth of 0.5% is adjusted through the collimation system, while the main beam parameters are measured through a devoted gamma-beam characterization system. The gamma-beam characterization system, designed by the EuroGammaS consortium, consists of four elements: a Compton spectrometer (CSPEC) which measures the gamma energy spectrum; a sampling calorimeter (GCAL), for a fast combined measurement of the beam average energy and its intensity, which will be used also as monitor during machine commissioning and development; a nuclear resonant scattering system (NRSS), for absolute energy inter-calibration of the other detectors; and a beam profile imager (BPI) to be used for alignment and diagnostics purposes.

In this presentation, the interplay between collimation and characterization systems will be discussed together with the inter-calibration procedure of different sub-detectors among themselves.

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ID: 76

Monte-Carlo Simulations as a Tool to Understand Gamma-ray Coincidence Spectra: ^{22}Na Decay Inside a Well-counter

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In a recent series of experiments investigating a possible effect of anti-neutrino flux on β+-decay, a ^{22}Na-source was placed inside a NaI well counter and set to continuously record data over a several months. The almost 4π configuration of the source-detector system leads to a gamma-ray spectrum consisting of several coincidence peaks. The ^{22}Na-decay yields a series of true coincidences: peaks made up of the summed effect of the positron decay (yielding two 511 keV photons) and the decay of the resulting ^{22}Ne nucleus to its ground state (yielding a photon at 1275 keV). At the same time, a part of the spectrum will be made up of accidental coincidences: i.e., peaks made up of gamma radiation of multiple ^{22}Na nuclei decaying within a time interval indistinguishable for the detecting system.

To better understand the structure of the spectra measured, we ran a series of Monte-Carlo simulations. Modern MC codes like MCNP and FLUKA have become very reliable and precise tools to reconstruct gamma ray spectra measured in a certain source-detector geometry. However, neither of these codes is equipped to include time information into the simulation. In other words, they are not useable by design for reconstructing the coincidence spectra we measured.

However, using the a-priori knowledge of the ^{22}Na decay scheme, and the possibility to simulate positron decay in MCNP, we were able to reconstruct the measured spectra in a very precise manner. This gave us a tool that has proven very valuable in describing our experimental observations. Not only can we reconstruct the shape of the true coincidence spectrum, the simulations also proved to be an invaluable tool to understand the background made up of double and even triple chance coincidences.

The paper describes the method we developed and its application to the well-counter experiments mentioned above.

ID: 77

A Compton Camera using DSSD and CsI(Tl) for Radioactive Waste Detection

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The Compton camera is a promising instrument for radioactive waste detection and medical imaging. We are developing a Compton camera using a double-sided silicon strip detector (DSSD) from Micron Semiconductor as scatter detector and four CsI(Tl) detectors as absorber detectors. The DSSD is 0.3 μm in thickness with an active area of 49 mm × 49 mm, and it has 16 strips per side, which provides a spatial resolution of 3 mm in 2 dimensions. Each CsI(Tl) crystal is 10 mm × 10 mm × 10 mm in size and the photos are read out by a 6 mm × 6 mm SiPM instead of a PMT to reduce the volume and to realize a compact design. These four absorber detectors are arranged in a 2 × 2 compact array whose front face is parallel to the DSSD. Simulations of the camera were performed in Geant4. The simulation results show that the imaging efficiency of this system can reach 10^{-5} with 3 cm distance from DSSD to CsI(Tl), while the angle resolution is about 5°. Thus, this Compton camera has great potential application in the location of radioactive sources and detection of the distribution of radioactive waste. The experimental system is under construction.

ID: 79

Measurement of Formation Cross-sections and Decay Properties for Short-lived Isomers Produced in Photonuclear Interactions

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Many elements possess short-lived isomeric states with half-lives ranging from seconds to minutes that are readily accessible via the interaction of high energy X-rays with the nucleus. This technique of gamma activation analysis (GAA) uses the decay of these isomers to determine the concentration of elements in a sample. The canonical example is gold, which can be measured with excellent sensitivity using the $^{197}Au(g,g')^{197M}Au$ reaction ($t_{1/2}$ = 7.73 s). We are currently developing a system to provide a commercial assay service for determining the concentration of gold in mineral ores.

