NuFor

Nuclear Forensics

10–12 October 2023

Mary Ward House Conference & Exhibition Centre, London, UK

NATIONAL NUCLEAR LABORATORY

AWE

IOP Institute of Physics

Programme

Tuesday 10 October

08:30 Registration

09:00 Welcome and Introduction
Roy Awbery

Session I
Chair: Roy Awbery

09:20 The Amazing Opportunities in the Nuclear Sector and why NuFor is so important
Sue Ion

10:00 Refreshment Break

Session II:
Chair: Roy Awbery

10:30 Nuclear Security in the 21st Century: A perspective from LLNL
Dr. Kimberly Budil

11:00 Myth vs Reality or is it Reality vs Myth?
Dr Mansie Iyer

11:30 The USG Approach to Advancing Nuclear Forensics Capabilities
Grant Ford

12:00 Lunch and Conference Photo

13:15 Flash Poster Presentations

Session III:
Chair: Karen Kennedy

13:30 New Publications and Workshop of the International Atomic Energy Agency on Nuclear Forensic Science (Online)
Eva Szeles

14:00 The FBI and Nuclear Forensics – Success Through Collaboration
Kevin Swearingen

14:30 Nuclear Forensics - Science Support to a Nuclear Security Event
Mr John Simm

15:00 Refreshment Break

15:30 Panel Discussion I: Addressing Global Nuclear Forensic Expert Attrition with a Pipeline Fellowship?
Dr. Adam Stratz

16:30 Poster Session

Wednesday 11 October

Session IV:
Chair: Chris Brook

09:00 Skills for the Nuclear Enterprise
Rebecca Weston

09:30 Radiological and Nuclear Security in the Home Office
Shaun Hipgrave

10:00 Refreshment Break

Session V:
Chair: Matt Gilbert

10:30 Defence Nuclear Opportunities
William Lee

11:00 Nuclear Threat Reduction and Forensics at AWE
Nick Ashwood

11:30 Where Energy Security Meets National Security: A View from the Department for Energy Security and Net Zero
Jonathan Virgo

12:00 Lunch

Session VI:
Chair: Lauren Johnstone

13:30 The Materials Research Facility at UKAEA – Capability, Case Studies and Careers
Dr Philip Earp

14:00 Women in Nuclear's role in securing the future of the industry
Dr Leanne Cowie

14:30 Enabling the Nuclear Workforce
Ms Alanna Downing

15:00 Refreshment Break

Chairs: Roy Awbery and Jeremy Edwards

15:30 Panel Discussion II: Shaping and Securing the Future of Nuclear Security and Forensic Research

19:30 Conference Dinner

Thursday 12 October

09:00 Conference Keynote reflections and Introduction to the Science and Future of Nuclear Forensics
Paul Howarth

Technical Talks: Session I
Chair: Peter Hiller and Caroline Pyke

09:30 Alpha Spectrometry to Characterize Uranium for Nuclear Forensics Education
Stephen LaMont

09:50 Developments in the Radiochronometric Analysis of Actinide Materials for Nuclear Forensics
Dr Matthew Higginson

10:10 Refreshment Break

Technical Talks: Session II
Chairs: Tom Scott and Matthew Higginson

10:40 AMS-UK: Providing 10^{-14} g/g actinide abundance and isotopic ratio analysis for nuclear forensic applications
Patrick Collins-Price

11:00 Simultaneous measurements of Mo, W, and U isotopes by RIMS in tagged uranium with application to Intentional Forensics
Ziva Shulaker

11:20 Intentional Forensics: Quantitative and qualitative results from major element doping of DU metals
Dr. Joseph Boro

11:40 Lithium and Uranium Sampling and Preservation Methods at the Y-12 National Security Complex
Jason McCall

12:00 Lunch

Technical Talks – Session III
Chairs: Simon Middleburgh and Luke McGarry

13:00 Plutonium Processing Science at Pacific Northwest National Laboratory
Dr. David Meier

13:20 Identifying morphological trends in plutonium (III) oxalate
Cody Nizinski

13:40 Inverse Prediction Methods for Inferring Plutonium Processing Conditions
Dr. Madeline Stricklin

14:00 Neutron capture in rare earth elements: A developing technique for nuclear forensics
Gregory A. Brennecka

14:20 Refreshment Break

Technical Talks: Session IV
Chairs: Giles Aldrich-Smith and Stephen LaMont

14:50 Multi-element isotope ratio analysis for nuclear material in the environment with resonance ionization mass spectrometry (RIMS)
Darcy Van Eerten

15:10 A prototype Lab on Chip Device for in situ detection for difficult to measure Radionuclides
Sarah Lu

15:30 Microfluidic Separations for Field-Deployable Nuclear Forensics
Kevin Glennon

15:50 An Introduction to Nuclear Industrial Archaeology
Erin Holland

16:10 Closing Remarks
David Smith

Posters

P1: New method of thermal neutrons imaging using a fast optical camera
Tianqi Gao

P2: A Non-Rigid Airship System for SLAM in Nuclear Environments: An Alternative Approach to Multi-Rotor UAVs
Miss Shanqi Song

P3: Organic semiconductor radiation detectors for alpha and neutron detection
Mr Aled Horner

P4: Enhancing Nuclear Security: Leveraging Non-Negative Matrix Factorization for High Sensitivity Threat Detection with Small Volume Gamma Detectors
Sam Fearn

P5: Organic Field Effect Transistors as radiation detectors
Mr Choudhry Amjad

P6: The problematic assumption of homogeneity
Caroline Pyke

P7: Humanitarian Landmine Detection Method: Ensuring Human Safety, Interrogation Efficiency, and Accuracy
Dr Mahmoud Bakr

P8: Passive Radiological Inspection of Shipping Containers using a UAV-Mounted Scintillator Detector
Euan Connolly

P9: Forensic Signatures of Local and Global Plutonium Contributions to Environmental Radioactivity
Argaia Madina

P10: Exploring the role of the stable oxygen isotopic signature in nuclear forensics.
Paulina Baranowska

P11: Morphology and Particle Size Round Robin : A collaborative exercise to test methods and applications of microscopy to nuclear forensics
Stuart Dunn

P12: Development of automated microfluidic system for actinide analysis
Mr Shuang Yu Han

P13: Recent developments of in-situ micromechanical tests for nuclear forensics
Nicholas Randall

P14: In-Situ Marine Radiation Monitoring Using a Novel Detection System for Nuclear Emergency Response: Preliminary Evaluation
Mohammed Al-Hijji

P15: Sediment Preparation and Thin Sectioning Technique for Analysis of Uranic Materials in Magnox Sludge
Philip Hutchinson

P16: Consortium for Nuclear Forensics: A United States University Based Research and Training Program
Ken Czerwinski

P17: Development of PuO2 LG-SIMS particle standards via thin filmpolymer assisted deposition
Alexa Hanson

P18: Regional analysis of neutron/gamma figure-of-merit in scintillator volumes using a multi-anode photomultiplier tube
Patrick Collins-Price

P19: An Intentional Forensics Approach to Nuclear Material Provenance Assessment
Dr. Naomi Marks

P20: Investigation of an end-to-end neural architecture for image-based source term estimation
Dr Abdullah Abdulaziz

P21: Rapid characterization of actinide abundances and isotopic compositions by HR-ICP-MS for nuclear forensics
Greg Brennecka

P22: An Overview of Galaxy Serpent V (GSV)
Ms Alice Shilling

The Amazing Opportunities in the Nuclear Sector and why NuFor is so important

Invited Talk I - **Dame Sue Ion**, October 10, 2023, 09:20 - 10:00

From fuel cycle, reactors for energy, transport, medicine and defence, nuclear forensics plays a vital role in ensuring the overall safety and security of the nuclear sector. The talk will show how the role of nuclear energy is expanding globally with a significant resurgence in the UK. It will highlight the role nuclear forensics plays in all aspects of the fuel cycle and in global security. It will include some personal insights and career history and emphasise the breadth of opportunities available to an increasingly diverse workforce.

Nuclear Security in the 21st Century: A perspective from LLNL

Invited Talk II – **Dr Kim Budil** (LLNL), October 10, 2023, 10:30 - 11:00

The international security environment today is extremely challenging and rapidly changing. Russia and China continue to modernize and expand their nuclear forces. Russia's withdrawal from existing treaties and invasion of Ukraine have severely undermined the norms and international frameworks that have underpinned global stability for decades. Add to this mix the increasing demand for energy around the world and a changing climate driving interest in carbon-free, baseload generation putting nuclear power at the fore. Finally, a wide range of emerging and disruptive technologies such as artificial intelligence and the increasing role of private sector players in key domains like cyber and space are lowering the barriers to access to technology once controlled by state actors. Drawing on examples from LLNL, this talk will highlight the ways in which the U.S. has used advanced science and technology along with strategic international partnerships and collaborations to foster global stability and security.

This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344. LLNL-MI-853283

Myth vs Reality or is it Reality vs Myth?

Invited Talk III – **Dr Mansie Iyer** (NNSA), October 10, 2023, 11:00 - 11:30

The U.S. Department of Energy/National Nuclear Security Administration (DOE/NNSA) Office of Nuclear Smuggling Detection & Deterrence (NSDD) builds capacity of partner countries to detect, disrupt, and investigate smuggling of nuclear and radiological materials that could be used in acts of terrorism. Part of this mission is to support partners in using nuclear forensics to identify and deter material out of regulatory control. My presentation will discuss how nuclear forensics personnel under the NSDD umbrella deal with international capacity building in nuclear forensics, its challenges and limitations, and work-life practices.

The USG Approach to Advancing Nuclear Forensics Capabilities

Invited Talk IV - **Grant Ford** (NNSA), October 10, 2023, 11:30 - 12:00

The U.S. Department of Energy/National Nuclear Security Administration (DOE/NNSA) Office of Nuclear Forensics, with our interagency partners, is responsible for developing and maintaining the operational capabilities in nuclear forensics. The U.S. government has consistently stated, through multiple NPRs, the Nuclear Security Summit series, and other venues, that nuclear forensics is a critical component of nuclear security. Credibility in nuclear forensics rests on our scientific ability to identify, and hold accountable, any perpetrators involved in any nuclear incident. To quote the 2021 U.S. National Academy of Sciences study on nuclear forensics “Nuclear forensics programs are a critical component of deterrence against trafficking nuclear materials and unclaimed nuclear attacks. A declared and credible nuclear forensics capability helps assure that the perpetrators of any unclaimed attack or attempt will be discovered and subject to reprisal.” Potential perpetrators must perceive that nuclear forensic capabilities will be used to hold them accountable and thus deter them such actions in the first place.

New Publications and Workshop of the International Atomic Energy Agency on Nuclear Forensic Science

Invited Talk V - **Eva Szeles** (IAEA) Online, October 10, 2023, 13:30 - 14:00

Nuclear forensic science has grown in recent decades and has become an influence worldwide. In the future, it is crucial to build a close connection to radiological crime scene management, to incorporate both in existing national nuclear security response systems and work in close cooperation with all relevant stakeholders. It is also essential to have a better understanding of the required equipment and national resources necessary for nuclear forensic science and the sustainability as a key area. The IAEA has recently published a new non-serial publication, with the title of “Establishing a Nuclear Forensic Capability: Application of Analytical Techniques” (IAEA-TECDOC-2019). This document provides technical information that describes the application of specific methods, analytical techniques and technical expertise used for nuclear forensic analysis in support of investigations. This publication covers the conduct of a nuclear forensic examination in the context of commonly used techniques for analysing the physical, chemical, elemental, and isotopic properties of nuclear or other radioactive material found out of regulatory control. Further IAEA documents will be published soon, a Technical Document on the Outcomes of the IAEA Technical Meeting on Nuclear Forensics was held in Vienna in 2022 and the recently closed IAEA Coordinated Research Project on “Applying Nuclear Forensic Science to Respond to a Nuclear Security Event”. A new program was developed: the Integrated Workshop on Radiological Crime Scene Management and Nuclear Forensics, will be held at the IAEA Training and Demonstration Centre in Seibersdorf. The purpose of the workshop is to provide awareness, as an introduction and information on the connection and collaboration between radiological crime scene management (RCSM) and nuclear forensics (NFS) and highlight the necessity for scientific support to RCSM and how NFS is supporting prosecution. The workshop is built on hypothetical but realistic scenarios and will contain mainly hands-on and interactive elements.

