NuFor
Nuclear Forensics

11–13 October 2022
Institute of Physics, London, UK

NATIONAL NUCLEAR LABORATORY

AWE

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Programme

<u>Tuesday 11 October</u>

Chair: Roy Awbery

09:30 **Welcome**

Roy Awbery *(AWE)*

09:45 **Nuclear Forensics: Introduction & History**

David Smith *(King's College London)*

10:30 **Career Pathways and Opportunities in Nuclear Forensics**

David Meier *(Pacific Northwest National Laboratory)*

11:00 **Break**

Chair: Giles Aldrich-Smith

11:30 **International Perspectives and Importance of Nuclear Forensics**

Eva Kovacs-Szeles *(IAEA)*

12:00 **Introduction to AWE and its Role in Supporting Nuclear Security**

Andrew Randewich *(AWE)*

12:30 **Introduction to NNL and its Role in Supporting Nuclear Security**

Paul Nevitt *(National Nuclear Laboratory)*

13:00 **Lunch**

14:00 **Interactive Panel Discussion**

Chair: Roy Awbery

With Mansie Iyer, Stephen LaMont, David Smith, Dave Meier, Eva Kovacs-Szeles and Klaus Mayer

14:50 **Tea Break**

15:10 **Interactive Panel Discussion cont'd**

Chair: Roy Awbery *(AWE)*

16:00 **Reception and Networking**

18:00 **Depart**

Wednesday 12 October

Chairs: Roy Awbery & Peter Martin

09:00 **Welcome**

Roy Awbery *(AWE)*

09:20 **Keynote 1: Case Studies in Radiochronometry Using Non-Destructive Analytical Techniques**

Stephen LaMont *(Los Alamos National Laboratory)*

Session 1 – Radiochemistry

09:50 **Establishing Discordance as a Radio-Chronometric Signature for Nuclear Forensics**

Matthew Higginson *(AWE)*

10:10 **Safe use of radioanalytical methods in specific forensics applications**

Josef Sabol *(Czech Department of Crises Management)*

10:30 **Break**

Session 2 – Materials & Processing

Chairs: Matt Gilbert & Simon Middleburgh

11:00 **Investigation into a British Thorium Processing Flowsheet and Determination of Characteristic Elemental and Isotopic Identifiers**

Erin Holland *(University of Bristol)*

11:20 **Taggants: An Intentional Forensics Approach to Nuclear Material Provenance Assessment**

Naomi Marks *(Lawrence Livermore National Laboratory)*

11:40 **Aqueous Plutonium Processing Nuclear Forensics Signature Development at PNNL**

David Meier *(Pacific Northwest National Laboratory)*

12:00 **Lunch**

13:30 **Keynote 2: Surviving the Pandemic**

Mansie Iyer *(IB3 Global Solutions)*

14:00 **Who? What? Where? When? Why?: An Attempt to Understand Uranium Trioxide**

Tyler Spano *(Oak Ridge National Laboratory)*

14:20 **Stable Element Doping of Sol-gel Toward Simulating Environmental Matrix in Surrogate Explosive Nuclear Debris**

Justin Cooper *(Idaho National Laboratory)*

14:40 **Tea Break**

Session 3 – Conventional & Technical Nuclear Forensics Interface

Chairs: Karen Kennedy & Peter Hiller

15:10 Keynote 3: Nuclear Forensics versus or with Conventional Forensics

Jim Blankenship *(FBI)*

15:40 Overview of the Conventional Forensic Analysis Capability (CFAC)

Samantha Lennard *(AWE)*

16:00 Exhibit Handling and Case Management

Simon Laslett *(AWE)*

16:20 Close

19:00 Conference Dinner at the Canal Museum

Thursday 13th October

Chairs: Matthew Higginson & Stephen LaMont

09:20 Keynote 4: Nuclear Forensics – Integrating Research and Application

Klaus Mayer *(EU-JRC)*

Session 4 – Analytical Techniques

09:50 Sellafield RAP Project: A New High Active Analytical Facility

Jonathan Hawkett *(National Nuclear Laboratory)*

10:10 Recent innovation in Scanning Electron Microscope (SEM) in-situ extreme micromechanical tests for nuclear forensics