To accurately measure the abundance of an element, we require information pertaining to several of its decay properties, including half-life, formation cross-section, emission energies & probabilities. The cross-sections for several of our isomers have been measured poorly, or not at all. Similarly, the energies and emission probabilities of their gamma-rays can be measured to a higher precision than is currently present in existing literature.

In this paper, we describe the design and operation of an experiment to produce and measure these short-lived isomers. An electron linear accelerator fitted with a tungsten converter was used as a source of Bremsstrahlung photons and was operated in the 6.5-10.5 MeV region. The gamma-rays produced by the decaying isomers were recorded using a large-area germanium detector. The sample was rapidly cycled between irradiation and measurement positions using a custom designed pneumatic actuator, allowing for isomers with half-lives down to a few seconds to be reliably detected.

We present measurements of the formation cross-sections, gamma-ray emission energies and probabilities of isomeric states for 11 elements with half-lives between 2 – 45 seconds: Ag, Au, Br, Er, Hf, Ir, Pd, Se, Tb, W & Y. Comparison is made with literature values for these parameters, where they exist. We discuss the implications of our results for the use of GAA in a commercial or research capacity for measurement of elements other than gold.

ID: 80

Radiation Damage Studies in Detector Grade n-Type 4H-SiC Schottky Barrier Diodes Exposed to Ion and Neutron Irradiation Using Nuclear Techniques and Transient Spectroscopies

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Simple planar semiconductor particle detectors have been fabricated in the form of a Schottky barrier diode prepared on epitaxial grown n-type 4H-SiC wafers. Low leakage currents of the order of pA (1 mm^2 active area) have been measured even for the highest applied reverse biases of up to 500 V. Full depletion capability has been established for reverse biases above 400 V applied to as-prepared 4H-SiC detectors based on the low-doped ([N] ~ 5×10^{14} cm^{-3}), approximately 50 μm-thick epitaxial layers. High crystal quality and uniformity of charge collection efficiency in the active sensing volume of detectors was further confirmed using the scanning nuclear microprobe technique called ion beam induced current (IBIC).

Selected devices have been irradiated using i) the selection of light ions accelerated to energies in the MeV energy range and ii) high energy neutrons in the MeV energy range that are typical products of radioactive decay in SNM or in nuclear reactors. Effects of radiation damage on electrical properties and particle detection properties of devices tested in various irradiation conditions (ion fluxes ranging from 10^{11} $cm^{-2}s^{-1}$ to 10^{13} $cm^{-2}s^{-1}$ or neutron flux ~ 10^7 $cm^{-2}s^{-1}$) are being studied for a wide particle fluence range (10^8 – 10^{12} cm^{-2}) using a unique experimental methodology developed recently for testing silicon detectors using the nuclear microprobe [1]. The focused micrometer-sized beam with reduced rate of ions (i.e. ion micro-beam) is being used for irradiations instead of the broad millimeter-sized ion beam (standard protocol for ion implantation studies) because it is more appropriate for simulation of radiation damage in detectors caused by detection of individual particles.

Deep level transient spectroscopy studies of as-irradiated samples under different irradiation conditions revealed an assembly of unidentified deep levels beside well documented, including the most known carbon vacancy related defects, $Z_{1/2}$ and $EH_{6/7}$. It should be noted that $Z_{1/2}$ and $EH_{6/7}$ are present in the non-irradiated samples. However, the DLTS (deep-level transient spectroscopy) intensity of those defects increases with the irradiation. Moreover, some deep levels show complex thermodynamic behavior observed in the repeated DLTS study of the unintentional annealed samples during the first temperature scan up to 780K. The observed low temperature annealing has enabled us to separate and to study defects that were previously reported but not analyzed. Suitability for operation of these devices as simple particle detectors or as building blocks of complex detection systems for nuclear detection or security applications will be discussed.

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ID: 84

A Comparative Study for the Identification of Microscopic Uranium Particles Using Fission Track Analysis, SEM-EDX, and SIMS

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Mass spectrometric analysis of small uranium oxide particles can provide valuable information about nuclear activities related to the place of their collection. An important preliminary step prior to isotopic analysis of the particles is their finding and identification on a sample covered with a large amount of environmental dust.

