NuSec Technical Workshop 2025

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Book of Abstracts

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Enhancing 'Big-Data' Visualisation and Presentation in Data-Rich Nuclear Security Scenarios

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The 'Internet of Things'(IoT); increasingly cheap, accessible, and available data storage volumes; greater data/sensor readout rates and the ability to access data remotely from anywhere in the world has resulted in "Big Data"- serving as a backbone upon which both modern Machine Learning (ML) and Artificial Intelligence (AI) reside. Like the multi-decade-long exponential growth in processing power brought about by unabating enhancements in transistor fill-factor, the amount of globally distributed "Big Data"is also increasing at a mind-boggling rate. While hard to accurately predict, industry and government estimates place the personal per-capita data volume to be more than 500 TB for citizens in developed countries - held only in a small part by the user, with sprawling amounts held by businesses, social media networks, video sharing platforms and ecommerce websites. As more countries (and their citizens) enter the "Big Data Age", this 'data density'(alongside the infrastructure and requirements that underpin it) is only going to increase.

Alongside these personal, commercial, and business uses for large datasets; nuclear security and monitoring, typically as part of complex wide-area detection networks, also collects and processes vast densities of intricate multi-variable data. As for non-radiometric datasets, with the size and complexity of monitoring data ballooning, a new challenge is emerging; How do you best represent such "Big Data"to allow for expert human operatives to make the most appropriate, timely, and informed decisions? What do they need to see? What is essential in underpinning their thought process? And what is surplus to the decision-making? These are all considerations and requirements that this project sought to address, for datasets such as SIGMA and the University of Bristol's own distributed monitoring network, where real-time decision making, contextualisation and response are required.

This project has successfully produced a scalable system whereby spatially distributed, contextualised, spectral radiometric data is visualised within a user-intuitive experience, whether big-screen or virtual reality (VR; e.g. Meta Quest) based, to enhance how this complex data is explored. The use of VR and AR in and across nuclear is still in its infancy, but it is hoped that developments and deployments such as this will highlight its promise and future applications across the space.

Session 3: Sigma Data and Algorithm Studies / 103

Real time identification and tracking of radioactive materials carried by humans

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The widespread availability of nuclear and radioactive materials, commonly used in industrial and medical applications, poses a significant risk of misuse in the form of radiological dispersal devices (RDDs) or "dirty bombs." If detonated in densely populated or strategically important locations, such devices could cause widespread panic and necessitate large-scale evacuation and cleanup operations. To mitigate this threat, effective screening for radioactive materials is essential. Deploying distributed detector nodes in urban areas with high traffic or near strategic targets offers a practical solution for identifying and intercepting materials trafficked with malicious intent. Such systems, employing scintillator-based gamma-ray spectrometers, can continuously monitor, detect, and localize nuclear and radioactive threats in real time. These spectrometers provide energy spectra of detected radiation, enabling the identification of materials, which is required to distinguish them

from benign sources, such as medical isotopes and naturally occurring radioactive materials. This project focuses on optimizing analysis of data from these spectrometers, such that radioactive material can be detected and identified in real-time. Additionally, it investigates the complex variations in background radiation spectra observed in urban environments, influenced by factors such as human activity, weather, and temperature. The findings will help to inform improvements to existing systems being tested in the UK and will facilitate the localisation of radioactive threats, helping to inform emergency response strategies.

Session 2: New Detectors and Instruments / 104

Low Power, Compact, Dual Mode Detectors for Nuclear Security Applications

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The detection of special nuclear material remains a matter of utmost importance due to potential security issues. Current neutron detection relies upon a combination of a 3He detector and a plastic scintillator. 3He is a rare material with decreasing global supply, so an alternative solution needs to be developed. This solution should be both low power and robust, in order to be deployed in field situations.

This is possible using dual mode scintillators, which can use pulse shape discrimination (PSD) methods to separate between neutron and gamma species present due to their different timing characteristics. The scintillator materials selected for investigation are, CLLBC, an inorganic scintillator made of Cerium, Lanthanum, Lithium and BromoChloride. As well as EJ-276, an organic plastic scintillator.

These materials are paired with Silicon Photomultipliers (SiPM's), which meet the requirements of being robust and having a low operating voltage, along with single photon sensitivity. Initial tests have taken place with these materials and photomultiplier tubes (PMT's), which were chosen to begin with due to a lower room temperature dark count than SiPM's.

Results taken using CLLBC have demonstrated a 5% gamma energy resolution and 17.6% intrinsic efficiency, both at 662keV. The investigation has now transitioned towards using SiPMs due to their robust and low power characteristics when compared to PMTs. Simulation work is ongoing with both GEANT4 and LTSpice simulations being developed to test designs and provide idealised results.

This work has further led to the design and construction of bespoke printed circuit boards (PCBs) with analog electronics to meet initial low power requirements. Work is currently underway to replicate accurate gamma and neutron species separation using PSD algorithms replicated in hardware, with the goal of creating a robust analog system that can perform as well as a digital PSD system at a fraction of the power requirements.

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Development of a novel neutron detector using trapped 3He

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The global demand for portable neutron detection is on the rise for security, monitoring and scientific investigations [1]. Practical uses could include deploying advanced radiological and nuclear detection capabilities at border points, as monitors around small modular reactors for energy or centres for medical radioisotope production, or directly as part of a scientific analysis package. Portable neutron detectors add flexibility and utility and are crucial for various current purposes and planned future uses. Helium-3 (3He) based detectors have been the standard for thermal neutron detection due to their high efficiency and excellent radiation discrimination, however, these detectors tend to be large and obtrusive and require high voltages to operate. [2] Therefore, the development of a compact 3He neutron radiation detector is critical.

Utilising our proprietary adaptation to known fabrication methods, we show how He can be embedded in high quantities. These 3He-embedded materials are then used as converter media, exploiting the reaction between 3He and a thermal neutron to produce tritium and a proton. This release of energy can then be detected using a photodiode. In this work, we will show how we produce these novel materials as well as how we characterise them. We have also incorporated these materials into a detector and shown a neutron response from our converter media.