Nicholas Randall *(Alemnis Ag)*

10:30 Break

11:00 Rudos Cove: An Interactive NF Exercise

Frank Wong *(Lawrence Livermore National Laboratory)*

12:00 Lunch

Session 5 – Sensor & Detection Technologies

Chairs: Chris Allwork & TBC

13:30 Algebraic Reconstruction of Gamma Radiation Fields in Complex Environments from Aerial Data

Dean Connor *(National Nuclear Laboratory)*

13:50 Active Interrogation System for SNM: Principle, Configuration and the First Experiment

Mahmoud Bakr *(University of Bristol)*

14:10 **Data Analytics of Low-Level U-235 Source Signature for Classification Using Gamma Spectral Measurements**

Nageswara Rao *(Oak Ridge National Laboratory)*

14:30 **Tea Break**

15:00 **A Novel Lab on Chip Device for In-situ Detection for Difficult to Measure Radionuclides**

Sarah Lu *(University of Southampton)*

15:20 **Organic Semiconductor Radiation Alpha and Neutron Detectors**

Theo Kreouzis *(Queen Mary University of London)*

15:40 **Closing Remarks**

David Smith *(King's College London)*

16:00 **End and Depart**

Keynote: Case Studies in Radiochronometry Using Non-Destructive Analysis Techniques

Stephen LaMont[1]

[1]Los Alamos National Laboratory, Los Alamos, USA

Radiochronometry is frequently used in nuclear forensic examinations to determine the model age of a material. Most often, this relies on measuring one or more radionuclide parent – progeny pairs to estimate when a nuclear material was last chemically purified. In other cases, it may involve comparing activities of radionuclide pairs that are produced in known activities, and subsequently decay at known rates, for example in spent nuclear reactor fuel. These measurements are most often made using rigorous radiochemistry techniques that require dissolving the sample, purifying the analytes of interest, and determining concentrations by alpha or mass spectrometry. For example, measuring the model age of U materials using the Th-230/U-234 radiochronometer requires sample dissolution, spiking aliquots with Th-229 and U-233 isotope dilution tracers, radiochemical purification of Th and U, and determining the Th-230 and U-234 by mass spectrometry. This process is very labor intensive, and while it offers higher precision, there are times when rapid non-destructive gamma-ray spectrometry can provide high-quality radiochronometry data. Two examples of this approach will be presented. In the first example, Eu-152 and Eu-154 activities were measured by gamma-ray spectrometry in a series of irradiated samples, and the Eu-152/Eu-154 ratios were used to determine the model irradiation date for the material. In a second example, the Th-234/U-238 ratios were determined in a fresh U metal casting, which served as a radiochronometry system that should behave identically to the more commonly used Th-230/U-234 system but is measurable by gamma-ray spectrometry. This work is providing new insights into how Th behaves during U casting operations, and how to interpret model age data in U metal samples.

Keynote: Surviving the Pandemic

Mansie Iyer[1]

[1]Ib3 Global, Contractor to the U.S. Department of Energy, USA

The U.S. Department of Energy/National Nuclear Security Administration (DOE/NNSA) Office of Nuclear Smuggling Detection and Deterrence (NSDD) works with partner countries to achieve nuclear security goals in which states' appropriate authorities are able to use technical nuclear forensics to detect, deter, and investigate nuclear security breaches. My presentation will discuss how NSDD, which builds partner agencies' capabilities in nuclear forensics, continued to achieve mission objectives during the pandemic. In this vein, I will focus on a virtual round-robin exercise named Spectral Flavor.

We all know that the science of spectrometry is well established and that the method of doing the actual analysis can vary based on instrumentation available and software used. NSDD has developed a monthly round-robin gamma spectrometry drill to hone and sustain the gamma spectrometry skills of their partner countries based only on their analytical skills. NSDD administers the monthly drill by distributing synthetic or real gamma spectra to participants and challenging them with investigative questions based on real life scenarios. The reception of the growing number of participants in this Spectral Flavor of the month drill has been very positive and the drill has proven to be a new, engaging way of exercising spectrometry capabilities simultaneously on a multilateral level. Without the need for on-site or in-person activities, it has been an extremely successful means of engaging partners in a virtual setting while travel restrictions existed.