In the present study, we describe and compare three methods of uranium particle search and identification. The first one is the method of fission track analysis (FTA), where the sample is exposed to a thermal-neutron flux and the uranium-containing particles are visualized through chemically enlarged tracks of U-235 fission fragments left behind in the attached plastic detector [1]. The second method is a combination of scanning electron microscopy and energy-dispersive X-ray spectroscopy (SEM-EDS) with automated particle search mode [2]. Here, the identification of uranium particles is based on high contrast of high-Z materials on a low-Z substrate in the backscattering electron imaging combined with chemical verification with EDS. The third method is the Secondary ion mass spectrometry (SIMS) with automated particle screening mode [3].

After finding uranium oxide particles and recording their coordinates using either of the methods the isotopic ratios were determined with SIMS. The performance of the three approaches has been evaluated through analysis of reference samples of uranium particles. The SIMS method is the only one that can both localize the particles and provide their isotopic composition. But it is destructive, which limits its performance in search for sub-micrometer size particles. The SEM-EDS method is non-destructive and can efficiently identify particles down to 1 μm size, with potential for improvement with further instrumental advances. FTA is the most reliable and robust method for uranium containing particle identification even below 1 μm size, but it requires access to a nuclear reactor. Further detail on analytical performance and comparison of the three methods is provided.

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ID: 85

A Distributed Data Acquisition System for Nuclear Detectors

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Nowadays, many examples of Data Acquisition (DAQ) software for nuclear detectors are monolithic processes that run on a computer attached to the DAQ hardware. We present here a distributed DAQ system developed for the C-BORD project. With our system, we propose a novel approach in which each task related to the DAQ (acquisition, preprocess, analysis, …) runs in a separate process. In other words, the system is composed of a set of servers that exchange information through dedicated communication sockets. With this architecture, we are able to run the processes also on different computers, in order to distribute the computational load. The initial tests of the system have been giving excellent results, both in terms of performance (*i.e.* maximum acquisition rates) and stability.

The project entitled "effective Container inspection at BORDer control points" (C-BORD) is funded by the European H2020 programme. Its aim is to develop a comprehensive set of technologies for the generalised Non-Intrusive Inspection (NII) of containers and large-volume freight at the EU border.

ID: 86

Advances on the Development of the Detection System of the C-BORD's Rapidly Relocatable Tagged Neutron Inspection System (RRTNIS)

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The European H2020 project entitled "effective Container inspection at BORDer control points" (C-BORD) focuses on the development, and in situ tests, of a comprehensive cost-effective solution for the generalized Non-Intrusive Inspection (NII) of containers and large-volume freight at the EU border. The opening procedures of suspects containers are time consuming and expensive, for economical and safety reasons; therefore, in order to reduce such operations, the C-BORD project's aim is to develop a set of technologies that can improve the quality of NII. Among these techniques, a Tagged Neutron Inspection System is being developed in the C-BORD project. It will be a second-line defense system, to be used on sealed containers in order to detect explosives, illicit drugs and chemical agents in suspect voxels (elementary volume units). This method employs a beam of tagged neutrons and a set of NaI(Tl) and $LaBr_3$ scintillators which will be used to detect prompt gamma-rays produced by the neutron interactions.

Here we report the advances on the development of the C-BORD's RRTNIS, in particular: the comprehensive characterization of the NaI(Tl) and LaBr3 gamma detectors (time and energy resolutions, high count rate behavior), the digital analysis for time coincidence measurements and the Data Acquisition System (DAQ).

ID: 87

An Integrated Detector Assembly for Detection and Discrimination of Fast Neutrons, Thermal Neutrons and Gamma-rays

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The scintillator EJ-299-33A, developed by Eljen Technology, is the first plastic scintillator with Pulse-Shape Discrimination (PSD) capabilities that became commercially available. Its discrimination performances do not match those of the best liquid scintillators, but it is much safer to handle and thus it is considered a good alternative. The scintillator EJ-420 is an inorganic scintillator that has a good response to thermal neutrons. It employs a lithium compound, whose Li content is isotopically enriched up to 95% of ^{6}Li, dispersed in a ZnS(Ag) matrix. By combining these two commercial scintillators, it is possible to simultaneously detect and discriminate thermal neutrons, fast neutrons and gamma-rays., An EJ-420 is mounted on the top of an EJ-299-33A cylinder, which is used as a light guide. The device has the capability to detect gamma rays as well as thermal and fast neutrons with a single Photomultiplier-Tuber (PMT) readout; the signal discrimination between the three types of radiations is performed on-line by means of waveform digitizers and PSD algorithms.