The FBI and Nuclear Forensics – Success Through Collaboration

Invited Talk VI - **Kevin Swearingen** (FBI), October 10, 2023, 14:00 - 14:30

Nuclear forensics is typically viewed as the analysis of special nuclear material and its fission products. Within law enforcement, nuclear forensics also includes any other radiological material and any conventional forensic evidence that may exist on the material or any other contaminated items. Forensic Examiners (FEs) from the Scientific Response and Analysis Unit (SRAU) within the Federal Bureau of Investigation (FBI) Laboratory at Quantico, Virginia are responsible for the examination of nuclear or radiological material and any other radiologically contaminated evidence. Partnerships within the FBI and across the United States (US) government are utilized to conduct these examinations. Several different facilities may be used depending on the specific characteristics and hazards of the evidence. At these facilities, the FBI's Hazardous Evidence Analysis Team (HEAT) is deployed to conduct conventional forensic examinations on any contaminated evidence under the direction of the SRAU lead FE. Two recent cases will be discussed to provide examples of these collaborations in action.

Nuclear Forensics - Science Support to a Nuclear Security Event

Invited Talk VII - **John Simm** (Met Police), October 10, 2023, 14:30 - 15:00

Within the PURSUE strand of the UK's Counter Terrorism Strategy (CONTEST), is the ability for law enforcement to investigate terrorist activity [1]. The presence of nuclear or other radioactive material at a crime scene presents several challenges for law enforcement, particularly around the ability to process the scene, recover items of investigative value and subsequent scientific examination. The finding of such material has the potential to create public fear disproportionate to the actual threat posed by the material and media companies will sensationalise such finds adding to those fears. To resolve these challenges the UK (UK) has ensured law enforcement can investigate a nuclear security event through the adaptation of procedures and processes and the development of specialist capabilities for use in the scene and in the laboratory; This extends beyond conventional Forensics, recovery of finger marks etc. in a laboratory known as the Conventional Forensic Analysis Capability (CFAC) and a Mobile Forensic Analysis Capability (MFAC) to Nuclear Forensics (NF) interpretation and presumptive identification though to categorisation of material using Technical Nuclear Forensics (TNF) as it is currently known. Law Enforcement needs to obtain evidence of initial characterisation through to categorisation and in some cases the linking of material to material, people to places, other people, or things in support of criminal prosecutions by providing an opinion on its makeup, origin, history and use.

UK law enforcement has taken well established crime scene management procedures and through collaborative partnership with the relevant scientific technical authorities has adapted these procedures to enable use in a radiological crime scene and subsequent laboratory submissions. As a result, specialist forensic officers supported by scientists can safely process the crime scene, including the recovery of items contaminated with nuclear or other radioactive material outside of regulatory control and samples of the material itself. To enhance the scene-based forensic science activities, law enforcement work with the Atomic Weapons Establishment (AWE). Work is always ongoing to refine and develop this capability.

Technical Nuclear Forensic techniques are conducted in laboratories designed for other purposes and may require the verification and validation of the methods associated with the different forensic science activities. As a result, validation plans may need to be developed, and subsequent studies initiated.

The current CT RN response capabilities are complemented with exercises that test the ability for AWE to receive items from scene and support the examination requests from the leading law enforcement entity. All these activities ensure that the scientific support provided by AWE to an investigation are to the standard expected by the UK Criminal Justice System and focus on answering the specific questions posed by Law Enforcement.

This presentation provides an overview of UK law enforcement's ability to recover and exploit RN contaminated evidence through joint law enforcement/science activities at the scene and in the laboratory in response to investigating a nuclear security event.

[1] CONTEST – The UK's Strategy for Countering Terrorism, Cm 9608, Her Majesty's Government, Her Majesty's Stationery Office (2018).

Panel Discussion I: Addressing Global Nuclear Forensic Expert Attrition with a Pipeline Fellowship

Dr. Adam Stratz (US National Nuclear Security Administration) October 10, 2023, 15:30 - 16:30

Countries around the world continue to establish, build, and refine national nuclear forensics programs through national response plans, laboratory equipment procurement, and training. However, many countries continue to experience difficulty in hiring, maintaining, and training nuclear forensics experts, a necessary component of perpetuating a national program. To that end, the U.S. National Nuclear Security Administration's (NNSA) Office of Nuclear Smuggling Detection and Deterrence (NSDD) developed a fellowship program to solicit, fund, and establish domestic hiring mechanisms for countries at risk of declining expertise. NNSA virtually presented this emerging fellowship concept at the 2021 NuFor conference and has since awarded fellowships to four students from Armenia, Serbia, Tajikistan, and Moldova. The fellowship funds master's level education in a subject relevant to nuclear forensic science, a monthly stipend, a U.S.-based virtual mentor, funding to attend two international nuclear forensics conferences per year for networking and research presentation purposes and works with in-country hiring authorities to ensure the fellows are hired for at least two years in their country of residence. This panel brings the four students together to give an account of their experience so far.

Skills for the Nuclear Enterprise

Invited Talk VIII - **Rebecca Weston** (MOD), October 11, 2023, 09:00 - 09:30

Military and civilian nuclear enterprises can benefit each other by sharing knowledge, developing shared capabilities, and investing together in the next generation of forensic experts and core skills useful to many capabilities required of a responsible nuclear enterprise.

Radiological and Nuclear Security in the Home Office

Invited Talk IX - **Shaun Hipgrave** (UK Home Office), October 11, 2023, 09:30 - 10:00

The Home Office's vision is for a safe, fair, and prosperous UK. The priority outcomes for the Home Office include reducing crime, strengthening homeland security, enabling legal movemennt of people and goods, and tackling illegal migration.

Over the last few years, threats to the homeland have grown and diversified. Economic crime and cyber-crime account for more than half of all crime, the terrorist threat is enduring and evolving, and State actors have accelerated their efforts to undermine our democracy and way of life. The Home Office's Homeland Security Group (HSG) mission is to reduce homeland security risks to the UK's people, prosperity and freedoms.

Within HSG, we have established a dedicated Radiological and Nuclear (RN) Security unit, whose mission is to deliver enhancements across the UK's end-to-end system for domestic nuclear security. We operate a range of capabilities across 'defensive layers' which each substantially reduce the risk of a successful radiological or nuclear attack. This covers border and inland detection, specialist response arrangements, specialist support to investigate authorities, established preparedness arrangements against a successful attack, and a cross-cutting Research and Development programme underpinning all endeavours.

"Nuclear Forensics" within the Home Office is focused on delivering an operational capability, with guaranteed arrangements in place to support investigative authorities and intelligence agencies to establish the malicious use of RN materials, or intent to do so, and attribute materials linking them to sources, individuals, places and events. A key part of this is leveraging the knowledge, experience and capabilities that exist across the UK's civil and defence nuclear sectors.

Shaun Higrave (as Director for Protect, Prepare, CBRNE and S&T within Home Office) will present on the Home Office's approach to strengthening Nuclear Security in the UK, and specifically highlight the importance of Nuclear Forensics as part of this system.

Defence Nuclear Opportunities

Invited Talk X - **Bill Lee** (MOD CSA), October 11, 2023, 10:30 - 11:00

The UK's defence and civil nuclear sectors are hugely important – for our security, our energy needs and our prosperity. That's why the Government have made ambitious commitments through the Integrated Review Refresh and Powering Up Britain, which will help to deliver on our priority to grow the economy, while also sharpening our technological edge and supporting investment across the whole of the UK. The need for significant expansion in capability in both civil and defence nuclear sectors will require that where appropriate they will increasingly work together in areas such as skills and training, and testing and facilities infrastructure. Nuclear Threat Reduction programmes have evolved with civil/defence collaborations in place and provide an exemplar of how such collaborations can work. This talk will highlight research opportunities in the UKs defence nuclear sector with an emphasis on areas where links with the civil sector can be strengthened.

Nuclear Threat Reduction and Forensics at AWE

Invited Talk XI - **Nick Ashwood** (AWE), October 11, 2023, 11:00 - 11:30

For over 70 years the Atomic Weapons Establishment has manufactured and maintained the UK's Nuclear Deterrent as well as providing expertise in UK Nuclear Threat Reduction activities. These missions are underpinned by combining world class STEM expertise with unique capabilities and facilities that AWE can provide. This presentation sets out how AWE supports the UK's international treaty obligations, national security and police and military operational responses through a variety of forensics techniques and the scientific challenges that need to be overcome.

Where Energy Security Meets National Security: A View from the Department for Energy Security and Net Zero

Invited Talk XII - **Jonathan Virgo** (DES&NZ), October 11, 2023, 11:30 - 12:00

The challenges we face in nuclear security are changing shape.

The nuclear renaissance we see today promises novel means by which to produce energy, renewing demands on policymakers to keep up with the pace of change to take full account of what today's decisions mean for tomorrow.

Jonny Virgo leads Nuclear Materials Security at the Department for Energy Security and Net Zero. He will explore how we can advance nuclear security as an enabler to our future nuclear ambitions; not as a blocker to innovation, but to enhance energy security and national security symbiotically.

This talk will cover what we can do to tackle a perennial challenge facing the nuclear sector: finding the balance between the pace to innovate and the duty to protect.

The Materials Research Facility at UKAEA – Capability, Case Studies and Careers

Invited Talk XIII – **Dr Philip Earp** (UKAEA), October 11, 2023, 13:30 - 14:00

The Materials Research Facility (MRF) at UKAEA is a medium active facility working with beta – gamma emitting materials and is positioned in the UK radioactive research field bridging between high active facilities and universities. Irradiated materials are sent to the MRF for scientific evaluation into their material properties and any specific effects of radiation damage. As Culham Science Centre is a non-licensed site, it is much easier for users to visit the MRF and perform their experiments compared to the more stringent security protocols of a nuclear licensed site.

The facility has a wide range of scientific equipment covering mechanical, microstructural and thermophysical characterisation, in addition to a suite of sample preparation equipment for non-radioactive and radioactive material. Scientific Equipment is integrated into Hot Cells and shielded Research Rooms, with associated nuclear ventilation and infrastructure to enable experiments to be performed remotely from the Control Room. A team of Equipment Scientists is available to operate and maintain the equipment, as well as to train users. Whilst the focus of UKAEA's core research is towards the delivery of fusion energy, the capabilities of the MRF in handling radioactive materials lend themselves well towards research relating to fission energy, particle accelerators, and nuclear forensic engineering.

In this presentation I will give an overview of the MRF's capability, including several specific case studies relevant to nuclear forensics. I will also give examples of different careers that are possible within our department, and the route that I took to get into my current role.

Acknowledgements: UKAEA's Materials Research Facility has been funded by and is part of the UK's National Nuclear User Facility and Henry Royce Institute for Advanced Materials

Women in Nuclear's role in securing the future of the industry

Invited Talk XIV - **Dr Leanne Cowie** (WiN), October 11, 2023, 14:00 - 14:30

Having been interested in the STEM field from an early age, Dr Leanne Cowie is currently the Strategy Director for WiN, helping build and execute a strategy to improve diversity at a senior level within the UK nuclear sector.