This work was supported by NuSec FEA 429056 Barton

[1] Future Market Insights, Inc. "Neutron Detectors Market", REP-GB-17843 Available at: https://www.futuremarketinsights.co
(Accessed 9 August 2024)
[2] Richard T. Kouzes, et al. Neutron detection alternatives to 3He for national security applications, NIM A, Volume 623, Issue 3, 2010. ISSN 0168-9002 https://doi.org/10.1016/j.nima.2010.08.021

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Stereo-scintillator detector arrangement for radioactive source localisation and characterisation within confined pipe networks

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We present a radioactive source localisation method within confined pipework using dual, low-volume, low-cost scintillator detectors. The proximity of cooling circuit pipework to operating nuclear reactor cores makes the pipe material susceptible to neutron activation (e.g. 60Co). This can create unknown volumes of radwastes that need to be characterised to plan for decommissioning. The complex geometry of thick metal pipework and surrounding systems renders external measurement of radioactive contamination difficult, so internal investigation is required.

Utilising small, novel, pipe-navigating robots as a deployment platform, we have implemented two, uncollimated <18 cm3, <0.09 kg CeBr3 scintillators in a stereo arrangement. Simulation and preliminary experimental results of the setup using 70 cm long section of steel pipe (Ø 227 mm, 17 mm wall thickness) have shown that the activity and polar distribution of single, point sources can be determined within 20±5 degrees by exploiting the collimating effect of the robotic platform and comparing the photopeak count recorded by either detector. Combined with the path-of-travel data of the robot along the pipe, the location of radioactive point sources can be ascertained to within a circular region on the pipe wall with diameter 45±10 mm and whether sources are located on the internal or external surface of the pipe wall, through analysis of the Peak-to-Compton ratios.

Further work is ongoing to improve the measurement accuracy by refinement of the detector setup and applying machine learning to the spectral data post-processing. In addition, we are exploring the capabilities of the robotic platform to operate Compton imaging-based systems.

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Boron-loaded opaque scintillator as a low-cost directional neutron detector

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The detection of concealed neutron sources is imperative for nuclear security as neutrons can signify the presence of fissile material. Neutron sensors with positional and directional sensitivity can greatly improve detection capabilities through source localisation. However, the cost of existing detection systems has limited their widespread use. We are proposing a new, low-cost type of scintillating neutron sensor based on the idea of an opaque scintillator that offers positional and directional sensitivity. Opaque scintillators have recently gained interest in the neutrino physics community where they are being proposed to greatly improve position resolution when imaging neutrino interactions in large-scale detectors. By using an "opaque"medium with a small scattering length but long attenuation length, scintillation light can be confined in a small region around its emission location. The light can then be extracted from the medium using an array of optical fibres coupled to photosensors located outside of the medium. We intend to augment this technique using a boron-loaded opaque scintillator comprising a low-cost mixture of boron nitride and zinc sulphide suspended in a base liquid, providing implicit sensitivity to thermal neutrons through neutron capture interactions. In this talk, we will discuss the detector concept as well as providing an overview of the progress that has been made towards realising a first prototype of this novel neutron sensor and plans for the future.

Session 1: Source Location and Tracking / 110

PReTSL: Proton Recoil Tracking for Source Location

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Illegal transport of Special Nuclear Materials (SNMs) is regarded as a major terrorist risk. These SNMs are difficult to detect at border controls because their gamma emissions are typically weak, low energy, and therefore easily shielded. Since their neutron emissions are more difficult to shield, they could be more suitable to assist with detection of SNMs. However, the levels of neutron emissions typically fall below the natural background at practical measurement distances.

The PReTSL (Proton Recoil Tracking for Source Location) project aims to address this challenge by employing a Time Projection Chamber (TPC) detector, in conjunction with a position-sensitive large-area fast-neutron detector array, to achieve directional imaging of fast neutrons. Nuclear physics experiments have seen a rise in the use of TPC detectors over the past decade due to their unrivalled ability to precisely measure the tracks of particles involved in nuclear reactions.

By using an isobutane gas inside the TeBAT (Texas-Birmingham Active Target) TPC detector, to act as a proton target, incident fast neutrons enter and elastically scatter. By precisely tracking the

recoiling protons in the TPC and by detecting the position of the scattered neutron, the reaction plane can be uniquely defined. This, along with measurement of the proton's energy allows the direction of the neutron source to be reconstructed.

This workshop contribution aims to describe the PReTSL concept and its advantages over conventional neutron monitors. It will present the results of Monte-Carlo simulations of the detector and testing of neutron direction reconstruction algorithms. Finally, it will show preliminary experimental results of detecting neutrons from a 252Cf source housed at Texas A&M University, with benchmarking experiments set to take place in late January 2025.

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PReTSL: Proton Recoil Tracking for Source Location

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Illegal transport of Special Nuclear Materials (SNMs) is regarded as a major terrorist risk. These SNMs are difficult to detect at border controls because their gamma emissions are typically weak, low energy, and therefore easily shielded. Since their neutron emissions are more difficult to shield, they could be more suitable to assist with detection of SNMs. However, the levels of neutron emissions typically fall below the natural background at practical measurement distances.

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Neutron Capture in a Plasma Environment

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The National Ignition Facility (NIF) laser at Lawrence Livermore National Laboratory is capable of producing a plasma environment with temperatures ~10 keV, particle densities ~10^32 m^-3, and neutron fluxes of up to 10^34 m^-2 s^-1. These features, combined with the advanced x-ray, neutron and radiochemistry diagnostics that are available at the NIF, make it uniquely suitable for carrying out experiments to investigate interactions between Plasma Physics and Nuclear Physics. A NIF Discovery Science experiment has recently been commissioned to measure the neutron capture cross section of Thulium-171 (171Tm) at a neutron energy of 2.45 MeV. This presentation will outline the main features and challenges of this experiment, predicted results, and future complementary experiments that could be carried out on the NIF.

The plasmas at the NIF are produced by using the laser to compress capsules (diameter ~1 mm) containing deuterium or deuterium-tritium fuel on timescales of ~1 ns, resulting in a neutron source of ~100 µm in diameter and duration ~100 ps. The commissioned experiment will include trace amounts of 171Tm and other monitor isotopes in a deuterium capsule designed to minimize the neutron scattering background in the plasma. Therefore, the 171Tm isotopes undergoing neutron capture will have a temperature of ~10 keV, and so a significant population of nuclear excited states of 171Tm will be created (first excited state is at 5.036 keV). Initial capture cross section calculations indicate that the ground state and excited state cross sections are similar. Thus the experiment will yield a combined cross section that shows little dependence on the excited-state population and will provide a baseline for future excited-state measurements where significant differences are expected. 171Tm and other reaction products will be recovered and counted after the experiment using NIFs radiochemistry diagnostics.