Since water is a good natural moderator for neutrons, it is possible to determine the water presence, by comparing the fast and slow cosmic neutrons. The water concentration can be probed on large volumes of terrain, and thus the soil moisture can be measured. This measurement is complementary to that obtained with classical EM probes, which is strongly dependent on the local moisture. Moisture concentration is an important measurement for geological and agricultural applications.

ID: 89

Detection of Special Nuclear Materials Using Multiple Monoenergetic Gamma Radiography

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The detection of special nuclear materials (SNM) or an assembled nuclear device smuggled in commercial cargo represents a significant challenge in nuclear security, due to the difficulty of detecting such materials among the large volume of cargo traffic. Additionally, a practical cargo inspection system must limit the radiation dose to which cargo, port workers, and stowaways are exposed. The strong variation in the photon interaction cross section as a function of the atomic number Z of a material may be leveraged to extract both material density and average elemental composition from radiographic measurements at different beam energies. This allows SNM to be identified by the high Z value of such materials. In particular, radiography with monoenergetic photons maximizes this leverage, allowing significant reduction in the radiation dose applied to the cargo. This paper describes the development of a nuclear reaction-based multiple monoenergetic gamma radiography (MMGR) system. The system utilizes 3 MeV deuterons incident on a boron target to produce monoenergetic 4.4 and 15.1 MeV photons via the $^{11}B(d,n\gamma)^{12}C$ reaction[1]. The transmission spectra of these photons through various material samples were acquired using an array of NaI detectors. Results from data taken at the MIT-Bates Research and Engineering Center indicated that this system is capable of producing rudimentary 2D images of the density and effective Z of scanned materials.

This talk will focus on recent work to expand this initial work via the application of analysis techniques informed by detailed simulation of the complete radiography system. The development of the simulation and the validation of its results against data will be described. This validated simulation model provides a platform for exploring new analysis techniques to improve upon the initial results from existing data, as well as the optimization of the system for future experiments. Recent radiographic analysis results, as well as plans for future improvement of the system informed by the optimization analysis (e.g., the addition of off-beam axis sensors) will be discussed.

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ID: 91

Perception Evaluation of Sao Paulo Food Bank on Food Irradiation

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Keywords: food bank, food irradiation, food waste, questionnaire, sensory analysis.

Despite the poverty in the world, a third of all food produced in the world is wasted. The energy of ionizing radiation in food expresses many positive results, such as improved insect infestation control. Food banks are organizations that act at various points in the food chain to collect and distribute food to the needy. Banks of food and new technologies to preserve and guarantee quality are courses of action requested by FAO (FAO, 2016).

The aim of this study was to initiate a partnership between irradiation and the food bank through the development of a questionnaire to evaluate and disseminate the knowledge and acceptance by individuals in the food bank in Brazil. In addition, this study aimed to standardize the basis for future research questionnaire assessment of irradiated foods. The questionnaire was applied in the Ceagesp food bank in the biggest center of food in Brazil. For the construction of the questionnaire as a measuring instrument, a comprehensive and rigorous literature review was made (Herdman *et al*., 1998).

According to each pre-test performed (three done) necessary alterations in the questionnaire were made, and it was tested again until 95% of respondents did not report doubts. The result was a questionnaire, shown in Fig. 1, which was tested and validated for this study and can be further used for analysis of public acceptance and knowledge both in the food banks of Brazil (main objective of this work) and as a standard instrument of initial measurement for other studies that aim at analysis of irradiated foods.