Keynote: Nuclear Forensics versus or with Conventional Forensics?

James Blankenship[1]

[1]US Department of Justice, Quantico, USA

Around the world the nuclear forensics community and the conventional forensics community are often times distinct, separate, and not well integrated. The nuclear forensics community, built upon nuclear security capabilities, has not had the same opportunities as the conventional forensics community to be almost daily employed, tested, and re-tested by law enforcement, the prosecutors, and in the courts. However, many similarities between nuclear forensics and conventional forensics exist, and looking towards these commonalities, improvements, and expansions for both nuclear forensics and conventional forensics are possible, especially in the international arena.

Keynote: Nuclear Forensics – Integrating Research and Application

Klaus Mayer[1], Maria Wallenius[1], Zsolt Varga[1], Michael Krachler[1], Alexander Knott[1], Nadya Rauff-Nisthar[1], and Adrian Nicholl

[1]European Commission – Joint Research Centre, Karlsruhe, Germany

Nuclear forensics is defined as "the examination of nuclear or other radioactive material, or of evidence that is contaminated with radionuclides, in the context of legal proceedings under international or national law related to nuclear security. The analysis of nuclear or other radioactive material seeks to identify what the materials are, how, when and where the materials were made, and what their intended uses were."

Nuclear forensic science has emerged as a relatively new and fascinating multidisciplinary area of research, combining methods of traditional forensics, radiochemistry, analytical chemistry, material science, isotope geochemistry, and nuclear physics. The development or adaptation of analytical methods and the quest for signatures which are characteristic for the processing history of the material was often inspired by real incidents.

The presentation will provide an overview of recent developments in nuclear forensic science, including microanalytical techniques, studies on the behavior of selected materials under a “dirty bomb” scenario, and the application of Artificial Intelligence in Nuclear Forensics. Where appropriate, examples of the investigation of real cases will be provided for illustration.

Establishing discordance as a radio-chronometric signature for nuclear forensics

Matthew Higginson[1], James Dunne[1], Chris Gilligan[1], Sam Cross[1], Theresa Kayzar-Boggs[1], Joanna Denton[1], John Engel[1], Matthew Sanborn[1], Allison Wende[1], Mark Edwards[1], Christine Chen[1], Amy Gaffney[1], John Rolison[1], Maya Morris[1], and Charlotte Eng[1]

[1]*AWE, Reading, UK*

The determination of the model age of a nuclear material is an important measurement for nuclear forensics. Measurements of decay products in samples by a variety of analytical techniques can be used to produce model ages for interpretation.

These measurements of trace elements require considerable effort. A variety of challenges remain to improve our ability to interpret discordant model ages relative to samples produced under controlled conditions. This is needed to improve confidence in forensic assessments of samples found outside of regulatory control. We will report an applied interlaboratory study with the aim to understand the impacts of uranium casting technologies on model ages.

Safe use of radioanalytical methods in specific forensics applications

Jozef Sabol[1]

[1]*Department Of Crises Management, Prague, Czech Republic*

Radioanalytical methods, especially Instrumental Neutron Activation Analysis (INAA), have been widely used in various branches of science, technology and medicine. The INAA is a physical technique that is based on the evaluation of radionuclides formed in the sample by nuclear reactions induced by neutrons. After the irradiation, the sample becomes radioactive when neutrons react with the nuclei of the relevant elements' atoms. The radiation emitted from such radionuclide is characterized by a unique type and energy, based on which the presence of some nuclides in the sample could be selectively detected with extremely high sensitivity. The method is often used in the identification of definite elements in illegally transported drugs and narcotics seized by the LEAs. This approach to the analysis of samples is fully non-destructive and could be used in many other forensics applications.

However, as with any technique based on the use of ionizing radiation, due attention should be paid to ensuring adequate protection against the harmful effects of radiation on persons and its possible impact on the radioactive contamination of the environment.

The paper summarizes the present requirements for radiation protection in the use of radioanalytical methods under normal and emergency situations in line with the latest international standards including the recommendations of the International Commission on Radiological Protection (ICRP) and requirements of the International Atomic Energy Agency (IAEA).