The NIF facility also includes diagnostics for accurately measuring the plasma temperature, density, size and duration. This information can be used for calculating the populations of nuclear excited states and for modelling processes, such as nuclear excitation by electron transfer and capture (NEET and NEEC), which can affect population rates. Future experiments will be designed to investigate these processes. This will support the development of a reliable platform on the NIF for measuring capture cross sections of excited state nuclei.

Session 1: Source Location and Tracking / 113

3D Position-Sensing Semiconductor Gamma-Ray Detectors: Current Research on CsPbBr3 and Commercialization on CZT Imaging Spectrometers

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This presentation summarizes the development of 3-dimensional position-sensitive (3-D) semiconductor gamma-ray detectors, including the advantages of 3-D single-polarity charge sensing and real-time gamma-ray imaging that have been pioneered by the University of Michigan. High energy resolution of close to 0.30% FWHM at 662 keV have been experimentally achieved on 6 cm3 CZT detectors, and larger volume CZT detectors up to 4x4x1.5 cm3 have been demonstrated. The 3-D detector technology has been advanced for CsPbBr3 perovskite gamma-ray detectors in recent years, and better than 1.0% FWHM energy resolution has been achieved on multiple detectors with thickness in the range of 5 –13 mm. These results have shown promise of CsPbBr3 for high-resolution gamma-ray spectrometers and imagers.

The commercialization of room-temperature semiconductor gamma-ray detectors by H3D Inc., a spin-off company from University of Michigan, will be introduced. Applications include nuclear safety in nuclear power plants, safeguard for IAEA nuclear inspectors, national security and emergency response, space applications, nuclear medicine imaging, as well as for basic science discoveries.

Session 2: New Detectors and Instruments / 114

Evaluating the suitability of organic semiconductor detectors for nuclear security

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Organic technologies are of active scientific interest due to their tuneable, scalable, and cost-effective nature. I will present radiation sensors based on organic semiconductor technology, particularly applications related to detection of hadronic radiation consisting of α radiation and thermal and fast neutrons. Neutron detection is useful in various fields, from fundamental particle and atomic physics research to the medical field and nuclear security portal monitors.

These organic sensors focus on NDI-type organic polymers including a novel material with carborane, a polyhedral cluster of carbon, boron, and hydrogen, directly incorporated in the molecular backbone (oCbT$_2$-NDI), sensitising to thermal neutrons via the boron neutron capture process. A comparison will be made with a similar polymer (PNDI(2OD)2T) with homogenously dispersed boron carbide (B_4C) nanoparticles, and a control sensor without any boron which is sensitive to more energetic fast neutrons.

Beyond this, I will present on the expansion of this technology: scaling up the size of the sensors and creating an array system synchronising multiple detectors to work together. These modes were probed for the application of making portal radiation detectors at strategic locations (ports, airports, areas of high pedestrian traffic) to identify illicit materials such as weapons grade plutonium and uranium.

The conclusion will discuss the end state of my PhD as a whole: where the project was successful, and any issues experienced. This will cover the technology readiness level at the end compared to the beginning, flaws found in the detector setups used, and outcomes of investigations probing these problems. Finally, potential future plans for the Organic Neutron Detection team at Queen Mary will be suggested in this field of organic semiconductor radiation detectors in the wake of this project.

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Active Interrogation System for Special Nuclear Materials: Principles and Initial Results

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Non-destructive inspection systems are essential for preventing terrorist threats and the smuggling of special nuclear materials (SNM) at airports and seaports. For decades, investigating SNMs such as Pu-239 and U-235 has been a primary concern of nuclear security efforts worldwide. This work presents experimental results from a novel, portable active interrogation system for the non-destructive detection of SNMs.
The system is based on threshold energy neutron analysis, utilizing a portable DD (2.45 MeV) neutron generator with an intensity of 5×107 n/sec to actively interrogate materials. It is coupled with arrays of tensioned metastable fluid detectors (TMFDs). In the presence of fissile material, prompt fission neutrons are emitted with an average energy of approximately 2 MeV, with ˜30% having energies higher than the DD source neutrons.
Experiments were conducted with 10 kg and 20 kg natural uranium (NU) metal samples placed inside an inspection volume of 1 m3. A series of 30-minute measurements, with and without NU, were

performed at a DD neutron source intensity of 106 n/sec and repeated multiple times. The neutron count rates were consistently higher with NU compared to without NU.
Using the experimental count rates, probabilities of detection (PD) and false alarm (PFA) were evaluated. For this analysis, the neutron source intensity was set to 5×107n/sec, and the inspection time was reduced to under 90 seconds. The results showed a PD of ˜98.7% for detecting 10 kg NU (containing ˜70 g U-235) and >99% for 20 kg NU (containing ˜170 g U-235), with a PFA of <5%. These results are encouraging compared to the target values (PD >90% and PFA <5%) outlined in ANSI standards.
The portable active interrogation system, experimental setup, and results will be discussed at the meeting.

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Characterisation and performance of vapour-deposited lead halide perovskite films for radiation detection applications

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Thin film (TF) metal halide perovskites are an emerging technology that are a promising material for use as radiation detectors, with potential for use as large-area imaging detectors. However, current solution-processing methods face challenges in achieving thick and uniform perovskite films. Vacuum-based deposition techniques can produce high quality uniform films but this approach has not been extensively developed for metal halide perovskite radiation detectors. In this study, single-source vacuum deposition (SSVD) using an in-house deposition system was employed to deposit lead halide perovskite films. Perovskite films were deposited onto glass substrates at different deposition rates and the film thickness and roughness were measured using a profilometer. SEM and EDS analysis was used to evaluate morphology and composition of the deposited films. Optical properties were characterised using photoluminescence (PL) measurements and the X-ray responses of the films assessed. Preliminary results showed that TFs achieved a maximum thickness of 7 µm with a roughness of ˜0.95 µm. SEM analysis indicated grain sizes ranging from 0.4 µm to 1 µm and some evidence of pinholes was observed. EDS and PL measurements confirmed the perovskite film composition. Work is ongoing to increase the film thickness and to improve the morphology, and a full study of X-ray sensitivity will be reported.