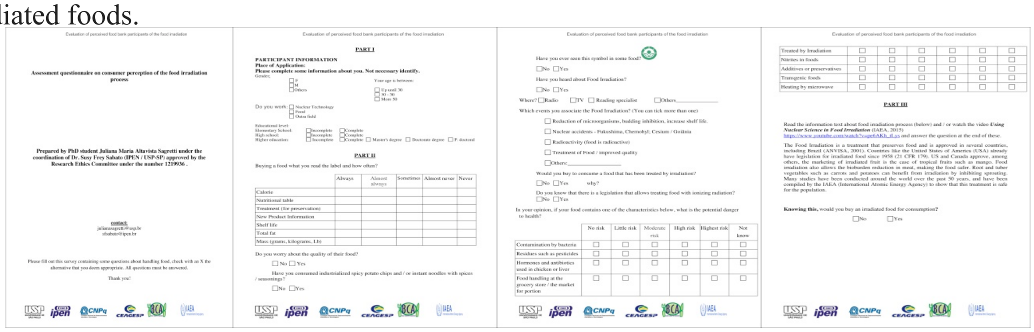

Figure 1. Image of the questionnaire applied at Banco Ceagesp.

In conclusion, 30 % of participants of the Ceagesp bank had already heard of food irradiation, but did not know about the mechanism, causing them to reject the idea due to association of the method with danger of radioactivity applied to food. The last question of the questionnaire showed a video explaining the safety of food irradiation. All individuals who saw the video declared they now understand the goal of radiation-based food treatment and accept consumption of irradiated foods.

ID: 92

Single-Volume Neutron Scatter Camera Simulation Results

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In order for passive neutron imaging to provide value in nuclear security applications, we need to improve on existing systems by making them smaller *and* more efficient. We present performance results from a simulation study of a very compact double-scatter fission-energy neutron imager, aimed at localization and characterization of special nuclear material. The imager relies on the detection and resolution of two neutron scatters detected within a single contiguous scintillator volume. Our simulation is informed by experimental studies of system components.

Neutron imaging characterizes the spatial distribution of plutonium or other neutron emitters, providing information that is valuable in arms control and emergency response applications about the fundamental nature of a nuclear explosive. Current neutron imaging systems, such as the SNL Neutron Scatter Camera and the ORNL/SNL Fast Neutron Coded Aperture Imager, have demonstrated imaging with up to ~1 cm spatial resolution at close range. But these systems are large and heavy, making them difficult to deploy; and their sensitivity is limited by geometrical efficiency and an inherent requirement of distance between the source object and imager. We are therefore working toward a new compact neutron imager that is easy to transport and deploy, has high efficiency, and can be placed near a threat object to increase sensitivity and spatial resolution.

Recent advances in photodetector (PD) technology have enabled PD coverage of large areas (hundreds of cm^2) with good spatial resolution (few mm) and excellent time resolution (tens of ps) for individual optical photon arrivals. This in turn allows us to consider imaging system designs that acquire and process large quantities of data from the scintillation photons that are emitted as a result of neutron scatters in the material. Experimental work has demonstrated aspects of the data acquisition and processing, such as the parsing of individual signal traces into a list of optical photon arrival times. Here we will present simulation studies that demonstrate the feasibility of using the detected photon positions and times at the faces of a $(10\ cm)^3$ active volume to reconstruct multiple neutron scatter locations and times to sub-cm and sub-ns accuracy, which in turn (Figure 1) allows the reconstruction of the neutron kinematic trajectories to determine the initial neutron energy and direction up to a conical ambiguity.

[*] Sandia National Laboratories is a multi-mission laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

ID: 93

Liquid Xenon Scintillation Measurements and Pulse Shape Discrimination in the LUX Dark Matter Detector

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The Large Underground Xenon (LUX) experiment is a 250 kg, dual-phase xenon time projection chamber (TPC) located in the Sanford Underground Research Facility in Lead, South Dakota, USA. The experiment searches for nuclear recoils (NR) that may be caused by Weakly Interacting Massive Particles (WIMPs), a leading candidate for the dark matter content of the universe. Residual backgrounds due to gamma rays and beta decays inside the detector create electronic recoils (ER) that must be identified to maximize sensitivity to rare NR events. Typically, particle-type identification is accomplished using the ratio of collected ionization charge to scintillation light. We present here a new analysis of LUX calibration data that studies the time structure of the liquid xenon scintillation pulse in an attempt to improve ER/NR separation by adding pulse shape discrimination (PSD). Using an advanced photon counting and timing algorithm, we construct average pulse shapes for ER/NR pulses. Our spectra are fit to an analytic model of liquid xenon scintillation emission, allowing us to infer the ratio of singlet/triplet state emission for both NR and ER at energies relevant to dark matter searches. In addition, we calculate the pulse-shape discrimination power in LUX as a function of the size of the scintillation pulse. The constrained analytic model can inform simulation packages used by the community, and our measurements will inform future analyses of LUX data. We will discuss our results, as well as the challenges and applications of PSD in current and future liquid xenon TPC dark matter experiments.