She will talk about her career path to date, including her entry into the nuclear energy industry following a successful academic career in geophysics, and will highlight the wide range of projects she has been involved in. In her time since joining AtkinsRéalis, she has been involved in projects across the nuclear sector, including new build, fusion and decommissioning efforts. Leanne has also been seconded to BEIS to build the nuclear programme at COP26 and has worked extensively with GBN on government policy for increasing the amount of nuclear power in the UK energy mix.

Leanne will cover how she became involved with WiN, and the fantastic network that it provides – a driven team of inspiring volunteers who help to build a community of support. The opportunities, networking events and engagement that WiN provides at all levels of the nuclear sector is invaluable in developing her working relationships, and she will highlight how this has helped in her professional growth and career progression.

She believes that gender balance is crucial at a senior level within our industry, improving thought leadership and further championing diversity in the talent pipeline. She will share how WiN and the wider industry can help inspire both early-career professionals and those leaving school and college to become as passionate about the journey to NetZero as she is.

Enabling the Nuclear Workforce

Invited Talk XV – **Ms Alanna Downing** (AWE), October 11, 2023, 14:30 - 15:00

Winning presentation at the Nuclear Institute Young Generation Network Speaking Competition Central England Region, and to be presented at the National Competition in Sept 2023

We have all heard of diversity and inclusivity in the workplace, but what does it mean and why is it important?

Diversity is any variation that can be applied to differing groups and people, such as religion, sexual orientation, and ethnicity. Whereas inclusivity is how these differences are enabled within a workforce. They are interconnected entities but differing in one is innate and one is applied.

In 2020 around 22% of the UK population was deemed disabled, whilst 15% had a diagnosed neurodiversity. However, in the UK, only 50% of disabled people and 21% of autistic people are employed, according to the Office for National Statistics. This compares to an 81% employment rate within the general population, highlighting the difficulties faced by disabled and/or neurodiverse individuals in finding work.

So, how does this affect the nuclear industry? It is reported that there are multiple benefits to having a diverse workforce, including having a wider talent pool for recruitment, more innovation, and better decision-making abilities. This talk aims to discuss the challenges surrounding diversity and highlight the difference between equality and equity. It will underline how the nuclear industry can help staff achieve their potential regardless of these challenges.

Conference Keynote reflections and Introduction to the Science and Future of Nuclear Forensics

Opening Remarks – **Paul Howarth** (NNL), October 12, 2023, 09:00 - 09:30

Paul Howarth provides comments on the keynote speeches and panel sessions, the importance of investment in the next generation of scientists through academia, national laboratories, and the wider nuclear enterprise. In Paul's role as CEO of the National Nuclear Laboratory, he will pass comment on his own career journey, the role of the National Nuclear Laboratory and the importance of science before introducing the technical sessions for the closing day of the conference.

Alpha Spectrometry to Characterize Uranium for Nuclear Forensics Education

Stephen LaMont[1], Michael Harris[1], Lisa Hudston[1], and Zsuzsanna Macsik[1]
[1]Los Alamos National Laboratory, USA

Nuclear forensic examination plans are typically designed to characterize the key attributes of a nuclear material that aid investigators identifying the material and assessing its provenance. For example, isotopic compositions are frequently measured to provide insights into a material's intended use. Similarly, model age measurements using radiochronometry can constrain a material's production and process history. Highly sophisticated mass spectrometry techniques are often used to determine the isotopic composition and model age of a material. However, in the case of uranium, alpha spectrometry is a reasonable alternative for isotopic and model age measurements and is a much more accessible method in many countries that do not have modern mass spectrometers capable of characterizing radioactive materials. While not as precise as mass spectrometry, quality alpha spectrometry results for uranium isotopic composition and model age are accurate, defensible, and sufficiently precise for presentation as evidence in judicial proceedings. Alpha spectrometry is also a technique accessible at many universities where laboratory experiments can introduce students to important nuclear forensics measurements and data assessment techniques. A properly designed lab to determine uranium isotopic composition and the Th-230/U-234 model age not only introduces students to nuclear forensic examinations but helps solidify important fundamentals of radiochemistry including sample dissolution and aliquoting, isotope dilution methods, radiochemical separations, electrodeposition, alpha spectrometry, data reduction, and uncertainty estimation. This presentation will focus on the development of a laboratory module to teach these concepts, including the development and validation of methods to determine uranium isotopic composition and model age. Also included will be a discussion of method limitations, for example the difficulty in quantifying U-236 and differences in measurement precision compared to modern mass spectrometry, as well as measurement of ultra-trace U-232, which can only be determined using alpha spectrometry.

Developments in the Radiochronometric Analysis of Actinide Materials for Nuclear Forensics

Dr Matthew Higginson[1], Dr James Dunne[1], Mr Sam Cross[1], Dr Chris Puxley[1], Miss Alice Shilling[1], Dr Steve Lamont[2], Dr Joanna Denton[2], Dr John Engel[2], Dr Amy Gaffney[2], and Dr Christine Chen[2]
[1]AWE, UK, [2]LLNL, USA

Radiochronometry is a key technique applied as part of the nuclear forensic analysis toolkit to answer temporal questions for law enforcement. A variety of model ages can be produced from the measurement of decay products in nuclear materials relying on rapid radiochemical methodologies.

We will present recent advancements in the radio-chronometric analysis of actinide materials with recent examples of interlaboratory comparisons to address key challenges in uranium materials radiochronometry as well as reporting the development of new chronometric tools based on the measurement of the Ac-He chronometer pair.

AMS-UK: Providing 10^{-14} g/g actinide abundance and isotopic ratio analysis for nuclear forensic applications

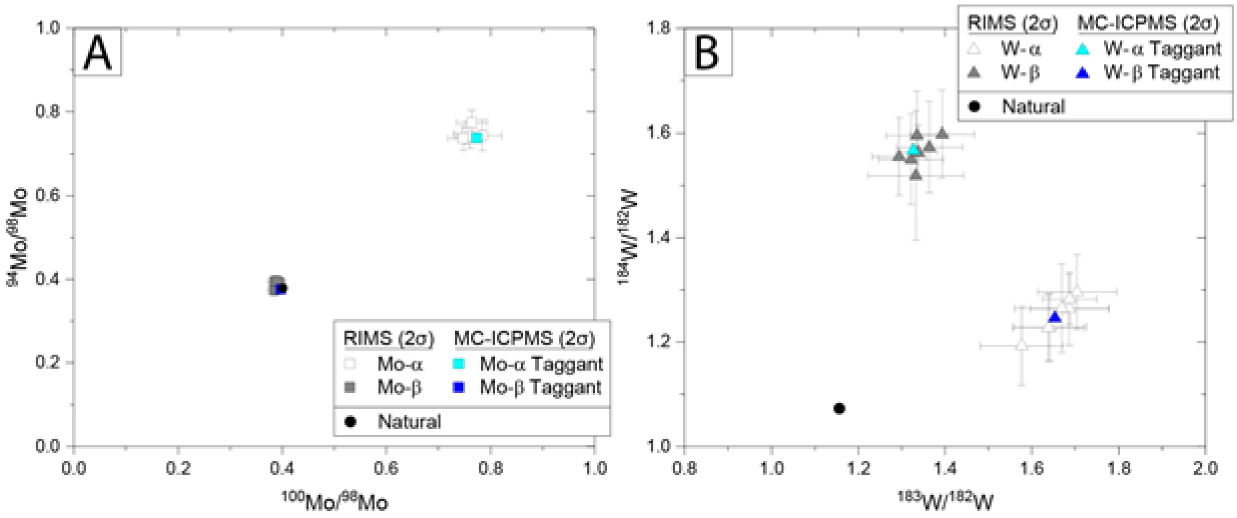
Patrick Collins-Price[1], and Prof Malcolm Joyce[1]
[1]Lancaster University, UK

The AMS-UK facility, situated at Lancaster University, is an advanced, compact Multi-Isotope Low Energy Accelerator (MILEA) Mass Spectrometer capable of quantifying trace actinide levels at 10^{-14} g/g levels of sensitivity, and the only such machine in the UK with this capability. AMS has a demonstrated capability to measure 55 different radionuclides at these exceptionally low concentrations of femtogram-picogram per gram levels, with a particular focus on the actinides. Leveraging small sample masses (1-5 g) allows multiple repeats, ensuring robust results. The mission of AMS-UK as part of the UK National Nuclear User Facility supports the decommissioning and development of nuclear fission sites across the UK. A paramount objective is to investigate baseline actinide concentrations in various environmental matrices, initially concentrating on soil samples, and to provide capability to UK decommissioning for the analysis of environmental contamination and special nuclear materials (SNMs) for both forensics and safeguarding purposes. AMS-UK's research applications encompass an array of disciplines: environmental monitoring for nuclear installations, fallout material surveillance, ecological sample measurements, hydrology, nuclear physics, pollution assessment, age-dating, and materials analysis. Building on studies conducted at the prototype MILEA at ETH Zürich focused on plutonium that used the facility's high forensic sensitivity to distinguish local contamination (reactor operations) from global contributions (weapons test fallout), this capability is currently being applied to environmental assessment of anthropogenic actinides to inform clean-up strategies, the conclusions of which will be reported. AMS-UK's capabilities have much to offer to nuclear forensic applications in determining the providence and enrichment level of SNMs by isotopic ratio analysis. AMS-UK is currently open to applications for access by external users, university researchers, and industry partners.

Simultaneous measurements of Mo, W, and U isotopes by RIMS in tagged uranium with application to Intentional Forensics

Ziva Shulaker[1], Manuel Raiwa[1], Mike Savina[1], Brett Isselhardt[1], and Naomi Marks[1]
[1]Lawrence Livermore National Laboratory, USA

Traditional nuclear forensics approaches leverage a number of isotope ratio measurements for characterizing nuclear forensics signatures in fuel cycle materials. Recent research and development activities have focused on adding isotopically perturbed transition metal taggants to fuel cycle materials to aid in provenance assessment. However, widely used isotope dilution mass spectrometry methods, such as thermal ionization mass spectrometry (TIMS) and multi-collector inductively coupled plasma mass spectrometry (MC-ICP-MS), for isotopic analyses require completely dissolving material and time-intensive chemical separation prior to analyses. Resonance Ionization Mass Spectrometry (RIMS) is a powerful analytical technique that has several advantages over other mass spectrometric techniques, such as TIMS or MC-ICP-MS. Firstly, RIMS has high spatial resolution and sensitivity compared to other techniques. Secondly, RIMS can discriminate against isobaric interferences by selectively ionizing only the elements of interest, eliminating the need for chemical separation of samples. Additionally, samples can be analyzed as solids or dried-down solutions. Here we present a case study for measuring uranium oxides that have been tagged with isotopically perturbed Mo and W by RIMS. Samples of tagged DU oxide were prepared with isotopically perturbed Mo or W, resulting in four samples with either Mo or W, at two specific concentrations. After the samples were powdered, micrometer-sized single particles were analyzed by RIMS at the Laser Ionization of Neutrals (LION) at Lawrence Livermore National Laboratory. Approximately 5% uncertainties (at 2σ) were obtained for Mo, W, and U after ~7-minutes, ~20-minutes, and ~10 minutes, respectively (Fig. 1). All Mo, W, and U isotopes were collected from each particle, with the entire particle remaining post-analysis. Ultimately, this method allows for accurately and precisely measuring taggant compositions in tagged uranium, enabling rapid and robust assessment of material provenance.



Intentional Forensics: Quantitative and qualitative results from major element doping of DU metals

Dr. Joseph Boro[1], Dr. Meena Said[1], Dr Kara Luitjohan[2], and Dr Naomi Marks[1]
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Historically, nuclear forensics has relied on the analysis of bulk composition, trace impurities, and isotopic distribution to trace the production, storage, and processing of nuclear materials, often referencing exemplars of known provenance. Strategies for advancement of forensic work include the deliberate incorporation of a taggant within nuclear fuels to provide a marker indicative of a respective site or process within the fuel cycle to aid in rapid assessment of material provenance. The purpose of Intentional Forensics research and development is to identify strategies for tagging nuclear material with elemental or isotopic taggants that will prove probative, robust, and benign in a nuclear reactor setting. Some of the most promising candidates include multi-elemental taggants that could be easily incorporated and detected in a uranium matrix. Target materials include nuclear materials that are sometimes associated with theft and interdiction, including UO2 fuel pellets and uranium metal. In support of Intentional Forensics R&D, LANL has produced a set of depleted uranium metal samples that are tagged with varying amounts of transition metal elemental taggants.