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Development of CsPbBr3-Polymer Composite Materials for Direct Detection of Radiation

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Interest surrounding the development of perovskite-based radiation detectors has largely emerged due to promising applications as an alternative or complementary candidate to silicon in solar cells. Such detectors can detect ionising radiation via both indirect scintillation and direct charge production mechanisms. The perovskite family encompasses a range of molecular combinations to

make up the ABX3 chemical structure, known for impressive charge-transport and photoluminescence. Chemical compositions can be chosen to optimise properties such as band gap and stability, whilst maintaining favourable performance. This work explores the direct radiation detection mechanisms and viability of 3D-printable perovskite-polymer composites, in contrast to recent studies that showcase indirect detection using similar composite scintillators. Such materials, formed from the combination of an inorganic perovskite and a suitable thermoplastic, could see applications in medicine and nuclear security, where there might be a need to construct context specific devices. Users could take advantage of rapid production methods using 3D printable composites, and basic manufacturing approaches to create custom radiation detectors as an alternative to expensive commercial products.

In this work, perovskite-polymer composites have been prepared from either caesium lead bromide (CsPbBr3) perovskite nanocrystals (NCs) or crushed-powder crystalline CsPbBr3 (PP). Polycaprolactone (PCL) thermoplastic was loaded with perovskite ranging from 10% to 30% by weight, (continuing from a previous investigation of the 1% to 9% range). For characterisation, composites were melted and pressed into 1 mm pellets, and gold contacts were deposited on opposite faces to facilitate charge collection. Compositional analysis has been performed using SEM imaging with EDS analysis to assess perovskite dispersion, and microCT imaging to check for defects and evaluate sample uniformity. IV-characterisation and photocurrent response tests have been performed under bias, using X-ray illumination across a range of exposure conditions to examine response linearity with dose-rate. Measurements including dark current, photocurrent and sensitivity are used in comparisons to perovskite-based materials in recent literature.

Promising results and challenges encountered during this work are shared, with the intent of contributing to discussions around perovskite-based direct detection devices.

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Optical characteristics and scintillation processes in 2D perovskite radiation detectors

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This study investigates the fundamental performance of perovskite scintillators for X-ray and gamma imaging, with a particular focus on their potential applications in nuclear security detection. By combining unique structural and optoelectronic properties, these materials offer promising prospects for developing next-generation radiation detection technologies, aligning with the goal to enhance detection capabilities for nuclear security.
Two-dimensional (2D) hybrid perovskites represent a versatile class of materials that combine the structural diversity of organic molecules with the ideal optoelectronic properties of inorganic frameworks. In this study, we present a comprehensive investigation of the optical and scintillation processes in 2D perovskites with Ruddlesden-Popper (RP) and Dion-Jacobson (DJ) structures. The materials studied include BA2PbBr4, PEA2PbBr4, BA2PbI4 (all RP), and TMPDAPbBr4 (DJ). Through steady-state and time-resolved photoluminescence (PL), X-ray and alpha scintillation measurements, and structural analysis, we show the correlation between their structural motifs and optoelectronic performance.
The bromide-based RP perovskites, BA2PbBr4 and PEA2PbBr4, exhibit bright photoluminescence, sharp emission spectra, and relatively small Stokes shifts. This is likely due to their efficient charge-carrier dynamics, with minimal non-radiative losses. These materials also show promising alpha particle scintillation responses, reinforcing their potential for radiation detection applications. However, the iodide-based BA2PbI4 displays dimmer photoluminescence and lower scintillation yields, potentially due to its small negative Stokes shift, which increases the likelihood of reabsorption of emitted photons. This effect, combined with the potential for enhanced non-radiative recombination pathways in the iodide system, likely contributes to the observed reduction in optical and scintillation performance. These three RP perovskites have very fast decay times in the several nanoseconds, making them ideal for a variety of nuclear security applications.

In contrast, the DJ perovskite TMPDAPbBr4 demonstrates distinctly different behaviour to the RP perovskites, characterised by a broad PL emission profile and a significantly larger Stokes shift. Just like the RP perovskites, TMPDAPbBr4 also has a fast decay time which is unusual for broad emitters. These features suggest the involvement of additional recombination mechanisms, likely mediated by defects or self-trapped excitonic states. Despite its rapid decay dynamics, TMPDAPbBr4 retains sufficient radiative efficiency to enable measurable scintillation, albeit with different characteristics compared to the RP materials.
The findings of this study highlight the influence of compositional and structural tuning on the optical and scintillation properties of 2D perovskites. While RP perovskites exhibit more conventional excitonic behaviour with narrowband emission, the DJ perovskite shows the potential for broader and more complex emission pathways. These insights provide a foundation for advancing the design of 2D perovskites tailored for applications in scintillation and radiation detection, where both high efficiency and fast response are critical.

Session 2: New Detectors and Instruments / 119

A Neutron Sensitive Detector using 3D-Printed Materials

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In this presentation, we will outline the development of a neutron-sensitive scintillator produced through 3D printing and its integration into a detector using a high-speed optical camera. The scintillator was produced using the Fused-Deposition Modelling (FDM) method of 3D-printing, whereby a thin plastic filament is heated and extruded to create layers of an object. Two methods for creating scintillating filaments are explored. The first used an organic scintillator based on polystyrene. The polystyrene was doped with PTP and POPOP to give visible scintillation, biphenyl to give appropriate mechanical properties for FDM printing and 6LiF for neutron sensitivity. The quantities of these additives were tested, with the greatest light emission found at 2% PTP, 0.05% POPOP and 0.1% 6Li by weight. The second method to be explored will use perovskite crystals in an inert plastic binder, either Polylactic Acid (PLA) or Polyethylene Terephthalate (PETG), both polymers commonly used for 3D-printing. Crystals of (PEA)2PbBr4:Li and CsPbBr3 are to be synthesised and combined with the PLA to produce a filament, along with 6Li to enhance neutron sensitivity. Each of these filament types was used to 3-D print scintillators, the design of which was optimised using MCMC simulations with Geant4. These were used to test the response of the material to neutron emission in a variety of configurations, allowing for the selection of designs with the highest light yield. These simulations were also used to calibrate the detector, determining the expected neutron spectrum. The final 3D-printed scintillators were imaged with a TimePix3-based camera, offering high spatial (16 μm) and temporal (1.56 ns) resolution. This was combined with an image intensifier, offering single-photon capability. This setup enabled the development of a neutron-discrimination algorithm that leverages the capabilities of the TimePix3 camera's capabilities. Finally, the detector was tested by exposing the scintillators to electrons, gamma-rays and thermal neutrons, with the results being compared to Geant4 simulations, allowing for a determination of the most effective filament. The ability to distinguish neutrons from gamma rays was demonstrated. This work supports the construction of a cheap, easily customisable radiation detector that can be tailored to suit any required application, offering significant promise for flexible, cost-effective radiation sensing.