ID: 94

Neutron Imager with Micro Channel Plates (MCP) in an Electrostatic Mirror Configuration: Experimental Test with Radiation Source

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The concept of a new high transparency device based on Micro Channel Plates (MCP) to be used for monitoring the flux and spatial profile of neutron beams has recently been presented [1]. This device consists of a very thin carbon (C) foil with a ^{6}Li deposit, which is placed in the neutron beam, and MCP equipped with a phosphor screen readout viewed by a CCD camera, which is placed outside the beam. A peculiar feature of this device is that it uses an electrostatic mirror to minimize perturbation of the neutron beam (i.e., absorption and scattering). It can be used at existing time-of-flight facilities, in particular at the n_TOF facility at CERN, for monitoring the flux and spatial profile of both thermal and epithermal neutron beams. The results of experiments using a radioactive source to test the behavior of the electrostatic mirror will be presented.

[1] V. Variale, Physics Procedia 66 (2015) 242-248

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ID: 95

Why is There Something, Rather Than Nothing, and What Does Neutrino-less Double Beta Decay Have to do with That?

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Our universe is filled with matter but antimatter is an ephemera, seen only naturally in the debris of high-energy processes and cosmic rays. Yet the standard model of particle physics and cosmic evolution requires that the universe begin in complete symmetry between matter and antimatter. Only about 1 proton or neutron in about 10^{20} should have escaped annihilation into photons. The measured ratio, however, of baryons–protons and neutrons–to the photons left over is about 6 x 10^{-10}, ten orders of magnitude greater. At some very early moment, something broke that initial symmetry, yielding ultimately the universe we inhabit and explore today. How did this happen? One attractive theory–*leptogenesis*–postulates the existence of very massive unstable neutrinos that induce an asymmetry between matter and antimatter. In leptogenesis these postulated massive neutrinos did their work and vanished, but left fingerprints on today's neutrinos–requiring them to be their own antiparticles. Importantly, leptogenesis predicts both this ratio of leftover matter to photons and the extremely small value of neutrino mass, suggestive of underlying truth.

How might we learn something–anything–about this scenario? We can, by searching for an almost unimaginably rare nuclear decay–without the emission of today's light neutrinos. To achieve the desired sensitivity, a ton of an isotope favorable to this decay mode is likely necessary! Substantial efforts to search for this decay mode are underway around the world.

I present one attractive technique aimed at this search, based on a high-pressure xenon gas Time Projection Chamber. The technical challenges are daunting: energy resolution must be excellent and backgrounds, primarily from energetic gamma rays, must be discriminated against with unprecedented efficiency. Surprisingly, a biochemistry technique might help us succeed, by enabling detection of xenon's double beta decay daughter, barium, since gamma rays do not convert xenon to barium. If the neutrino-less decay mode is observed, we learn that the neutrino and the anti-neutrino are identical and neither matter nor anti-matter–a unique possibility among spin ½ particles. And, perhaps, we will have gained a glimpse into the first seminal moments of our universe.

ID: 97

Experimental Study of Materials Radiation Resistance in Reactor Mixed Fields for the Construction of the SPES facility at the Legnaro National Laboratories of INFN

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The SPES facility at Legnaro National Laboratories (LNL) of the Italian National Institute of Nuclear Physics (INFN), now in the construction phase, is a second generation accelerator for the production of neutron rich radioactive ion beams (RIB). The radioactive nuclear species are produced with the ISOL technique by fission of an ^{238}U target, in the form of a series of thin porous $^{238}UC_x$ discs, on which a 200 μA primary proton beam of 40 MeV energy impinges. The ^{238}U fission, at the foreseen rate of 10^{13} fission/s, generates a highly radioactive environment, with neutron and photon fields whose fluxes are larger than 10^{10} particle/(cm^2 s). Materials and components constituting the SPES Target & Ion Source assembly (TIS) are submitted to a serious radioactive damage, due to intense neutron and photon fields. The materials most sensitive to radiation effects are the organic ones, in particular polymeric ones, and the most critical components are vacuum O-rings, lubricant and greases, cable insulators, optical fibers, signal cables, electronic devices and pneumatic motors.