In our research, we investigated the spatial distribution and behavior of tagged depleted uranium (DU) metal samples using microbeam techniques in order understand the spatial distribution and diffusion profiles of tagged materials using microbeam techniques and to understand the effects of specific taggant candidates on grain size and other basic properties of tagged material. Here we present results which show the spatial, concentrative, and isotopic distribution of 1% 0.44 Co – 0.38 Nb – 0.08 W – 0.32 Ir and 0.02 C – 0.22 Co – 0.19 Nb – 0.04 W – 0.16 Ir and doped DU metal. In both sample sets, W and Ir are more miscible than Co and Nb, and secondary phases of various phases show distinct and recognizable morphologies. Results of these studies will inform future taggant production and incorporation strategies within the intentional forensics venture.

Lithium and Uranium Sampling and Preservation Methods at the Y-12 National Security Complex

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The National Nuclear Security Administration's (NNSA) Y-12 National Security Complex collects and preserves numerous physical samples of nuclear materials. These materials may be used for analytical reference, nuclear forensic analysis, evaluation, comparison, and other applications.

The natural reactivity of lithium compounds represents a challenge when sampling these materials for analysis and also for long-term storage. In addition to the lithium challenges, acquiring pristine uranium metallurgical coupons/samples to improve uranium morphology studies from plant operations has been a challenge as well. Y-12 has been working on multiple lithium and uranium centric projects in recent years and is planning to improve its sampling and preservation techniques in support of future nuclear forensics projects. The lithium compounds and uranium to be sampled and preserved are representative of the current and historical nuclear production processes for the United States (U.S.) Department of Energy (DOE)/NNSA.

Y-12's historic and continued contributions to the DOE/NNSA nuclear inventory have made the site a prime candidate for conducting these activities. Y-12's lithium sampling, uranium sampling, and preservation improvements to be implemented for future nuclear forensics activities at Y-12 will be discussed.

Plutonium Processing Science at Pacific Northwest National Laboratory

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Pacific Northwest National Laboratory (PNNL) has established plutonium processing capabilities to study nuclear forensic sciences. The processing capabilities emulate historical efforts used by the United States since the 1940's. This capability is a modular system that can process various flow sheets associated with the plutonium nitrate precipitation methods including Pu (III) and Pu (IV) oxalate and peroxide. Principal operations for this capability include dissolution, ion exchange, precipitation, filtration, and calcination. A comprehensive suite of analytical capabilities including inorganic, radiochemical, and physical analysis, as well as state-of-the art microscopy systems are used to characterize the feed, process, and product materials. Additionally, machine learning algorithms are being employed to further understand the correlation between morphologies and the various processes. We will present data associated with the current R&D efforts.

Identifying morphological trends in plutonium (III) oxalate

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A 76-experiment parametric statistical design study (SDS) was performed for the plutonium (III) oxalate precipitation method at Pacific Northwest National Laboratory (PNNL). The oxalates from each experimental run were calcined to PuO_2 and imaged by scanning electron microscopy (SEM), resulting in a dataset that contains a diverse collection of morphological features. An image processing pipeline was developed to extract and quantify robust feature vectors for individual particles using an unsupervised vector quantized variational autoencoder (VQ-VAE). A neural network architecture that simultaneously performs multi-parameter classification and clustering of similar particle types was developed to investigate how process parameters affect particle morphologies. Our unique hierarchical vector quantizer (HVQ) clustering algorithm learns with the classification network, ensuring that clustering of like particles is performed with the features most useful for classification rather than spurious features. The developed method was able to attain classification accuracies as high as 80% for several parameters when predicting for a single particle; significantly higher classification accuracies were seen for all parameters when multiple particles were available at test-time. The HVQ clustering analysis generated reproducible quantification of particle morphology distributions, enabling the discovery of several key trends that show promise as signatures for nuclear forensics analysis. Our model can be expanded upon as SEM data of PuO_2 from the plutonium (IV) oxalate and plutonium peroxide precipitations are collected.

Inverse Prediction Methods for Inferring Plutonium Processing Conditions

Dr. Madeline Stricklin[1], Adah Zhang[2], Dr. Audrey McCombs[2], and Dr. Daniel Ries[2]
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In the past decade, nuclear chemists and physicists have been conducting studies to investigate the signatures associated with the production of special nuclear material. More specifically, these scientists hypothesize that different production processes produce nuclear end-products with different signatures, and that these signatures could allow a forensic examiner to determine which processes were used to produce the material. In turn, the forensic analyst could potentially make inferences on where the material originated. By better understanding the relationship that exists between production processes and the physical, chemical, and morphological characteristics of the nuclear end-product, scientists can better contribute to nuclear forensics investigations by quantifying their results and ultimately shortening the forensic timeline.

This presentation considers methods that allow for statistically analyzing and quantifying these relationships via inverse methods (Ries et al., 2022). These methods aim to quantitatively and probabilistically relate experimental processing conditions to the physical, chemical, and morphological measurements made on the resulting plutonium particles. One such method uses Bayesian Adaptive Spline Surface models in conjunction with Bayesian model calibration techniques to probabilistically determine processing conditions as an inverse function of morphological characteristics (Ausdemore et al., 2022). Another method uses Bayesian seemingly unrelated regressions, accounting for correlations between responses to better predict conditions and quantify uncertainty (McCombs et al., 2023).

The methods considered in this presentation not only allow for providing point estimates of a sample of SNM, but also incorporate uncertainty into these predictions. The models prove sufficient for predicting processing conditions within a standard deviation of the observed processing conditions, on average, provide a solid foundation for future work in predicting processing conditions of particles of special nuclear material using only their observed morphological characteristics, and are generalizable to the field of chemometrics for applicability across different materials.

Ries, D., Zhang, A., Tucker, J., Shuler, K., and Ausdemore, M. (2022). A framework for inverse prediction using functional response data. J. Comput. Inf. Sci. Eng. 23, 4053752. doi:10.1115/1.4053752

Ausdemore, M. A., McCombs, A., Ries, D., Zhang, A., Shuler, K., Tucker, J.D., Goode, K.J., and Huerta, J.G., (2022) A probabilistic inverse prediction method for predicting plutonium processing conditions. Frontiers in Nuclear Engineering, 1 p.1083164.

McCombs, A., Stricklin, M. A., Goode, K.J., Shuler, K., Tucker, J.D., Zhang, A., Ries, D. Inverse prediction of Pu processing conditions using Bayesian Seemingly Unrelated Regression models with functional data. Manuscript in preparation.

Neutron capture in rare earth elements: A developing technique for nuclear forensics

Adelicia Johnson[1], Quinn R. Shollenberger[1], **Gregory A. Brennecka**[1], Jeremy Inglis[2], Ted Ditchman[3], Elizabeth Keegan[3]
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Contextualizing nuclear materials confiscated by law enforcement is important for international nuclear security. In some cases, there may be a need to determine the ore body from which seized nuclear materials originally derived. While prior work in this area has focused on utilizing radiogenic signatures in the materials, we are developing a novel method to identify ore bodies through the natural phenomenon of neutron capture which occurs to differing extents based on factors such as ore grade and age of the deposit. This quantification of neutron capture expands upon similar work using samarium isotopes in uranium ore concentrates [Shollenberger et al. 2021], however, we now also include gadolinium isotope ratios, in concert with the 236U/238U uranium isotope ratio, as an additional proxy to help determine neutron fluence within the original ore body, thus providing a new tool for nuclear forensics.

Multi-element isotope ratio analysis for nuclear material in the environment with resonance ionization mass spectrometry (RIMS)

Darcy Van Eerten[1], Paul Hanemann[1], Manuel Raiwa[2], Laura Leifermann[1], Tobias Weissenborn[1], Wolfgang Schulz[1], Martin Weiss[1], Danielle Ziva Shulaker[2], Peter Boone[2], David Willingham[2], Keenan Thomas, Brian Sammis, Brett Isselhardt[2], Mike Savina[2], and Clemens Walther[1]
[1]Leibniz University Hannover, Hannover, Germany, [2]Lawrence Livermore National Laboratory, Livermore, USA

Nuclear materials that contaminate the environment present an ongoing challenge to characterize due to their small size and diverse morphology. The analysis of isotope ratios in actinides and fission products can provide determination of origin, age and environmental weathering of these materials. Resonance ionisation mass spectrometry (RIMS) utilizes selective laser ionization to target single elements and suppress the isobaric interferences typically found in mass spectrometry. Two specialized instruments were used to analyse single hot particles from Chornobyl: SIRIUS at the IRS in Hannover, Germany, and LION at LLNL in Livermore, USA. Results from multiple particles are presented with interpretations of isotope ratios in U, Pu, Cs, Rb, Sr and Ba.

A prototype Lab on Chip Device for in situ detection for difficult to measure Radionuclides

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In situ microfluidic radiochemical analysis has the potential to offer an alternative to traditional manual sampling in industrial, environmental, and nuclear forensic applications. Pure β-emitting radionuclides are typically monitored via discrete manual sampling followed by destructive analysis at an off-site laboratory, leading to delays in data availability and response times. The development

of an in situ microfluidic Lab on Chip (LoC) device with an integrated detection system capable of detecting pure β-emitting radionuclides presents an alternative to manual sampling and the technical challenges that accompany this method. The advantages of a LoC device include the ability to reduce occupational exposure, reagent usage and production of contaminated waste. Small sample volumes and in situ detection also enable shorter lead times for initial analytical data, whilst providing improved temporal resolution through near real-time data acquisition. Pure β-emitting radionuclide measurement often relies on counting photons arising from the Cherenkov Effect (for high energy β-emitters) or via liquid scintillators. Therefore, a prototype radioanalytical LoC system integrated with a detection system has been developed to maximise photon transport through a microfluidic system. The prototype LoC system has been manufactured and undergone evaluation with ^{90}Sr to establish key parameters, including linearity, minimum detectable activity, and sample carryover. Finally, we employed the prototype LoC system to analyse additional β-emitting radionuclides, including ^{99}Tc and ^{36}Cl, to demonstrate linearity with emission energy and activity. Our work and development method using numerical modelling has established the capability to reduce material consumption and the requirement for specialist facilities for handling radioactive materials during the initial characterisation process. This work constitutes the first step toward robust in situ microfluidic detection for pure β-emitting radionuclides capable of field deployment and integration with autonomous platforms to enable remote detection and monitoring.

Microfluidic Separations for Field-Deployable Nuclear Forensics

Kevin Glennon[1], Jennifer Shusterman[1], Hector Valdovinos[1], Tashi Parsons-Davis[1], and Narek Gharibyan[1]
[1]Lawrence Livermore National Laboratory, USA

To expedite analysis of post-detonation nuclear debris, a small-scale chemistry and detection platform has been developed. This platform was designed for future field-deployable use, aiming to keep the footprint small, volume of reagents low, and reagents and detectors stable and operable in ambient conditions. Supported liquid membrane (SLM) microfluidic modules have been designed and 3D-printed for separation of uranium and plutonium from fission products, debris matrix elements, and other actinides. Online UV-Visible spectrophotometry and gamma spectrometry are used for uranium quantification and online alpha spectrometry to measure plutonium isotope ratios. The platform has been used to successfully separate and characterize uranium and plutonium constituents from various surrogate debris matrices containing actinides and fission products.

