# Portable African Neutron-Gama Laboratory for Innovative Nuclear Science[*] [**]

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iThemba LABS has pioneered a mobile gamma-ray detection unit which allows a user to operate in the field and chart the location, strength and energy of gamma radiation. The system incorporates a sensitive scintillation detector[1] typically used for accelerator-based spectroscopy at the SSC laboratory and was integrated into a backpack incorporating a fast 125 MHz digitiser for readout and a GPS enabled Raspberry Pi microprocessor system, allowing in situ measurements of radiation around the Cape Town site, with collected data streamed to the cloud and analysed offline. After conducting a series of rollout radiation measurement tests at Faure site, iThemba LABS has successfully used the gamma-ray detection system in collaboration with local and regional institutions to take radiation monitoring measurements from calibrated sources in the field, including radiation measurements tests conducted at Kruger National Park and at mining areas both in South Africa and in Botswana. It has also been used in the commissioning of the SAIF facility monitoring the performance of the water-cooling circuits.

The Portable African Neutron-Gamma Laboratory for Innovative Nuclear Science (PANGoLINS) project aims to investigate measurements of both gamma rays and neutrons which forms an important component part on site or in transit and the detection of both fissile material for the use in decarbonised energy sources or disposal thereof. A core component of the project is be to miniaturize the weight of the gamma ray detection device and associated infrastructure so that it can be loaded on an unmanned aerial vehicle to enable access to, and enhance performance of radiation monitoring measurements at remote sites leading to autonomous operations.

Benefits of the outcome of this project includes economic impact, contribution to GDP etc., increased highly skilled capacity and knowledge base and increased capabilities for technological innovation and social impact including improvement in quality of life, poverty alleviation and the potential impact in lowering barriers to entry for other South African technology innovations.

An overview of the project, its progress and potential outcomes will be presented.

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# Characterization of liquid organic scintillator detectors suitable for neutron spectrometry

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The ELISA (ELastic and Inelastic Scattering Array) spectrometer is one of the various experimental setups installed at the GELINA neutron time-of-flight facility of the EC-JRC in Geel. It is a unique instrument in Europe used to measure high-resolution cross sections and angular distributions of neutron elastic and inelastic scattering. The spectrometer consists of two main parts: a $^{235}$U ionization chamber for the measurements of the neutron flux and 32 liquid organic scintillators for the detection of the scattered neutrons. Two different types of scintillators are used. Half of them are filled with the EJ315 scintillation material, using highly purified deuterated benzene ($C_6D_6$), and the other half are filled with the EJ301 material, a liquid based on xylene ($C_8H_{10}$). Both detector types have a time resolution of less than 1 ns and high pulse shape discrimination capabilities making them suitable for time-of-flight measurements in mixed n-γ fields [1-3].

Dedicated calibration measurements were performed at PIAF (PTB's Ion Accelerator Facility) to characterize the response functions and neutron efficiency of these detectors. For the response to photons, measurements with calibrated radionuclide sources were performed covering the energy range 300 keV - 4.5 MeV. For the neutron response functions and efficiency, measurements at PTB's Van de Graaff accelerator with a 2.5 MeV quasi-monoenergetic neutron beam were performed. Additional measurements at PTB's cyclotron with a white neutron beam with energies from 500 keV to 18 MeV were performed using the time-of-flight technique. The experimental light output distributions produced from these measurements were compared with theoretical response functions for both photons and neutrons, produced via Monte Carlo simulations.

In this presentation, the calibration experiments along with analysis of the acquired data and the first results for both types of detectors are presented.

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# Neutron spectrometry in space and aviation with a compact scintillator-based detector

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Cosmic radiation consisting of Galactic Cosmic Rays (GCRs) and Solar Energetic Particles (SEPs), and their associated secondary particles are a known radiation hazard for space operations, satellites, and aviation. To improve risk models associated with these environments it is critical to fully characterize the different components of the mixed radiation fields at the point of interest. Secondary neutrons, with enhancements in the energy spectrum around 1 MeV and 100 MeV [1], are produced from cosmic ray interactions with matter posing particular dosimetric challenges. Existing measurement technologies are limited in their use outside of the laboratory due to constraints on size, power requirement, and safe operation [2].