A project aimed at performing extensive experimental campaigns of testing of products of potential use in the TIS construction was started in the framework of the SPES project. Irradiations of the material samples are performed in the neutron and photon mixed field of the TRIGA Mark II research reactor of the LENA Laboratory of the University of Pavia, at different values of adsorbed dose. The main motivation for the choice of a reactor neutron and gamma mixed field to perform irradiations is that in testing radiation resistance of materials, it is important to reproduce, as close as possible, the actual environmental service conditions.

In the present work, the procedures adopted for performing irradiation and testing of samples of elastomeric materials as well as lubricant and greases are described. Results obtained both for different types of elastomeric materials, generally used for construction of vacuum O-rings, as well as for different types of lubricant and greases, are presented. The evolution with the dose absorbed in the presence of reactor neutron and gamma mixed fields of the materials properties is examined, and the best choice for the specific application is suggested. Considered materials are both conventional ones as well as materials specifically developed for applications in the presence of ionizing radiation. The latter materials were previously tested only in gamma radiation fields.

ID: 98

Development of Low Background Methods for Detection of Rare Low Energy Neutrino and Dark Matter Signals

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Experiments that attempt to detect rare signals produced by low energy neutrinos or dark matter particles are usually background limited. Backgrounds originate from natural radioactivity in the detector itself, from sources of radioactivity external to the detector, and from cosmic rays. Using on-going efforts to achieve very low background in Borexino for solar neutrino measurements and efforts toward low background in dark matter experiments, some of the general problems and tentative solutions will be illustrated.

ID: 99

Studies of Prompt Diagnostic Signatures of Nuclear Detonations Using MeV Electron Beams

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At the Idaho Accelerator Center at Idaho State University, we are undertaking a program to study a particular effect of a nuclear detonation called Teller light, which is a flash of ultraviolet fluorescence that occurs before the shock wave or fireball form. This fluorescence is produced when prompt fission gamma rays, emitted during the last few tens of nanoseconds of the chain reaction, exit the assembly and Compton scatter in the surrounding air. Typical energies of these gamma rays are in the range of 1.5 to 2.0 MeV. Using low energy electron linear accelerators to simulate these Compton electrons, we intend to study Teller light formation in complex environments such as would be found on a city street, and also study its propagation. We will explore what can be learned about a particular bomb's characteristics by this effect, and drawing on the navigational techniques of honey bees, explore methods to determine the distance to and direction of a nuclear detonation. In addition, we will perform scoping studies to see if we can replicate some radiofrequency signatures of a nuclear detonation with our accelerators.

This work is being performed under contract HDTRA1-17-1-004.

ID: 100

The ISOLPHARM Project: New ISOL-Production Method of High Specific Activity Beta-Emitting Radionuclides as Radiopharmaceutical Precursors

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At INFN-LNL (Istituto Nazionale di Fisica Nucleare – Laboratori Nazionali di Legnaro) a new facility for the production of radioactive ion beams is being implemented, SPES (Selective Production of Exotic Species). This new facility, besides being operated for nuclear physics studies, may play a pivotal role in the production of medically relevant radionuclides by means of the ISOL (Isotope Separation On-Line) technique.

In the case of SPES at INFN-LNL radioactive ion beams of neutron-rich nuclei with high purity, in the range of mass between 80 and 160 amu, will be produced. The production of the radioactive isotopes will be obtained by nuclear reactions induced by 40 MeV protons (accelerated by a cyclotron) that will bombard a target composed of 7 discs of carbon dispersed uranium carbide (UCx), properly spaced in order to dissipate the heat (8 kW) generated by the reaction. The uranium contained in the target material will be ^{238}U, so that the radioactive isotopes produced will belong to elements having an atomic number between 28 and 57 (elements between nickel and lanthanum). In particular, most of the produced nuclides will be neutron-rich, i.e. they will have an excess of neutrons with respect to the element's stable nuclear configuration.