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Machine learning enhanced analysis for compromised LiF:Mg,Ti. thermoluminescent glow-curves using an augmented seed dataset.

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Thermoluminescence dosimetry (TLD) enables the measurement of ionising radiation exposure by analysing the light emitted from an irradiated material after heating. This technique provides a retrospective assessment of absorbed radiation doses, which is particularly useful in health monitoring. Thermoluminescence (TL), or emitted light, is a result of trapped electron re-combination and is depicted typically by a glow curve of light intensity as a function of temperature. The fading of the TL response over time, the impact of material defects and composition, the restricted position of the dosimeter and the capture of low-dose exposure may compromise an accurate measurement of the absorbed dose.

This research presents the use of machine learning (ML) to model amended compromised glow-curve responses in LiF:Mg,Ti. TLD-100 and TLD-100H chips using an augmented experimental seed training dataset. The LiF:Mg,Ti. TLD-100 and TLD-100H chips were irradiated with a Sr^{90}/Y^{90} beta source with an activity of 37 MBq at a dose rate of 0.0155 Gy s^{-1} with maximum energies between 0.546-2.28 MeV at varied irradiation times with absorbed doses up to 2 Gy, pre-heat temperatures and thermoluminescence (TL) temperatures. The models source data from an ongoing extensive empirical labelled dataset and uses a noise augmentation method to change the photon intensity counts, while protecting the shape of the glow-curve arrays with integrals and peak-fitting methods. A data synchronisation method supports augmentation of the temperature, facilitating glow-curves to be fine-tuned across a broader range.

This work introduces a user-defined augmented dataset designed to resolve compromised glow curves at specific array indices. This method achieves a mean accuracy of 98% in plotting the augmented data array while maintaining the integrity of the glow-curve peak shapes. Assuming first-order kinetics, the Randall-Wilkins thermoluminescence (TL) intensity equation describes the thermally stimulated luminescence emission from a material as a function of temperature and time. This may be used to plot glow-peaks at various temperature ranges dependent on the frequency factor, instantaneous occupancy of the trap, shape factor and trap depth.

Future work will apply similar principles to analyse glow curves from silica beads across a range of irradiated doses, including those with compromised TL responses. This approach will generate a training dataset that enables machine learning techniques to explore the relationship between glow curve mathematical modelling and kinetic order. Ultimately improving the accuracy and broadening the application of silica beads as a reliable TLD material.

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Detection of anomalies in large radiation data streams using changepoint theory

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Detecting the presence of particular radioactive isotopes present for small periods of time in large time series datasets is useful in a number of nuclear security problems. This is a challenging computational task because the number of intervals in a signal quickly becomes large. To tackle it I will combine two mathematical approaches. First, I develop a multivariate likelihood ratio testing framework for this scenario, and show how this provides improvements in statistical power the over use of other approaches such as whole signal detection, photopeak detection, or signal to noise ratio scaling. Second, I will combine this with a changepoint theory approach to recursively test all

intervals in the signal without iterating over them. The resulting method is statistically powerful at finding its given targets, and does so using a very low amount of computation even when scanning large signals.

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SIGMA Data 2

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SIGMA data 2. The original SIGMA dataset, made available around two years ago, while both useful and relevant, contains real data with a limited number of threats and lacks ground truth. The priority for iteration of the dataset was identified as injected threats and AWE is in the process of making this happen. Plans and timescales are outlined to provide a hybrid dataset (real background, injected simulated threats) derived from the SIGMA data and potentially including time periods not included in the originally released dataset. The ONRL RADAI/REX dataset is also described as it represents an available fully simulated dataset and will be included in the planned SIGMA data 2 release.

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GROUSE 2025 update

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AWE is developing a spectroscopic RN detection algorithm GROUSE validated on down-sampled SIGMA data with injected simulated threats and simulated threat templates. Our top-level approach is described and detail provided of our anomaly detection in Poisson stats approach (POODLE) which feeds spectroscopic data to GROUSE, as well as the inject data, and templates. Initial performance is also outlined as are lessons learnt from the development journey thus far.

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Insights from the SIGMA Dataset: AI-Driven Radiation Detection in Complex Environments

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The SIGMA data challenge provided the academic community with unprecedented access to 1.5 billion gamma spectra collected in London, made available through NuSec. This extensive dataset

enabled research into both detector performance and advanced machine learning methodologies. Multiple academic teams have engaged with the data, with the Surrey campaign supporting a postdoctoral fellowship, two master's dissertations, and four bachelor of science projects.

This talk presents key findings using the SIGMA dataset, including:
• the application of neural networks to sparse isotope signal detection,
• assessment of the impact of temperature variations on in-field detector performance,
• enhancement of Geant4 modelling for moving isotope signal prediction,
• curation of AI-compatible training datasets for user-defined isotope tracking scenarios, and
• development of genetic algorithms to falsify signals, compromising isotope recognition.

These results highlight the advancements made possible through open-access datasets. To support the growing use of artificial intelligence (AI) in applied nuclear physics, for both civil and defence applications, plans are advancing for a Centre in AI for Applied Nuclear Physics. Following an awareness event at Nuclear Forensics (NuFor) 2024, this talk will present the latest progress toward this initiative. The centre aims to foster a collaborative research space for data and AI code sharing, establish best practices in machine learning for nuclear applications, support career development across academia, industry, and government, and contribute to shaping AI-related nuclear policy.

Session 1: Source Location and Tracking / 125

Neutron Detection with Sodium Iodide

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Sodium iodide is one of, if not the, most ubiquitous radiation detection materials deployed in the world today. It is favoured for its good light yield, good density and gamma detection efficiency, and its relative low cost of production to large (16") crystal sizes. It is not widely recognised as one of the so-called dual-mode, or gamma-neutron, radiation detectors. That is both a disservice to a long-standing workhorse material, and potential source of significant error in measurements.

Sodium iodide is a thermal neutron detector⋯

Using advanced pulse processing techniques, it is possible to take advantage of the relatively small neutron cross section of 127I, 6.2 barns at thermal energies. Neutron captures on 127I result in subsequent de-excitations and cascade release of gamma rays. With a neutron separation energy of almost 7 MeV for 128I and primary gamma rays of 4 MeV and above, there is a low probability of interaction even for the largest sodium iodide crystals. However, this de-excitation also occurs through a complex cascade of lower energy gamma ray transitions, many of which are available for re-absorption in the scintillator. In particular, there exists a long-lived (845 ns) isomeric state in 128I at 137.9 keV which can be exploited [1]. By utilising coincident measurements of this isomeric state with the prompt gamma emission we can gain access to an efficient mechanism for the detection of thermal neutrons.