Progress towards an autonomous, compact detector system suitable for measurements of cosmic ray induced neutrons with energies up to 140 MeV is presented. The detector system is comprised of a 6 mm x 6 mm x 120 mm prism of EJ-276 plastic scintillator, one or more MICROFC-60035 silicon photomultipliers, and digital data acquisition. Neutron fluence spectra are obtained through the unfolding of measured light output spectra with respect to calibrated detector response functions. For neutron energies below 20 MeV, detector response functions were simulated with Geant4 and validated with respect to mono-energetic measurements at fast neutron reference facilities AMANDE (Institut de Radioprotection et de Sûreté Nucléaire, France), and PIAF (Physikalisch-Technische Bundesanstalt, Germany). Above 20 MeV neutron reaction cross section data are insufficient, requiring measurement of detector response functions. Measurements were made at the neutron facility at iThemba LABS (South Africa) between 10 MeV and 64 MeV, and nearly mono-energetic detector response functions were derived from time-of-flight analyses. The spectroscopic capabilities of the prototype device are demonstrated through the unfolding of known neutron fields.

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# Design of the Anti-Compton HPGe gamma spectrometer and performance comparison with Monte Carlo simulation

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This paper presents the results of designing a low-background gamma spectrometer for prompt-gamma activation analysis and instrumental neutron activation analysis. The gamma spectrometer is based on an HPGe detector with 30% registration efficiency and an energy resolution of 1.7 keV at 1332 keV. A cylindrical BGO scintillation crystal, 25 mm thick, was used as an anti-Compton detector. Using MCC-MT Monte Carlo tools, we optimized the spectrometer design to achieve the highest Compton attenuation factor. For comparison with the simulation, a set of experimental data obtained from an HPGe spectrometer was used. Measurements have shown that the Compton attenuation factor ranges from 6 to 10, depending on the selected energy region. Simulated and measured spectra of Co-60, Cs-137, Eu-152, and Th-232 are presented.

# Signal Analysis Algorithms for Improved Energy and Position Resolution in Pixelated CZT Detectors*

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Cadmium Zinc Telluride (CZT) detectors are a promising room-temperature alternative to germanium detector systems for the measurement of gamma rays. They provide good energy resolution, and through pixelization, good position resolution for gamma interactions. Decreasing detector pixel size improves the intrinsic position resolution and enhances the small pixel effect, minimising the negative contribution of poor hole-mobility lifetimes. This comes at the cost of an increased number of channels, and thus system complexity, while introducing potential degradation of energy resolution through charge-sharing.

This work presents an alternative approach to decreasing pixel size by instead utilising signal analysis algorithms to exploit the position-dependent signal response of CZT detectors. Through application of these algorithms the position resolution is improved, and from this the energy resolution degradation resulting from incomplete charge-collection is corrected for. Time-dependent and position-dependent signals arising in a pixelated CZT detector and collected through collimated gamma-scanning techniques at the University of Liverpool are provided in Figure 1. Analysis algorithms were applied to the charge collection signals, which vary as a function of interaction depth, and the transient image charge signals, which vary as a function of interaction position across the pixel width, to achieve sub-voxel position resolution. In this work a selection of CZT pixel geometries, ranging from relatively thin detectors with large pixels (2.46 mm pixels, 5 mm thick) to thick detectors with small pixels (0.8 mm pixels, 10 mm thick), were studied and the position resolution through this methodology quantified.

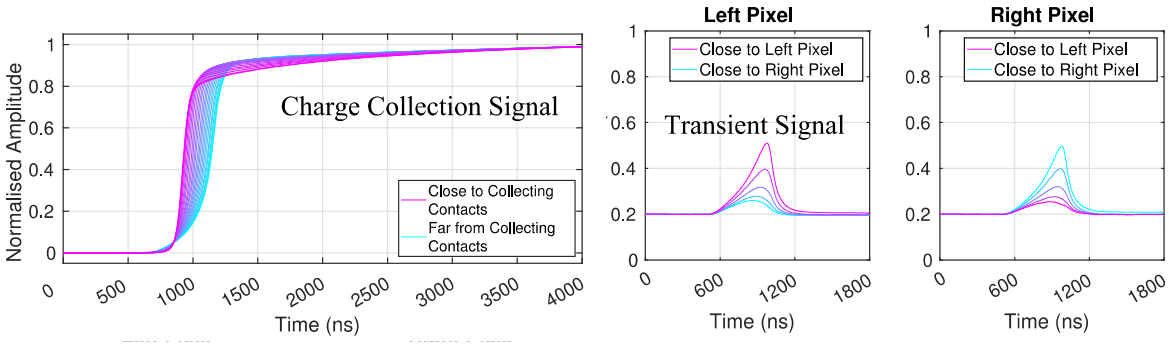


*Figure 1- Left: Average charge collection signals from gamma-ray interaction positions through crystal depth. Right: Average transient image charge signals from interaction positions across pixel width.*