LLNL-ABS-847017. This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344. This work was funded by the Office of Defense Nuclear Nonproliferation Research and Development within the U.S. Department of Energy¹s National Nuclear Security Administration.

An Introduction to Nuclear Industrial Archaeology

Erin Holland[1], Dr. Ing. Yannick Verbelen[1], Dr. Dean Connor[2], Dr. Thomas Martin[1], Matthew Higginson[3], Prof. Dr. Thomas Scott[1]
[1]Interface Analysis Centre, University of Bristol, UK, [2]National Nuclear Laboratory (NNL), UK, [3]AWE, UK

The legacy of the early days of the Atomic Age consists of many problematic sites worldwide, including radioactive waste dumps, uranium mines, spent fuel reprocessing plants, and defunct processing and enrichment plants. Although nature quickly reclaims abandoned sites, any remaining radioisotopes can pose a threat for millennia to come, long after the benefits gained from nuclear technology have faded. The field of nuclear industrial archaeology specialises in finding and characterising these sites to support local communities and site owners. Where maps and building

plans have been lost, nuclear archaeologists deploy state-of-the-art analysis techniques on the ground to unravel the current state of legacy sites and quantify the remaining radioactive inventories to the standard required by the nation the site is located within. The objectives of nuclear industrial archaeology are varied and site dependent. Whether the objective is to puzzle the forgotten history of activity back together or safeguard and recover dangerous radioactive materials, nuclear industrial archaeology adapts radioanalytical laboratory and site-surveying techniques in order to understand the site and allow scientists to communicate this information to support remediation efforts. This paper discusses current methodologies alongside a case study.

P1: New method of thermal neutrons imaging using a fast optical camera

Tianqi Gao[1]
[1]The University of Manchester, UK

We present a novel and condensed imaging technique for thermal neutrons utilizing a fast event mode optical camera (Timepix3) combined with a 6Li:LYSO scintillator. Previous studies have demonstrated the high spatial-resolution imaging capabilities of 6LiF:ZnS scintillators compared to traditional neutron imaging [1]. However, the proposed 6Li:LYSO scintillator exhibits a significantly faster decay time (~35 ns) due to its unique composition, in contrast to the microseconds decay time of 6LiF:ZnS scintillators required for gamma discrimination. Building upon successful statistical analysis-based thermal neutron reconstruction [2], our research encompasses three main components.

The research is separated into three parts:

1. Measurement using the setup.
2. Simulating ways to reduce gamma accompanied with neutron sources.
3. Experimental result analysis and comparison to the simulation.

Firstly, the experimental setup focuses on the interaction products (alpha and tritium) of the thermal neutron with 6Li to produce localized flashes of light in the LYSO crystal scintillator. These photons were guided through an optical path to be captured by a micro-channel plate intensifier connected to a fast optical camera, TPX3CAM, as shown below.

Figure 1 Left is the photo/illustration of the setup with the labelled components, the black arrow represents the thermal neutron path and the green arrows represent the photon path. Right is the setup in measurements, the Lead blocks were simulated to attenuate >90% of the gamma from the AmBe source.

Secondly, we explore ways to reduce the gamma rays arriving at the LYSO scintillator using the TOPAS simulation package. LYSO exhibits peak absolute quantum efficiency at ~200 keV, coinciding with the peak of the AmBe gamma spectrum [3]. Simulation results show that the attenuation of gamma rays using 5 cm of lead allows us to mitigate their impact, at the cost of reducing the total efficiency of the neutrons moderation and the 6Li reaction.

Thirdly, we analyse the acquired data. A centre-of-mass reconstruction algorithm is applied to the data recorded from the Timepix3. Each reconstructed neutron event consists of sub-clusters, representing groups of photons generated by the photon multiplier from a single photon input. Background sources, including gamma rays from the source, Lutetium radiation, and DAC noise, are considered during data analysis. Figure 2 shows an example of an event, each blue dot is a photon. It has 4 photon groups that are all within 40 ns time window of each other and is not shaped as a line, then this event could be determined as the result of a neutron hit.

Figure 2 Shows a reconstructed neutron event. The time (ToA) is the horizontal axis in ns, the x and y are the pixels of the Timepix3 camera, each pixel is 55 x 55 um.

Our findings demonstrate the potential of this optical neutron imaging technique, enabling remote and long-distance detection with a variable field of view. By employing a faster decaying scintillator, the clustering time window is reduced from milliseconds to nanoseconds, significantly decreasing the "exposure" time required for thermal neutron detection applications such as imaging and nuclear security scans.

[1] Losko, A. S., et al. "New perspectives for neutron imaging through advanced event-mode data acquisition." Scientific reports 11.1 (2021): 1-11.

[2] Gao, T, et al. "Novel imaging technique for thermal neutrons using a fast optical camera." Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment (2022): 167604.
[3] Allahverdy, A, et al. "Gamma Spectrometry in the Presence of Fast Neutrons." Frontiers in Biomedical Technologies 6.1 (2019): 22-27.

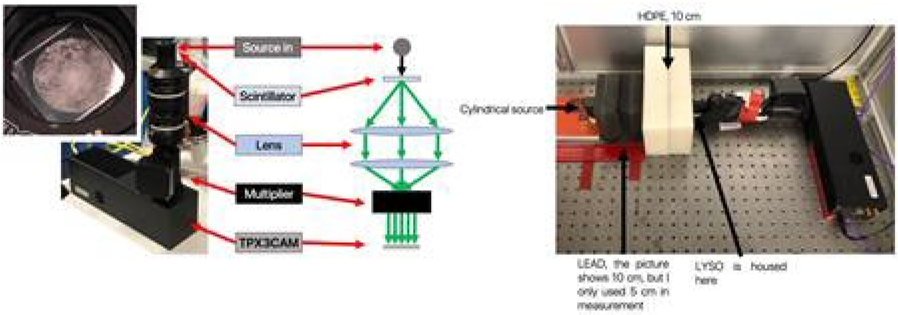

Figure 1

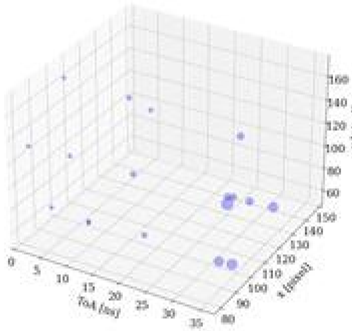

Figure 2

P2: A Non-Rigid Airship System for SLAM in Nuclear Environments: An Alternative Approach to Multi-Rotor UAVs

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This paper introduces a novel non-rigid airship (NRA) system equipped with RPLIDAR S1 and BerryIMU v4 sensors, designed for simultaneous localization and mapping (SLAM) within nuclear power plants and waste storage management. The NRA system serves as a promising alternative to traditional multi-rotor Unmanned Aerial Vehicles (UAVs), effectively addressing their limitations, including downdraft-induced particulate aerosolization and restricted flight duration.

The buoyancy of the NRA, achieved through helium filling, allows it to maintain a stable and stationary position in the air for extended periods, spanning multiple weeks. This feature significantly enhances its operational efficiency, enabling prolonged monitoring tasks without the need for frequent takeoffs and landings. Moreover, the NRA's simplified onboard electronics are less susceptible to radiation interference compared to the complex electronics of multi-rotor UAVs. Consequently, the NRA requires reduced shielding and has a longer flight duration.

To achieve precise SLAM, the proposed system integrates the RPLIDAR S1 and BerryIMU. These sensors record data, which is processed through SLAM algorithms to accurately localize the airship and construct a detailed point cloud of the surroundings. To enhance the RPLIDAR's capabilities, a mirror is attached at a 45-degree angle, converting the 2D LIDAR into a 2.5D LIDAR. This modification allows the RPLIDAR to capture both vertical and horizontal localization information.

An Raspberry Pi serves as the onboard computer, running ROS nodes for the RPLIDAR and IMU, and transmitting the collected data to a laptop for further processing. This multi-sensor setup effectively meets the limited payload requirement (~200g for a 2m long, 1.5m^3 NRA) of the airship.

The adoption of the NRA system for indoor inspections in nuclear sites offers a safer and more efficient method, while reducing potential risks to personnel and equipment.

Keywords: non-rigid airship, SLAM, indoor inspection, RPLIDAR S1, BerryIMU v4, nuclear sites, Raspberry Pi, multi-sensor combination

P3: Organic semiconductor radiation detectors for alpha and neutron detection

Mr Aled Horner[1], Miss Fani Eirini Taifakou[1], Mr Choudhry Zahaab Amjad[1], Professor Adrian Bevan[1], Dr Theo Kreouzis[1], Dr Chris Allwork[2], and Dr Filip Aniés[3]
[1]Queen Mary, University of London, UK, [2]AWE, UK, [3]KAUST, Saudi Arabia

In recent decades organic electronics have entered mainstream use in consumer electronics found in households around the world. I will present radiation sensors based on organic semiconductor technology, and in particular applications related to detection of hadronic radiation. This includes α, fast, and thermal neutron radiation.

P4: Enhancing Nuclear Security: Leveraging Non-Negative Matrix Factorization for High Sensitivity Threat Detection with Small Volume Gamma Detectors

Sam Fearn[1], Euan Connolly[1], and Dr Peter Martin[1]
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The threat from nuclear terrorism represents a complex challenge for global governments. Although current systems for detecting threats from illicit materials exist, each have inherent limitations. It is crucial that a system can detect material being transported with malicious intent which is likely to cause health risks and require extensive clean-up operations. One monitoring approach comprises the use of a network(s) of distributed detectors to detect anomalous events. To keep costs low, these networks may be made up primarily or entirely of small volume, handheld, scintillator-based detectors. Utilising algorithms capable of raising the alarm when detecting a threat, but with a low false alarm rate, is vital. For these small-volume and portable systems this can be a challenging task as signal to noise ratios are low. One currently applied method for the detection of radioactive sources uses principal component analysis (PCA) to characterise complex background environments. An implementation of this approach is described by Shokhirev et al. (Shokhirev et al., 2012). From the components found using PCA, incoming spectra can be reconstructed, maximizing the Poisson distributed likelihood. Another approach that additionally creates components from which to reconstruct incoming spectra is non-negative matrix factorization (NMF). NMF has the advantage of being a more physical treatment of the background than PCA as there are no negative components. Both of these source detection methods have been implemented using an existing set of background data from portable scintillator detectors deployed around London. The performance was tested using threats injected into the dataset, generated using GEANT4 and empirically measured detector response parameters. A comparison of the performances of the PCA and NMF-based approaches has been completed and visualised via their receiver operating characteristic curves (ROC curves). Utilising NMF components achieves high sensitivity to threats with a high precision, providing a promising method for nuclear security with small volume gamma detectors.

P5: Organic Field Effect Transistors as radiation detectors

Mr Choudhry Amjad[1], Mr Aled Horner[1], Ms Fani Taifakou[1], Mr Sam Moss[1], Professor Adrian Bevan[1], Professor Theo Kreouzis[1], and Dr Christopher Allwork[2]
[1]Queen Mary University of London, UK, [2]AWE, UK

Organic semiconductor radiation detectors based on diode-like structures are well established. Here I present preliminary results on the potential for Organic Field Effect Transistors (OFET) as radiation detectors, where the nature of the OFET means that the signal is intrinsically amplified by the device.