While it is unlikely that sodium iodide will become the detector of choice for neutron spectroscopy, developing a reliable thermal neutron detection mechanism on an already widely deployed piece of equipment could provide an essential additional utility.

[1] E. Yakushev et al., NIM A, 848, 2017, 162-165

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Data driven techniques to analyse gamma-ray spectra from the London SIGMA sensor network

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Sensor networks continue to define measurements across the field of environmental monitoring, including that of radiation detection. NuSec and AWE's SIGMA Data Challenge provides access to measurements of gamma-ray activity recorded by a sensor network of around 100 detectors distributed across central London. We have analysed data from three detectors centred around St Thomas' Hospital and more than 10 detectors in a 'local' vicinity around Waterloo Station, Charing Cross and Westminster to identify anomalies in the data that may be linked to anthropogenic disturbances.

Initially, data driven techniques were used to analyse the gamma-ray spectra of the three detectors located in St Thomas' Hospital. The temporal correlations between these three detectors were investigated by subtracting average gamma-ray activity to look for relative peaks and troughs over small timespans for each detector. The days over which the data was investigated correspond to those used in the testing of the GROUSE algorithm (Garrood J. et al, 2023). Additionally, the methods of background subtraction featured in the GROUSE algorithm were also investigated and compared a variety of other methods for sampling an average background.

Both spatial and temporal correlations of peaks in gamma-ray spectra were considered when expanding the sensor network to over 10 detectors centred on St. Thomas' hospital. A 2D heat map was created to illustrate peaks in gamma-ray spectra across multiple detectors in this area over a given time. Gaussian processes (Sousa and Forbes, 2024) and Machine Learning techniques can be used to further probe the spatio-temporal correlation in gamma-ray spectra peaks across the given area.

Through these data-driven techniques, we will demonstrate the extent to which relative peaks in gamma-ray spectra are correlated both spatially and temporally. We will also discuss if a conclusion can be made as to why this correlation occurs, either through environmental reasons or human intervention.

Garrood, J. et al. (2023) 'In-House Distributed RD Detection Algorithm Development' [PowerPoint Presentation] Available at: https://indico.cern.ch/event/731980/contributions/5584919/attachments/2729477/4744422/
(Accessed: 21/01/2025)

Sousa, J.A. and Forbes, A.B., 2024. 'Gaussian processes and sensor network calibration', Measurement: Sensors, p.101512.

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Quantum Dot-Based Scintillators for Neutron Detection

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There is significant interest in developing cost-effective radiation detectors with particle identification capabilities for both fundamental research and industrial applications. While high-resolution detectors can distinguish alpha, beta, and gamma rays, identifying neutrons remains a major challenge. Quantum dots, an emerging technology with diverse potential applications, including scintillators, present a promising solution. In this study, we explore the feasibility of using quantum dots for neutron detection. Novel quantum dots were synthesized, and a custom detection system was designed to evaluate their neutron detection capabilities using the Sheffield fast pulse D-T neutron generator.

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From the Higgs boson to Detector Development for Nuclear Security

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Using a multidisciplinary background ranging from chemistry, materials science and condensed matter through to instrument development for particle physics, our group has developed novel capabilities in radiation detection and sensing that may be relevant for civil nuclear and nuclear security applications. We summarise these developments and reflect on the journey taken from a fundamental science capability to one with a more applied outlook. We will review work funded by AWE, NuSec, NTR-Net and other sources that cover the outcomes of pilot projects and the work of PhD students, alongside UKRI and university funded innovations.

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Advancing Neural Network Training Datasets for Mobile Radioisotope Detection

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The automatic detection and identification of gamma-ray spectra are essential for the deployment of radioactive threat detection networks in urban environments. The Sigma dataset, comprising 1.5 billion gamma-ray spectra collected across London, highlights the necessity of automated systems, such as convolutional neural networks (CNNs), to efficiently analyse vast amounts of spectral data and detect potential threats in real time. However, training such models requires realistic threat spectra, including those from moving sources, which presents an opportunity for further research.

This work details the development of a framework that integrates Geant4 simulations with laboratory experiments, enabling the generation of spectra from moving radioactive sources. A custom-built pulley system was used to move sources at controlled speeds, ranging from 1 to 5 cm/s, through the field of view of a sodium iodide (NaI) detector. Initial studies were conducted on static sources, ^{137}Cs and ^{60}Co, to refine the simulation model. The laboratory setup for the moving source was then comprehensively modelled in Geant4.

The resulting spectra from the moving source demonstrated strong agreement between experimental and simulated data across different speeds and distances. Simulated spectra were then combined with Sigma background data and tested within a Sigma-trained CNN, with strong results reported even at the extremes of the detector field of view. These simulations provide a crucial step toward training CNN-based detection systems for real-world deployment.

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Muon Tracking in an Opaque Scintillator Detector

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The LiquidO Consortium is bringing a novel approach to particle detection by using opaque scintillator to achieve self-segmentation down to the millimetre scale. Opacity via short scattering length stochastically confines scintillation photons close to the point of production and arrays of wavelength-shifting fibres trap and transmit the light to silicon photomultipliers.

At Sussex, we use 64-fibre detector prototypes with a 3.2 mm fibre pitch. The prototypes are characterised with cosmic ray muons, and using a wax-based opaque scintillator a one-dimensional position resolution of 0.45 mm is achieved. This poster will discuss the muon tracking capabilities of a small-scale LiquidO detector, as well as compare the performance of the prototypes with transparent and opaque scintillator.

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WbLS in neutrino detectors for non-proliferation

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Nuclear reactors generate large fluxes of anti-neutrinos. The weakly interacting neutrinos possess the remarkable ability to traverse extensive distances without interacting with matter. This unique characteristic holds the potential to enable remote monitoring of reactors from hundreds of kilometres, thereby serving as a potent tool for nuclear non-proliferation.

The low light yield inherent in pure water poses a challenge in discriminating low-energy neutrinos using a conventional water Cherenkov detector. In contrast, the novel Water-based Liquid Scintillator (WbLS), developed at Brookhaven National Laboratory (BNL) in the United States, combines the advantages of high light yield from liquid scintillator and prompt Cherenkov signal from water. With the implementation of WbLS, it is feasible to enhance energy resolution while preserving the directionality of detection.