An increased sensitivity of signal response to position of gamma interaction is found when the pixels are large relative to detector thickness. As such, this approach is proposed as a methodology that is particularly promising for crystals with weak small pixel effects, as excellent position and energy resolution can still be achieved while channel number, system complexity, and cost are reduced. These methods enable three-dimensional localisation of gamma-interactions, which has applications in Compton imaging and collimator-based medical imaging.

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# “SOLARIS” a neutron tracker for the next generation solar missions

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Neutron detection and imaging in space environment is pushing for cutting edge technology and innovative setups in order to provide reliable, low-power, and adaptive detection systems. The in-progress Parker Solar Probe and ESA Solar Orbiter space missions have already showcased the capability to approach the outer corona of the Sun, offering fresh insights into plasma dynamics governing solar wind and flares, where high-energy particles are produced and accelerated. Within this framework, neutron flux characterization and imaging could unveil crucial aspects of the nuclear and plasma processes intertwining on the solar surface. A next-generation neutron tracker detector is being proposed, simulated, and characterized. The proof-of-concept setup aims to amalgamate simplicity with high performance, surpassing the current state-of-the-art of on-board neutron detection systems. Notably, the introduction of mechanical adaptive features enables real-time optimization of the trade-off between efficiency and tracking angular resolution. All facets of this new detection system will be thoroughly analysed and discussed.

# Examining the effect of scatter radiation spread in $LaCl_3$:Ce and $LaBr_3$:Ce scintillators under nuclear medicine imaging exposure conditions

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Crystalline scintillator materials are used as part of a radiation detection system. Their high atomic number and their efficiency in converting the detected radiation photons to a plethora of optical photons, leads to high sensitivity radiation detection systems. An important application of crystalline scintillators is Nuclear Medicine imaging instrumentation in gamma cameras, or in conjunction with X-ray imaging as in Computed Tomography assisted Single Photon Emission Tomography (SPECT/CT). Recently $LaCl_3$:Ce and $LaBr_3$:Ce scintillators have been studied as candidates for a hybrid SPECT/CT detector system [1], [2]. In such a detector system the spread of the scatter radiation in the scintillator may play a significant role in the crystal's dimension choice. The scope of this work is to theoretically examine the scatter radiation of $LaCl_3$:Ce and $LaBr_3$:Ce scintillators for nuclear medicine imaging applications.

The PenEasy Monte Carlo code [3] was utilized to investigate the scatter radiation spread in $LaCl_3$:Ce and $LaBr_3$:Ce as well as, its lateral distribution at the exit of the scintillators. The considered irradiation conditions were photons of 140 keV energy to simulate the effect of Tc99m and X-ray spectra of 120 kV and 140 kV filtered with 21.5 mmAl to simulate a CT spectrum passing a body. The scintillator thickness selected to be 0.5 cm, 1 cm, 1.5 cm and 2 cm. The scatter distribution considered at a mathematical plane 0.25cm before the exit edge of the scintillator. The simulation assumes cylindrical symmetry. It was found that for all the above irradiation conditions and 1cm scintillator thickness the scatter radiation spreads lateral up to 0.6 cm distance. In addition, it was found that the higher the thickness of the scintillator the higher the scatter component near its exit, although no significant values were calculated for distances further that 0.6 cm. As an example for 140 keV and at 0.6 cm lateral to the beam entrance the dose percentage related to the entrance position was for $LaBr_3$:Ce a) 1.05% for 0.5 cm thickness, b) 2.62% for 1 cm thickness, c) 3.73% for 1.5cm thickness and d) 4.94% for 2 cm thickness. The corresponding percentages for $LaCl_3$:Ce were 1.09%, 2.59%, 3.83% and 4.46% respectively. The results for lateral distances of 0.3 cm at 140 keV range from 11.7% to 20.4% for $LaBr_3$:Ce and from 9.8% to 19.2% for $LaCl_3$:Ce. The results of the work indicate that at scintillator crystals with a cylindrical base radius smaller than 0.3 cm scatter radiation may crossover neighboring crystals resulting in image degradation.

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