P6: The problematic assumption of homogeneity

Caroline Pyke[1], and Luke McGarry[1]
[1]National Nuclear Laboratory, UK

A key underlying assumption in the statistical analysis of Nuclear Forensics data is that the samples tested are representative of a known or assumed homogenous material. Analytical errors are carefully calculated and considered and these errors are used to infer confidence about our decisions relating to provenance. Modern analytical techniques such as ICP-MS mean that resulting analytical data is highly accurate in characterising the sample. However, perhaps a more challenging question is whether the sample itself is representative of the bulk material it has been taken from or indeed from the wider population we are trying to compare the sample against. The extent of this challenge can range from materials such as fuel, manufactured from a relatively controlled process, to wastes combined into single packages from a variety of historic sources. Uncertainties are not always known or provided in Nuclear Forensics libraries, which makes comparisons between high precision analytical data and these Nuclear Forensics libraries problematic. Information about the relative homogeneity of the reference material is important to:

- underpin the assumptions of statistical analysis and essential for the use of the Guided Decision Framework (GDF)
- support in field measurements and selection of lab samples to extract representative samples
- guide prosecutors in their understanding and presentation of confidence in their decision making

This interactive poster aims to outline the main challenges associated with sampling uncertainty in nuclear forensics, spark conversation and ideas and directs conference delegates to HAVE YOUR SAY on this important topic.

P7: Humanitarian Landmine Detection Method: Ensuring Human Safety, Interrogation Efficiency, and Accuracy

Dr Mahmoud Bakr[1], and Professor Tom Scott[1]
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Addressing the global issue of detecting and eliminating humanitarian landmines carries immense significance, given the substantial number of casualties, especially among civilians, resulting from landmine explosions yearly. Traditional methods for detecting landmines often involve conventional techniques like using dogs or vehicles. However, these methods are inadequate when identifying humanitarian landmines and pose a significant risk to human lives. In response to these challenges, alternative techniques for landmine detection have been proposed.

Explosives used in landmines have distinctive molecular "signatures" composed of elements such as hydrogen, nitrogen, oxygen, and carbon. Neutron activation analysis is employed to pinpoint these signatures. This process involves analyzing the gamma-ray spectrum emitted by these materials when subjected to a specific neutron flux spectrum. While previous studies have focused on detecting this unique composition by moving the explosives past a stationary neutron source, practical identification of improvised explosive devices (IEDs) or landmines requires taking the detection apparatus to the location of the explosive.

One approach involves using a wheeled vehicle with a neutron source attached to its front. Although this method has its advantages in certain environments, effectively covering large off-road areas within a limited timeframe remains challenging. Additionally, the vehicle itself might be susceptible to the very explosives it aims to detect.

Introducing an innovative technique for uncovering concealed explosives is crucial in minimizing the risk associated with detection efforts. This technology identifies nuclear indicators in various devices, including landmines, IEDs, nuclear weapons, chemical weapons, and dirty bombs. The capability is achieved through specialized nuclear detection mechanisms and signature analysis methods. The distinguishing factor of this technology lies in its ability to detect explosives from substantial standoff distances, coupled with its efficiency in rapidly and accurately scanning expansive regions. This remarkable technology retains its effectiveness even when a line of sight is obstructed or submerged under up to 1 meter of water or soil. The principles and system configuration will be elaborated upon during the meeting.

P8: Passive Radiological Inspection of Shipping Containers using a UAV-Mounted Scintillator Detector

Euan Connolly[1], Ewan Woodbridge[1], and Dr Peter Martin[1]
[1]University of Bristol, UK

Radiation detectors mounted on unmanned aerial vehicles (UAVs) can be utilised to screen freight passing through a seaport for radioactive material that could be used in radiological dispersal or improvised nuclear explosive devices. Payload and battery life restrictions limit the size of the sensor package that can be deployed on a UAV and as a result a low-cost system is likely to deploy small and lightweight detectors that produce count-starved spectra. To support existing screening infrastructure in place at seaports using drone-based detectors radioactive source identification from these limited spectra is necessary. An established technique for processing count-starved spectra to identify different radioactive isotopes and special nuclear materials uses the ratio of counts in different spectral bins, effectively comparing the shape of different spectra and thus being less susceptible to background. A challenge in the application of this method to screening shipping containers arises from the inherent shielding present; scattering in cargo materials changes the shape of the spectra. This work presents an investigation into the optimum spectral bins required for detecting concealed 137Cs, 60Co and special nuclear materials using the method of spectral comparison ratios. A shift in the optimum bins is seen with 2.5 cm of iron shielding for 137Cs and 60Co sources, while the shielding effect is expected to have less impact for special nuclear materials.

P9: Forensic Signatures of Local and Global Plutonium Contributions to Environmental Radioactivity

Argaia Madina[1], Joyce Malcolm[1], Marcus Christl[2], Philip Gautschi[2], and Francis Livens[3]
[1]Lancaster University, UK, [2]ETH Zürich, Switzerland, [3]The University of Manchester, UK

The objective of the investigation described in this work is to consider whether isotopic signatures associated with trace actinide environmental radioactivity, and particularly plutonium, can be used to differentiate local sources of contamination (i.e., industrial operations) from global contributions (c.f., weapons test fallout). Measurements of environmental radioactivity from the shores of two lakes in the English Lake District have been made with broad-energy, high-resolution γ-ray spectroscopy (HRGS, Culham Centre for Fusion Energy) and accelerator mass spectrometry (AMS, ETH Zürich). The average mass concentrations of 239Pu, 240Pu, and 244Pu have been estimated in samples derived from a data set comprising 24 samples using AMS, of (228 ± 23) fg/g-1, (41 ± 5) fg/g-1 and (4 ± 1) × 10−2 (fg/g-1), respectively, and the corresponding isotopic ratios have been determined. As 241Pu cannot be inferred with AMS, it has been measured with HRGS via 241Am and compared with the prior art of more than 20 years ago.

P10: Exploring the role of the stable oxygen isotopic signature in nuclear forensics.

Paulina Baranowska[1], Dr Jack Lacey[2], Dr James Dunne[3], Prof Matthew Jones[1], Dr Emily O'Donnell[1], Stuart Dunn[3], and Scott Sanders[3]
[1]University of Nottingham, UK, [2]British Geological Survey, UK, [3]AWE, UK

Nuclear forensic science focuses on the examination and identification of evidence to support the government in incidents involving nuclear and other radioactive materials out of regulatory control. A wide range of forensic signatures is used to assess the origin of the material and inform law enforcement for further investigation. By incorporating various analytical techniques, the production route of a trafficked or lost material can be found. This includes where, when and how the material was produced.

This project focuses on the characterisation of the oxygen isotope content of uranium oxides. The work aims to explore the use of surface science techniques to constrain the environmental conditions that have caused a material to corrode. By combining the surface science chemistry and the isotopic information of the material it will be possible to assess the forensic signatures of the given material.

To gain a better understanding of the unknown corrosion environments, a set of experiments using surrogate materials will be prepared. The surrogate material will include MoO2 and MoO3 as molybdenum possesses similar characteristics to uranium and can recreate the behaviour of UO2 and UO3. For instance, both elements create stable compounds in the +4 and +6 oxidation states. The corrosion rate and surface hydration will be assessed by Raman Spectroscopy, SEM, XPS and XRD.

A classical fluorination line and an elemental analyser-based micro fluorination system at the British Geological Survey will be used to liberate the oxygen from both the uranium and molybdenum oxide samples for isotopic analysis via Isotope Ratio Mass Spectrometry (IRMS).

P11: Morphology and Particle Size Round Robin: A collaborative exercise to test methods and applications of microscopy to nuclear forensics

Stuart Dunn[1]
[1]AWE, UK

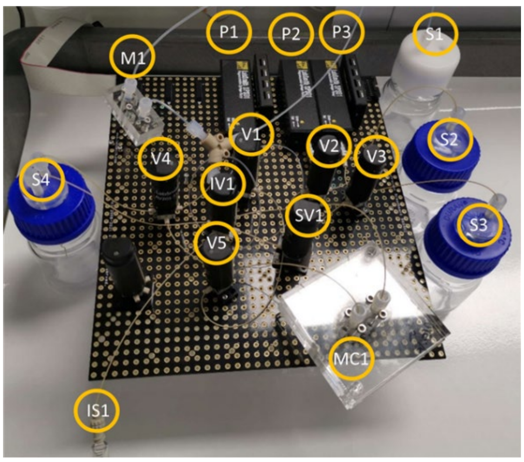
Morphology and particles size analysis in recent years has been shown through numerous studies to be a vital tool in nuclear forensic focused studies. Shown to be able to supporting assignment of nuclear materials and nuclear processing signatures. An important aspect of such measurements is standardisation in order to maintain continuity across the nuclear forensics' community. This can be challenging due to the requirement of relevant standards and the subjectivity of morphology descriptions. The Morphology and Particle Size Round Robin (MaPS RR) looks to test such analysis methods to understand where biases may arise in order to enhance the robustness and further develop morphology and particle assessments in support of nuclear forensics.

P12: Development of automated microfluidic system for actinide analysis

Mr Shuang Yu Han[1], Dr Bernard Treves Brown[1], Dr Matthew Higginson[2], Dr Philip Kaye[2], Professor Clint Sharrad[1], and Professor Scott Heath[1]
[1]The University of Manchester, UK, [2]AWE, UK

Advancement in analytical device miniaturisation through microfluidic technology offers an alternative approach towards radiochemical analysis. When compared to traditional macroscale analytical process, microfluidics devices manipulate and process fluid samples typically in the microlitre range, which provides benefits in terms of more efficient mixing and precise conditions control that are not feasible in macroscopic systems while reducing waste generation.

Microfluidic extraction devices are fabricated using poly (methyl methacrylate). Recovery and separation of uranium from trace elements relevant to the nuclear fuel cycle are demonstrated using UTEVA® chromatographic resins packed within the microdevice in concentrated nitric acid media. enabling analysis of nuclear materials with a drastic volume reduction to ≤ 0.1 ml per analysis. A novel online analytical system was also developed in parallel. Where flows from the microfluidic separation system are redirected towards a coupled ICP-MS system, enabling online analysis of trace elements and actinide as it is separated within the microdevice with minimal operator - sample interaction. Such an online microdevice – ICP-MS system enables automated separation-detection of radioactive samples within 1 hour of sample uptake while generates less radioactive waste, satisfying the As Low As Reasonably Achievable (ALARA) principle.



P13: Recent developments of in-situ micromechanical tests for nuclear forensics

Nicholas Randall[1], and Remo Widmer[1]
[1]Alemnis Ag, Switzerland

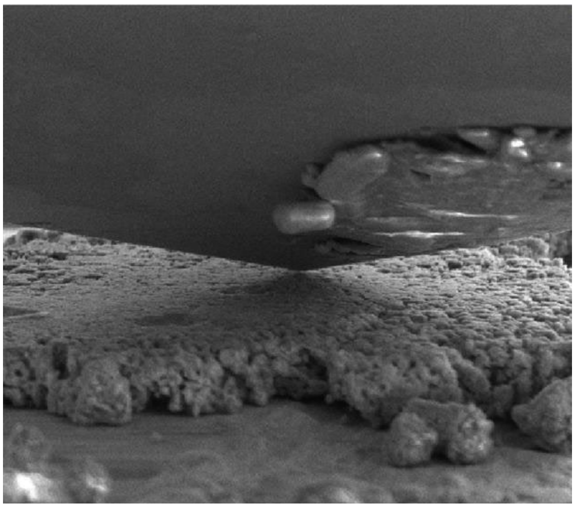
Micromechanical tests are already being used to investigate material properties at very small scales. Such testing of nuclear materials may provide information on the provenance, manufacture and processing, as well as providing important indicators of the material's origin, history and intended use.

Such measurements have moved beyond the basic measurement of hardness and elastic modulus to encompass a host of different mechanical properties such as strain rate sensitivity, stress relaxation, creep, and fracture toughness by taking advantage of focused ion beam milled geometries. New developments, such as high cycle fatigue, are extending the range of properties which can be studied at the micro and nanoscale. Piezo-based nanoindentation methods are now allowing access to extremely high strain rates (>104 s-1) and high oscillation frequencies (up to 10 kHz).