Investigation into a British Thorium Processing Flow Sheet and Determination of Characteristic Elemental and Isotopic Identifiers

Erin Holland[1], Matthew Higginson[2], Philip Kaye[2], Tomas Martin[1], Roy Awbery[2], and Tom Scott[1]

[1]University Of Bristol, United Kingdom, [2]Atomic Weapons Establishment, UK

An exploration, recreation and analysis of a historical UK processing pathway producing thorium and thoria from ore. This work characterises the process from bulk ore to final product and analyses the "fingerprints" which remain at each point in the chain. These forensic attributes include physical characteristics, REE ratios, HPGe spectra, XRF, ratios of trace metals (using XRF and SEM) and characterisation of the wastes produced. This work will ensure that, should any of this material turn up outside of regulatory control in the future, we would have additional knowledge of the Th fuel cycle to apply to nuclear forensic assessment or comparative analysis. Historical documents have been reviewed to expand our understanding of past scientific endeavours and to ensure that the flow follows the pathway as closely as possible.

Taggants: An Intentional Forensics Approach to Nuclear Material Provenance Assessment.

Naomi Marks[1], R M Chamberlin[2], A E Shields[3], and M S Wellons[4]

[1]Lawrence Livermore National Laboratory, USA, [2]Los Alamos National Laboratory, USA, [3]Oak Ridge National Laboratory, USA and [4]Savannah River National Laboratory, 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? The most promising candidates include multi-isotopic taggants with perturbed isotopic distribution that could be easily incorporated into the bulk or on the surface of metallic or ceramic nuclear fuels. This presentation will give an overview of the challenges in developing a taggant selection scheme that integrates probative value, manufacturability, reactor safety, and persistence in the fuel cycle.

Aqueous Plutonium Processing Nuclear Forensics Signature Development at Pacific Northwest National Laboratory

<u>David Meier[1]</u>

[1]Pacific Northwest National Laboratory, USA

Pacific Northwest National Laboratory (PNNL) has established aqueous plutonium processing capabilities to enable nuclear forensics signature development. The processing capabilities simulate historical efforts used by U.S. plutonium processing sites including, Hanford, Savannah River, and Rocky Flats. This flexible processing capability can process various flow sheets associated with the plutonium nitrate chemistries including Pu (III) and Pu (IV) oxalate, and Pu (IV) peroxide precipitations. Key operations for this capability include dissolution, ion exchange, precipitation, and calcination. A comprehensive suite of analytical capabilities including state-of-the art microscopy systems were used to characterize the plutonium products. Additionally, machine learning algorithms are being employed to further understand the correlation between morphologies and the various process chemistries. Numerous processing experiments have been conducted on PNNL's aqueous processing capability including a 76-experiment parametric statistical design study focusing on the plutonium (III) oxalate precipitation method. Data, images, and observations from various processing experiments will be presented.

Who? What? Where? When? Why?: An Attempt to Understand Uranium Trioxide

<u>Dr. Tyler Spano[1]</u>, Ashley Shields[1], Brodie Barth[1,2], Jennifer Niedziela[1], Rodney Hunt[1], and Andrew Miskowiec[1]

[1]Oak Ridge National Laboratory, Oak Ridge, USA, [2]University of Notre Dame, Notre Dame, USA

Uranium trioxide (UO3) is ubiquitous in both front and back-end nuclear fuel cycle processes. This stoichiometry can adopt at least six structural forms as a function of the processes used to create it. While numerous reports of UO3 are available from Manhattan Project era research, only recently has systematic investigation revealed the ways in which optical vibrational (Raman and infrared) spectra can provide insight into underlying crystal chemistry of this complex family of polymorphs. α- and γ-UO3 are relatively well studied with respect to their structures and resulting spectroscopic observables. β-, δ-, and ε-UO3 however are more exotic and require more complex preparation conditions. To this end, we have reviewed and optimized synthetic methods for β-, δ-, and ε-UO3 found in the literature, performed density functional theory (DFT) calculations and made DFT-informed assignments of features in the optical vibrational spectra to the structural attributes from which they arise. Our investigation of β-UO3 involved development of a novel analysis method towards assigning specific vibrational modes to the atomic vibrations from which they originate. In exploring, δ-UO3, we found unexpected Raman-active vibrational modes, and provide insight into possible structural origins thereof. Finally, we solved the structure of ε-UO3 from powder X-ray diffraction data and confirm that this is indeed a unique structural modification of uranium trioxide. Our combined efforts have illuminated the unique Raman and infrared spectroscopic signatures of these three elusive UO3 polymorphs and demonstrate that rapid, nondestructive optical vibrational spectroscopic measurements can provide insight into fuel cycle processes.