BUTTON is a 30-tonne detector, currently under construction at the Boulby underground facility in North Yorkshire, England. Its purpose is to evaluate the performance of various detection media, including pure water, WbLS, and Gd-loading in water/WbLS. One of the BUTTON-PMT modules, constructed at the University of Edinburgh has been sent to BNL. As planned in our NuSec2024 project, the initial test of a BUTTON-PMT in WbLS is currently underway. This report presents updates on the ongoing collaborative effort between the UK and the USA in this field.

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AM-OTech: Antineutrino-Based Reactor Monitoring with LiquidO Opaque Scintillator Technology

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The AntiMatter-OTech (AM-OTech) project, funded by the European Innovation Council (EIC) and UK Research and Innovation (UKRI), is a pioneering initiative in nuclear security and reactor diagnostics. Led by a collaboration of European academic institutions and EDF, AM-OTech explores the use of antineutrinos from nuclear fission as a non-intrusive, real-time probe for monitoring industrial nuclear reactors. The project is based at EDF Chooz-B, a key site in neutrino research.

Traditional reactor diagnostics primarily rely on thermal and neutron flux measurements. Antineutrinos, which are produced in vast numbers during nuclear fission, offer a unique, uninterrupted signature of a reactor's power output and fuel composition. By exploiting antineutrino detection, AM-OTech aims to complement existing reactor diagnostics, enhancing safety and operational efficiency.

At the core of AM-OTech's innovation is LiquidO, an opaque scintillator-based detection technology. Unlike traditional transparent scintillators, LiquidO exploits stochastic light confinement in a highly scattering medium, enabling self-segmentation of the detection volume without dead materials and significantly improving event topology reconstruction and particle identification.

AM-OTech will be deployed at an ultra-near detector site, within 35 meters of the Chooz reactor cores. The 5–10 ton LiquidO detector consists of an opaque scintillator medium embedded with over 10,000 wavelength-shifting fibres, achieving a designed light yield exceeding 200 photoelectrons per MeV. The implementation of LiquidO technology enables precise identification of inverse beta decay (IBD) antineutrino interactions and unprecedented rejection of cosmic-ray-induced backgrounds, achieving a signal-to-background ratio exceeding 100 during reactor operation and remaining above unity even during reactor shutdowns. This exceptional performance allows for high-precision reactor antineutrino flux measurements with uncertainties below 1%, facilitating stringent tests of reactor antineutrino models and enabling validation of reactor predictions during ON-OFF transitions.

Session 1: Source Location and Tracking / 133

Multi-modal Sensing for Radiation Detection and Imaging: From Robot Dogs to City-scale Networks

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Multi-modal sensing continues to enable the development of new and improved radiation detection and imaging capabilities for nuclear security. These advancements range from increased radiological/nuclear domain awareness, to enhanced detection sensitivity and imaging performance in real-world environments. This presentation will discuss the development and application of multi-sensor systems and radiological-contextual fusion methods currently being developed at Lawrence Berkeley National Laboratory, including work taking place in collaboration with UK partners. Future directions, including the use of advanced robotic platforms, autonomy, and greater exploitation of contextual features, will also be explored.

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A Fast Variable Intensity LED Flasher for the Calibration of Cherenkov Experiments

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Our universe offers a natural and unique laboratory to test particle acceleration theories and pave the way towards understanding the violent processes happening in the universe. Gamma ray astronomy has always been at the forefront of unravelling these mysteries. Ground-based imaging telescopes rely on detecting faint, fleeting flashes of Cherenkov light produced when gamma rays interact with Earth's atmosphere. However, the route to such precise measurement demands in-depth calibration —ensuring the encapsulation of spatial and temporal information of every incoming gamma ray particle. Instrumental uncertainties could obscure critical astrophysical signals without a reliable and stable calibration source.

Fast, bright and stable are the three essential features of an ideal calibration system. It should mimic the time profile of Cherenkov light, allowing telescopes to benchmark their detectors with precision. It must cover a broad dynamic range—from single-photon sensitivity to high-intensity flashes —while remaining resistant to environmental variations like temperature drift. Furthermore, a tunable brightness and pulse width extends its usage in different cherenkov light detection environments - from Imaging type telescopes to water cherenkov-based telescopes.

The development and usage of such a system are not new, but the quest is to develop a simple, inexpensive, reliable logic that ensures high-quality calibration results. We have developed a fast, variable-intensity LED flasher system for the Cherenkov Telescope Array(CTA) Small Sized Telescope Camera(SSTCAM). At its core, this system consists of a two-board design: a flasher daughterboard equipped with a high-speed Texas Instruments LMG1025 LED driver and a Maxim DS1023 programmable timing element, and a control board that manages pulse generation, communication, and power. This architecture allows us to generate nanosecond pulses with full-width-at-half-maximum (FWHM) as low as 2 ns, closely resembling the Cherenkov light pulses observed in air showers. The brightness is finely adjustable over four orders of magnitude, making it suitable for both absolute and relative calibration of photodetectors.

The Flasher calibration system has been subjected to extensive laboratory characterization tests, which confirmed its reliability and precision. Lab tests using Silicon Photomultipliers (SiPMs) and Multi-Anode Photomultipliers (MAPMs) demonstrated minimal pulse distortion and excellent stability over prolonged operation. The trigger frequency-dependent intensity variations are limited to just 2%, ensuring consistent performance. A careful analysis of temperature dependence revealed a linear drift of 0.06 V per 10℃, which can be corrected in real time. Beam uniformity tests showed a variation of less than 10% across the focal plane and less than 5 % post beam-modelling-based corrections.

The potential applications of this system extend far beyond gamma-ray astronomy. Any field requiring precise, high-speed optical calibration—such as neutrino observatories, fluorescence spectroscopy, or biomedical imaging—could benefit from this cost-effective, robust alternative to expensive laser-based systems. By providing a reliable and tunable source of fast optical pulses, this LED flasher paves the way for improved calibration standards across multiple scientific and industrial domains.