This talk will focus on the most recent developments in instrumentation for in-situ extreme mechanics testing at the micro and nanoscales, with specific focus on a testing platform capable of strain rate testing over the range 0.0001/s up to 10'000/s (8 orders of magnitude) with simultaneous high-speed actuation and sensing capabilities, with nanometer and micronewton resolution respectively.

The additional challenge of performing tests in nuclear environments and over the temperature range -150 to 1000 °C will be discussed together with the associated challenges. The inherent advantages of using small volumes of sample material, e.g., small ion beam milled pillars, will be discussed together with the associated instrumentation, technique development, data analysis methodology and experimental protocols.

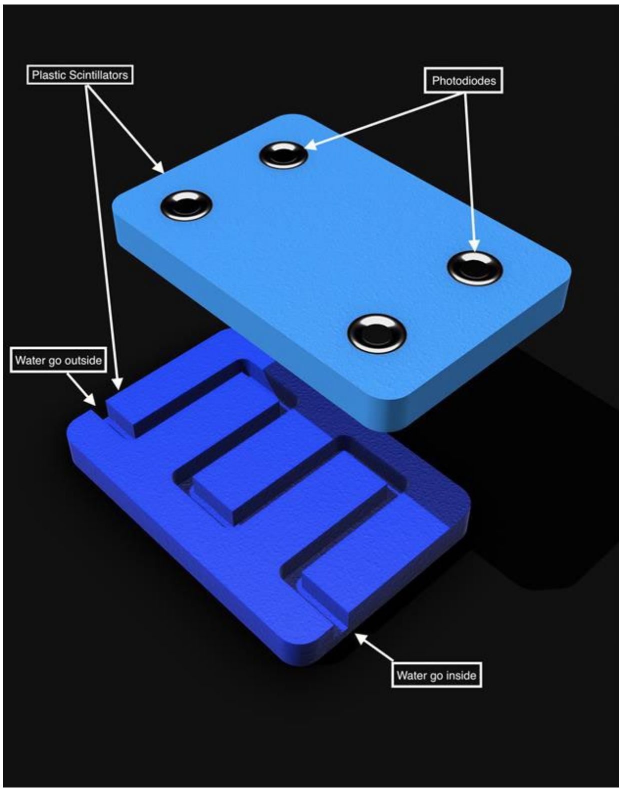
Specific focus will be given to test setup modifications required for testing of radioactive materials and future research directions in this sub-field of micromechanics will be discussed.



P14: In-Situ Marine Radiation Monitoring Using a Novel Detection System for Nuclear Emergency Response: Preliminary Evaluation

Mohammed Al-Hijji[1], Dr Peter Martin[1], Professor Thomas Scott[1], Dr Mahmoud Bakr Arby[1], and Dr Sarah Lu[2]
[1]University of Bristol, Interface Analysis Centre (IAC) Group, UK, [2]University of Southampton, UK

Anthropogenic contamination of the marine environment can impact the health of exposed human populations and the surrounding ecosystem. Radionuclides can travel long distances by water currents, presenting a challenge to managing contamination due to their mobility, bioavailability and long half-lives. Consequently, an early warning detection system capable of identifying contamination sources and their levels is crucial to effectively managing unauthorised releases. While conventional approaches for detecting marine radioactivity are highly accurate and precise, they are inappropriate for real-time monitoring. In-situ marine-based techniques can enable rapid assessment of contaminated areas without laborious sample collection and processing and provide real-time identification of areas of significance. In-situ radioactivity measurements in the marine environment are challenging and demand innovative detection systems. Plus, environments with highly saline and humid marine ecosystems face additional technological demands. This research conducted an experimental and simulated evaluation to test the detection limits of a novel plastic scintillator detector tailored to detect gamma-ray from contaminated seawater caused by nuclear accidents, taking into account the radiation levels in seawater, the material and geometry of the detector, and the interaction between the photons with the atoms of the seawater and the detector. A GEANT4-based Monte Carlo simulation was also conducted to evaluate the minimum detectable activity for Cs-137 in seawater. This work presents a first step towards developing an in-situ radiation detector for the marine environment.



P15: Sediment Preparation and Thin Sectioning Technique for Analysis of Uranic Materials in Magnox Sludge

Philip Hutchinson[1]
[1]University of Bristol, UK

A sediment preparation and thin sectioning technique has been developed for low temperature immobilisation and analysis of uranic materials within soft sediment matrices. A 3- step process of solvent exchange, resin impregnation, and precise thin sectioning has been used to dry, immobilise, and prepare, partially corroded uranium metal encapsulated in magnox sludge. Magnox sludge is a highly viscous sediment, with a high yield strength, capable of isolating encapsulated uranium metal fuel from its wet storage environment; the extent of uranium metal isolation within magnox sludge and its implications for uranium corrosion behaviour remain poorly understood. By systematically isolating and studying uranium distribution through thin sections, we gain insight into the behaviour of uranic materials within the pore network of magnox sludge. This technique has been developed to assist Sellafield in the characterisation of an inventory of spent magnox fuel encapsulated in magnox sludge stored in an open-air fuel pond. However, the technique holds potential for broader applications in nuclear forensics, such as: monitoring contamination levels in soils and sediments stemming from depleted uranium munitions, radiological releases, or characterisation of various sedimentous nuclear waste forms. Complementing material characterisation and gamma spectroscopy of contaminated sediments, this preparation technique helps reveal the spatial distribution of active materials within a pore network structure, yielding insights into the materials mobility for assessments of the long-term behaviour within soils and sediments.

P16: Consortium for Nuclear Forensics: A United States University Based Research and Training Program

Ken Czerwinski[1]
[1]University of Nevada, Las Vegas, USA

The United States National Nuclear Security Administration (NNSA) is set to bolster its commitment to advancing nuclear forensics through its support of the Consortium for Nuclear Forensics (CNF), commencing in October 2023. This collaborative endeavor unites 16 universities and 7 US National Laboratories, collectively embarking on research and human capital development. This initiative is poised to catalyze novel scientific breakthroughs, cutting-edge technologies, and transformative capabilities that align with the objectives of NNSA's Defense Nuclear Nonproliferation Research and Development (DNN R&D) Office.

The consortium encompasses five Thrust Areas (TAs)

- TA1 - Rapid Turnaround Forensics,
- TA2 - Advanced Analytical Methods,
- TA3 - Ultrasensitive Measurements,
- TA4 - Signature Discovery, and
- TA5 - Prompt Effects and Measurements.

By harnessing their collective expertise spanning radiochemistry, geochemistry, analytical chemistry, nuclear physics, nuclear material science, shock physics, quantum-enabled sensing, high-performance computing (HPC)/data science, as well as training and education, the CNF endeavors to achieve its overarching objectives.

In addition to these TAs, the CNF has identified two cross-cutting areas (CCA) integral to its mission. The first CCA revolves around High-Performance Computing and Data Science, strategically positioned to accelerate progress within individual TAs through the synergistic integration of HPC and

Artificial Intelligence (AI)-driven capabilities. The second CCA is dedicated to augmenting the proficiency of students, researchers, and faculty, facilitating enriched training and outreach initiatives in nuclear forensics applications, in close collaboration with the National Laboratories (NLs) and esteemed international forensics institutions. Collaborative research projects orchestrated between universities and partnering NLs are expected to amplify existing collaborations and foster emergent ones. During summer internships, laboratory scientists will mentor CNF students, while extended visits by CNF faculty and their university research teams to the NLs will foster idea development. The consortium's synergy extends to the formal participation of laboratory scientists on CNF students' dissertation committees.

The CNF's global perspective remains an essential component of its vision. Through active engagement with the international nuclear forensic community, the consortium aims to leverage established and nascent interactions. Collaborations with international laboratories will be anchored in robust discussions concerning nuclear forensics research efforts. This dynamic interchange will facilitate the exchange of ongoing initiatives, identification of shared interests, and the formulation of joint research pathways. Notably, the Atomic Weapons Establishment is anticipated to emerge as a pivotal international partner in the CNF's pursuit of excellence. The Consortium for Nuclear Forensics represents a transformative nexus of scientific expertise, interdisciplinary collaboration, and international engagement. This is expected to benefit nuclear forensics through groundbreaking research, technology development, and knowledge exchange.

P17: Development of PuO2 LG-SIMS particle standards via thin filmpolymer assisted deposition

Alexa Hanson[1], Benjamin Naes, Travis Tenner, Laura Wolfsberg, Lisa Hudston, Brian Scott, and Stephen Lamont
[1]Los Alamos National Laboratory, USA

PuO2 epitaxial thin films are currently being developed via the polymer assisted deposition (PAD) synthetic thin film technique for large geometry secondary ion mass spectrometry (LG-SIMS) particle standards. The PAD technique involves complexing metal ions to polymers in solution, spin coating the polymer precursors onto a single crystal substrate with appropriate lattice match, and heating to dissipate the polymer and form the epitaxial film. This method was initially developed for metal oxides as a substitute for traditional thin film synthetic techniques including sol-gel and physical and chemical vapor deposition and is particularly advantageous to the hazardous nature of actinides and transuranic elements as it requires microgram levels of material and does not require gas phase methods. Following its initial report in 2004, the PAD technique has been used to synthesize a variety of single crystal quality materials including actinide oxides, which enabled a variety of first-time characterization methodologies and greatly advanced electronic structure measurements. This study aims to build upon previous characterizations of PuO2 epitaxial thin films by developing particle standards for LG-SIMS, which has been traditionally used in nuclear forensics to detect trace amounts of nuclear material in environmental samples and identify isotopic heterogeneity in samples of actinide particles. We have completed principal LG-SIMS analyses on a U3O8 thin film bonded to a yttria-stabilized zirconium substrate prepared via the PAD method. The film was found to have adequate isotopic precision and higher uranium concentration in the center, indicating the inner region of the film is most advantageous for analysis. These initial analyses ultimately demonstrated the efficacy of the LG-SIMS technique for PuO2 epitaxial thin films, in addition to future thin film samples. Preliminary results for PuO2 films will be presented including radiographic film images showing distribution of radioactive material.

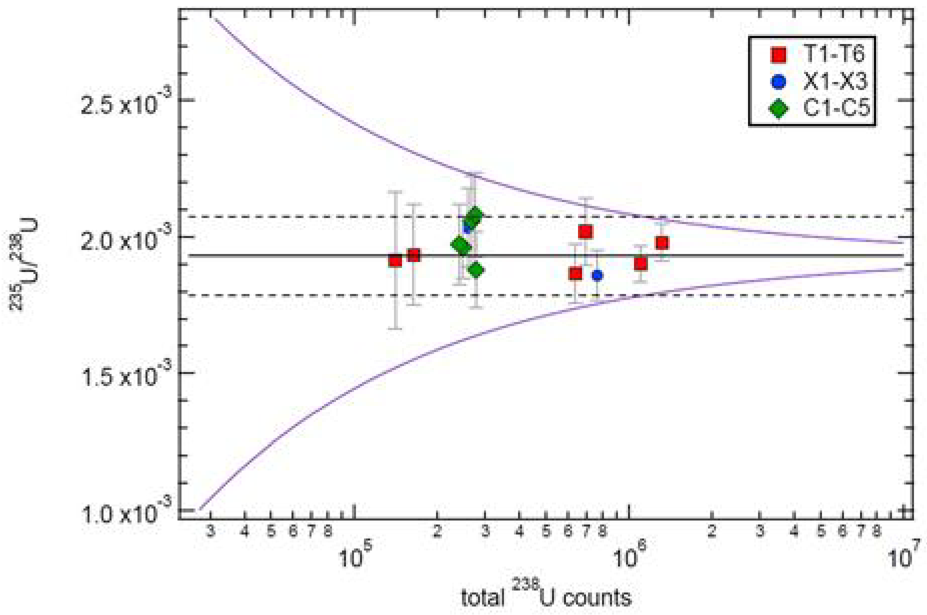


Figure 1. LG-SIMS particle dataset for isotope ratio, $^{235}U/^{238}U$ versus total ^{238}U counts. The black lines represent the calculated average and 2σ combined uncertainty for all measurements, and the curved purple lines represent the calculated uncertainty envelope if the dataset is isotopically homogeneous. Error bars represent 2σ uncertainties for each data point.