The reaction products will be extracted from the target by evaporation at high temperature (~2000 °C), then forced to pass through a transfer tube towards an ionization cavity, where they will be ionized to the 1+ state. The ionization source used will vary depending on the ionization potential of the elements of interest. Once ionized, the isotopes will be accelerated through an electrode at high potential (up to 40 kV). The formed beam will be subsequently directed and focused using different electromagnetic systems and purified in order to have a pure isotope beam without contaminants.

The core of the method is the possibility to obtain pure isobaric beams following mass separation; in this way no isotopic contamination will be present in the beam and afterwards in the trapping substrate. Only potential isobaric contamination can affect radiochemical and radionuclide purity, but proper methods can be developed to separate chemically different elements

The goal of the ISOLPHARM project is to provide a feasibility study for an innovative technology for the production of extremely very high specific-activity beta-emitting radionuclides as radiopharmaceutical precursors. This revolutionary technique will allow to obtain radiopharmaceuticals, impossible in most cases to obtain in the standard production facilities (neutron reactors or cyclotrons), with lower costs with respect to traditional techniques and reduced environmental impact. The ground-breaking idea of the ISOLPHARM method was granted an International patent (INFN).

The steps to be addressed for the preparation of the radiopharmaceutical are: (1) Trapping of the radionuclide of interest present in the beam by means of the construction and placement of a suitable substrate; (2) Preparation of a medicinal product compatible with the method of administration; and (3) Agreement with the requirements of quality guaranteed by compliance with the principles of Good Manufacturing Practice (GMP) in the field of radiopharmaceuticals.

ID: 101

Organic Liquid Scintillators Based Source Localisation in Radiation Monitoring

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Portal radiation monitors are used to detect radioactive materials contained in moving vehicles at border crossings or to prevent illicit import of nuclear and radiological materials into the port. Portal monitor systems are also used in security applications in hospital and industry environments, for example to protect radioactive materials from theft. These systems are passive (not designed to generate or emit radiation) and activate an alarm in the event of detection of radioactive material; however provide little information on energy of detected radiation to the operator. They often use detectors based on the use of helium-3 gas for neutron detection and plastic scintillator detectors for gamma-ray detection. The currently used Helium-3 is generated as a result of tritium radioactive decay and the production of helium-3 has drastically decreased in recent years. Fast organic liquid scintillators became popular as a result of recent advances in digital pulse-shape discrimination methods and demanding requirements in security applications associated with helium-3 replacement. In this paper we are going to use an array of organic liquid scintillators (which is sensitive to both neutrons and gamma rays) and investigate the potential of localisation of radioactive sources in three-dimensional space relevant to portal monitoring applications.

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ID: 102

WATCHMAN: a Demonstration of Remote Reactor Monitoring with Gadolinium Doped Water Detectors

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The relatively high rate of emission of antineutrinos from operating nuclear reactors offers the prospects of monitoring, discovering, or excluding the existence of reactors at tens to hundreds of kilometer standoff. WATCHMAN - the WATer CHerenkov Monitor of AntiNeutrinos - is a proposed experiment which aims to demonstrate the feasibility of tracking reactor operations remotely, using gadolinium-doped water Cherenkov detection technology. The gadolinium dopant acts a neutron capture agent, suppressing otherwise overwhelming backgrounds and permitting efficient detection of charged-current antineutrino interactions on protons. The WATCHMAN collaboration consists of U.S. and U.K. National Laboratories and Universities. The specific goal of WATCHMAN is to track the operational status of a nuclear reactor at 10-25 kilometers standoff.. Candidate sites for the deployment have been identified in the U.S. and the U.K., taking advantage of the proximity of existing mines to operating reactors. Depending on the site, WATCHMAN will measure a few tens of antineutrinos per day from the reactor of interest, above a background of similar scale. A successful deployment at this range will exercise the water-based technology on a large scale, demonstrate a capability that itself may be useful for a range of verification tasks at tens of kilometer standoff, and serve as a stepping-stone to the one hundred kiloton to megaton mass devices that would be required for true remote detection. Water-based technology is also being considered for future large-scale neutrino physics experiments. In our view, it is likely the only scalable approach to reaching such large detector sizes.