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Graph Acceleration and Contextual Analysis in Radioactive Source Localisation

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Within the nuclear industry the ability to effectively map and estimate the activity of radiological sources is paramount to ensuring that facilities remain safe, hazardous material is kept secure, and that trust in the nuclear sector from the general public remains high. Activity quantification and source localisation has uses in a wide range of security applications from border security to non-proliferation and decommissioning with signicant variation in scanning times, acquisition areas and activities.
In order to maximise the performance of source localisation across a wide range of scenarios, UC Berkeley utilises MLEM algorithms in conjunction with LIDAR mapping and RGB photogrammetry, this provides additional context to the reconstructions but comes with significant computational overheads. Through a collaboration between the University of Liverpool and UC Berkeley a scoping study was performed to evaluate the use of graph acceleration and contextual analysis to produce a more efficient and informative description of a scanned environment. These hierarchical descriptions provide more efficient descriptions of geometrical objects for faster localisation and quantification of hazardous radioactive material and through the use of AI can improve detection accuracy and quantification through improved contextual analysis.
It is hoped that this work will further improve the capability of scene data fusion and make it a more easily accessible option to the nuclear security sector, further accelerating the use of these technologies in both the US and UK.

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Long range imaging system for alpha emitters

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Short-lived, highly radioactive materials, such as plutonium, are prevalent in the nuclear industry. These substances, often alpha emitters, pose significant detection challenges as alpha particles travel only a few centimeters in air, depending on their energy. Despite their limited range, these materials are extremely hazardous; if ingested or inhaled, they can cause serious health risks, potentially leading to cancer and death. A notable example is polonium-210, one of the most radiotoxic substances globally, infamously used in the assassination of Alexander Litvinenko. Therefore, detecting such alpha emitters is crucial for both industrial and public safety, necessitating the development of technology to detect and monitor alpha-emitting radionuclides from a distance.

Current methods for alpha particle detection, such as hand-held ionization chambers, require direct interaction with alpha particles. These methods necessitate proximity, often millimeters from contaminated areas, making the approach labor-intensive and time-consuming, increasing contamination risks and dose uptake for workers, and leading to higher costs for decontaminating or replacing detectors.

We have developed a prototype alpha-imaging camera capable of detecting alpha emitters from meters away by capturing UV light emitted when alpha particles collide with nitrogen molecules in the air, a phenomenon known as radioluminescence. The system utilizes a deep-cooled CCD camera and a specially designed lens system with a low f-number to maximize signal intensity. Additionally, we have developed a novel sandwich filter system to effectively reject ambient background and a background subtraction algorithm to further enhance sensitivity, especially in environments with UV background. The design of the alpha camera and process algorithm is patented. The system is user-friendly and rapidly deployable, weighing 3 kilograms and fitting into a suitcase, with setup achievable within 10 minutes by a single operator. This capability significantly reduces radiation exposure risks and accelerates the monitoring process, potentially lowering decontamination and

downtime costs. Furthermore, the camera's high-resolution CCD technology and its ability to integrate UV fluorescence with RGB imaging provide millimeter-level accuracy in contamination source identification. It adapts to various environmental conditions, from under sunlight to controlled indoor settings. Integration with existing monitoring infrastructures, such as gloveboxes and robotic platforms, enhances its utility and market appeal. Our device achieves unparalleled sensitivity for alpha detection: in environments without high UV, like inside a room lit by LED, the detection limit is 3 kBq at 1 meter in 10 minutes, while under sunlight, it is 3 MBq at 1 meter in 10 minutes. We have tested with real alpha sources under various conditions, including sunlight.

Our device improves safety and efficiency in hazardous environments by enabling workers to conduct alpha surveys from a safe distance or monitor areas remotely, thus avoiding direct exposure to high-radiation zones where human entry is restricted. This aligns with regulatory requirements and offers an ideal solution for remote operation, significantly reducing labor and equipment costs. Unlike traditional detectors that require proximity to contamination and frequent decontamination and replacement, our device operates without direct contact with alpha particles, allowing for permanent installation and minimal maintenance.

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Hyperspectral Imaging Inspection of Nuclear Assets through Leaded Glass Windows

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Inspection of nuclear assets and structures is fundamental towards security in the nuclear industry, where the use of sensor technologies can play a key role in the early detection of corrosion, leaks, degradation, defects or other anomalies, reducing nuclear threat and enhancing safety. However, deploying and operating sensors within the nuclear industry presents significant barriers. One particularly challenging scenario arises when assets and structures are enclosed within protective rooms for safety, with leaded glass windows to allow visual inspection. In such cases, many sensors struggle to capture data effectively from outside due to the partial transparency of these windows, which obstructs their vision, resulting in the need to access the rooms, with increased costs and safety implications. The objective of this project was to evaluate the case in which hyperspectral imaging (HSI), a promising technology being progressively introduced in the industry, is captured through a leaded glass window. A real sample of this type of window, provided by the National Nuclear Laboratory (NNL), was used in the experiments to gain a deeper understanding of how this leaded glass impacts the sensor data. Experiments evaluated the effect of this window on the captured HSI data in three different spectral ranges (visible, infrared and ultraviolet), and explored how artificial intelligence can address this challenge through data recovery techniques.

Session 2: New Detectors and Instruments / 138

Development of Polycrystalline Solid-State Radiation Detectors

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Solid-state gamma-ray detection devices have traditionally relied on single crystal materials due to their reduced crystallographic and bulk defect density, and resultant charge transport properties. Development of new, room-temperature capable semiconductors has been ongoing for decades, and continuously experiences challenges in costly fabrication and scaling towards larger area devices. In addition, many semiconductor materials that are currently being investigated suffer from environmental degradation and have limited field application. Polycrystalline materials offer several potential benefits, both in more rapid material discovery, but also in enabling larger device areas and environmental robustness. This presentation overviews ongoing materials investigations in developing polycrystalline materials and evaluating their application as solid-state gamma-ray detectors. The underlying hypothesis of this work focuses on reducing grain boundary density and defect concentration in an effort to reduce bulk electron-hole recombination, enabling more efficient charge extraction. This hypothesis is tested in two host material systems, CsPbBr3 and emerging wide band gap oxide perovskites. Novel manufacturing processes are investigated and developed for polycrystalline CsPbBr3, with an emphasis on composition and phase control, and maximizing grain size. These microstructural trends are then linked to alpha particle and gamma-ray spectra. The manufacturing processes developed are then used to investigate new wide band gap materials, including NaTaO3. Materials processing development is directly related to microstructure refinement, and subsequent gamma-ray spectra. Initial results are promising and suggest that polycrystalline devices have thin active volumes, likely due to grain boundary recombination. Future development of materials and processes are on-going and may lead to further reductions in energy resolution and more efficient detection of high-energy photons.

Session 3: Sigma Data and Algorithm Studies / 139

NTRnet Updates

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We will present a summary of current events and opportunities from NTRnet.

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Final Remarks

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An overview of the NuSec network and collaborations