P18: Regional analysis of neutron/gamma figure-of-merit in scintillator volumes using a multi-anode photomultiplier tube

Patrick Collins-Price[1], and Professor Malcolm Joyce[1]
[1]Lancaster University, UK

Accurate neutron detection can be important for nuclear forensics, safeguards, and nuclear security applications. Organic scintillation detectors are used widely due to their resilience, rapid timing characteristics, and their dual sensitivity to both gamma and fast neutron events. Pulse-shape discrimination (PSD) is often used to separate gamma and neutron events as part of the analysis of data obtained with these systems, but challenges can arise at lower energies approaching 500 keV where the gamma and fast neutron plumes tend to overlap. The associated figure-of-merit (FoM) quantifies the separation possible by dividing the distance between the neutron and gamma event plumes by the sum of their respective widths, but this parameter is prone to artificial augmentation via energy cut-offs, which can exclude the low-energy overlap zone somewhat selectively, inherently reducing the overall detection efficiency. Moreover, FoM is only representative of the specific field within which it was measured: for example, high-energy fields such as that derived from americium-beryllium sources often yield a degree of separation that is superior to that achievable with californium-252, highlighting that the neutron/gamma discrimination performance may not be directly transferable to realistic neutron fields encountered in nuclear safeguarding or SNM monitoring scenarios. This study reports on a novel approach to the assessment and improvement of FoM via simultaneous location and analysis of event pulses within a continuous scintillator by employing a 16 × 16 multi-anode photomultiplier tube (MAPMT). Real-time measurement of centre-of-interaction coordinates showing anisotropy in full-volume event data is demonstrated that enables a regional quantification of FoM across a scintillator volume. This allows for the selection or rejection of events based on pulse quality metrics, eliminating the need for arbitrary and rigid energy thresholds. On this basis it is anticipated that FoM might instead be optimised in-field according to situational needs, allowing more accurate measurements across the full spectrum capabilities of the detector and amplifying the efficacy of established nuclear safeguarding and SNM forensic monitoring methods.

P19: An Intentional Forensics Approach to Nuclear Material Provenance Assessment

Dr. Naomi Marks[1], Dr. Rebecca Chamberlin, Dr. Matthew Wellons, and Dr. Ashley Shields
[1]Lawrence Livermore National Laboratory, Livermore, USA

Intentional Forensics is the deliberate introduction of benign and persistent material signatures into nuclear fuel fabrication and processing. Its purpose is to reduce the lag time between the recovery of a material outside of regulatory control and the identification of its original provenance. An integrated, multi-laboratory project has been initiated to develop a scientific and technical basis that would enable adoption of this forward-looking approach to nuclear forensics. Key research questions are: What are the best strategies for intentionally tagging various nuclear materials, and where in the fuel cycle should they be introduced? How can we design taggants that provide the desired nuclear forensics outcomes while also remaining benign under reactor irradiation? How can we rapidly measure and confidently assess the information encoded in tagged nuclear material, even after it has been processed? Since the project was initiated, significant progress has been made in several areas, including nuclear data development, to taggant formulation, synthesis, and incorporation, modeling of taggant behaviour, and even irradiation of tagged minifuels fuels in the High Flux Isotope Reactor at Oak Ridge National Laboratory. As our collaborative work on Intentional Forensics has progressed, several candidate taggants have stood out as especially promising (Ni, Ti), while others have proven to be more challenging to use in this context (W, Mo). This presentation will give an overview of our multi-lab work on taggants that evaluates the probative value, manufacturability, reactor safety, and persistence of various taggants within the fuel cycle.

P20: Investigation of an end-to-end neural architecture for image-based source term estimation

Dr Abdullah Abdulaziz[1], Prof Mile E. Davies[2], Prof Steven McLaughlin[1], and Dr Yoann Altmann[1]
[1]Heriot-watt University, UK, [2]University of Edinburgh, UK

In various critical applications, the accurate estimation of physical parameters is a necessity for ensuring public safety and effective decision-making. The ability to quantify uncertainty in these estimations is particularly vital, as it allows for more robust and reliable emergency responses. One such critical application where these considerations come into play is source term estimation (STE) in the context of hazardous material releases. The urgency for rapid and precise STE is accentuated by the growing risks of hazardous material releases due to accidents, acts of terrorism, or natural disasters. Quick identification of key release parameters such as the source location, timing, and environmental variables like wind speeds is essential for safeguarding public health and orchestrating effective emergency measures. Atmospheric Dispersion Simulation (ADS) models have traditionally been employed for this purpose. While these models are efficient and simple, they require several input variables, some of which are often unknown and must be inferred from sensor data. In this work, we present a first artificial neural network (ANN) approach for end-to-end source term estimation (STE) using time-series of multispectral satellite images. The architecture consists of two successive ANNs. The first-stage ANN estimates the hazardous material release rate over time, producing a 3D concentration map, while the second-stage ANN utilizes the generated concentration map to estimate the 2D source location, release time, and wind speed components. By leveraging the inherent nonlinearity of ANNs and advances in parallel computing, our proposed method aims to eventually overcome the limitations of existing optimization and Bayesian inference techniques in handling the nonlinear STE problem. In this preliminary study, we validate the performance of our approach on a simulated dataset, demonstrating its potential for enhancing the accuracy and speed of STE in real-world applications.

P21: Rapid characterization of actinide abundances and isotopic compositions by HR-ICP-MS for nuclear forensics

Greg Brennecka, and Josh Wimpenny
[1]LLNL, USA

The rapid, accurate determination of isotopic information is crucial for the field of nuclear forensics. However, high-precision actinide isotopic and elemental analyses typically require time-consuming sample preparation prior to analysis, and the measurement of U, Pu, Am, and Np each require different, multi-stage purification procedures. For samples with complicated matrices, where actinides are trace constituents, this is particularly true. Here, we present our latest actinide isotopic and elemental data from historic fallout melt glass and doped geostandards using high resolution inductively coupled plasma mass spectrometry (HR-ICP-MS), an analytical technique requiring minimal sample preparation. These data are directly compared to the results of high precision isotopic analyses and elemental assay by multi-collector (MC-ICP-MS), which requires lengthy sample processing. Although the data obtained by HR-ICP-MS is of significantly lower precision, the comparison shows broad overlap between the results of the two techniques. Thus, it is a viable method to obtain actinide elemental and isotopic data on a more rapid timeframe than traditional high-precision techniques.

P22: An Overview of Galaxy Serpent V (GSV)

S Yu Han[2], E Holland[3], L Johnstone[1], K Mayse[1], T Shaw[1], **Ms Alice Shilling**[1], M Marceau[1], and S Cross[1]
[1]AWE, UK, [2]University of Manchester, UK [3]University of Bristol, UK

Galaxy Serpent V is the fifth in a series of international nuclear forensics statistical exercises run by the National Nuclear Forensics Libraries Task Group of the Nuclear Forensics International Technical Working Group [1]. The aim of Galaxy Serpent is to raise awareness of the benefits and technicalities of creating and interpreting a National Nuclear Forensic Library (NNFL) [2]. A team of AWE staff and sponsored PhD students participated in the exercise, with a variety of expertise, from Subject Matter Experts (SMEs) to those new to nuclear forensics. This ambitious team was assembled in order to train new SMEs whilst having the support of senior SMEs.

This work will present an overview of the exercise including how the team came to an agreement for the provided questions. There will also be a discussion on the observed benefits and difficulties encountered with using this method of statistical analysis and decision framework. GSVs scenario comprised of a vehicle found at an international border with two containers of unknown black powder located inside, suspected to be a form of radioactive material. Analytical data was provided for the initial samples, along with data from additional samples taken from further scenes. These were compared to the NNFL containing interdicted materials, fuel pellets and ore concentrates. Questions were asked ranging from whether samples were consistent, to what advice should be given to law enforcement on exhibit storage.

Analysis was conducted primarily using the ITWGs Guided Decision Framework model [3]. This model assigns confidence levels using statistical consistency (p-value). The value is used in combination with SME judgement to determine material consistency and answer the customer's questions. Completing the exercise has enabled the team to practice the communication of scientific data and concepts, to answer questions that may be asked by law enforcement in nuclear forensics scenarios.

[1] International Technical Working Group, “Nuclear Forensics Update”, Issue 19, June 2021.
[2] J.D. Borgardta, F.M.G. Wong, “Galaxy Serpent: A Web-Based Table-Top Exercise for National Nuclear Forensics Libraries”, in Conf International Conference on Advances in Nuclear Forensics IAEA CN-218, Vienna, Austria, 2014.
[3] Nuclear Forensic International Technical Working Group, “INFL Guideline on a Graded Nuclear Forensics Decision Framework”, Version 3, 2021.

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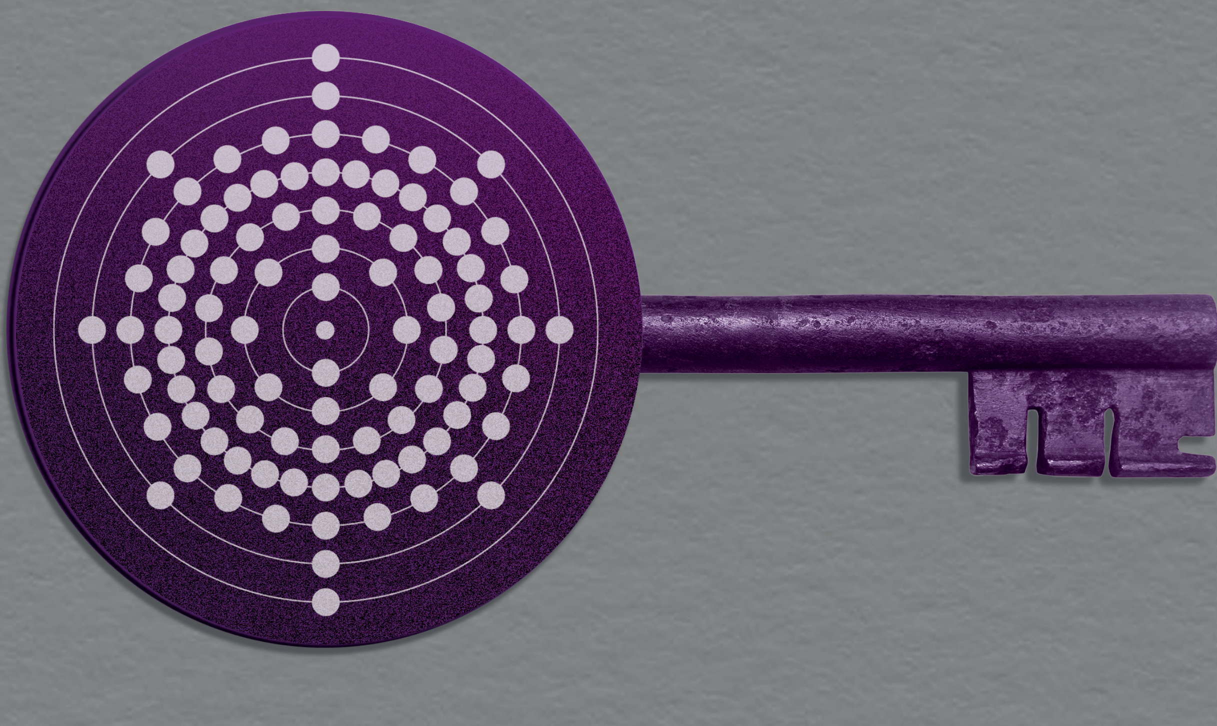

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