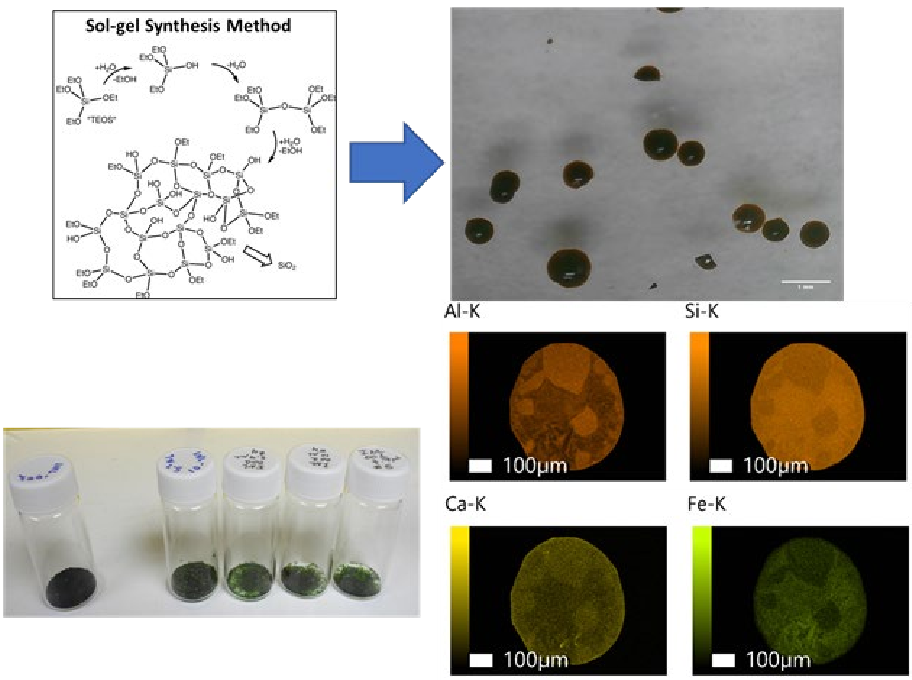
Stable Element Doping of Sol-gel Toward Simulating Environmental Matrix in Surrogate Explosive Nuclear Debris

Justin Cooper[1], Mathew Cooper[1], and George Diehl[2]

[1]*Idaho National Laboratory, Idaho Falls, USA,* [2]*University of Utah, Salt Lake City, USA*

Training nuclear forensic analysis personnel in post-detonation scenarios is of critical importance to nuclear threat response capabilities. Thus, realistic nuclear debris simulants which resemble the size, color, elemental composition, and radionuclide content of actual nuclear fallout from a recent detonation would be valuable for training nuclear first responders in realistic scenarios. As nuclear fallout types vary significantly based on detonation environment (rural, urban, maritime etc.) and collection location, the ability to tailor each of these parameters accurately in simulated debris would be of immense benefit to the post-detonation analysis community for training both in-field collections and the triage and validation of laboratory level nuclear forensic techniques.

Sol-gel synthesis techniques can provide the tunability of size, shape and composition required for producing surrogate nuclear debris of a wide variety. The sol-gel process consists of forming a metal oxide material, often silica, through polymerization of a metal-alkoxy precursor. In this work, we characterize the ability to load the sol-gel particles with secondary elemental components such as iron, aluminum, and calcium toward approximating the elemental composition of debris from various detonation environments and demonstrate the ability to produce particles with controllable size, shape, and color. We also demonstrate quantitative radionuclide encapsulation toward reproducing the radionuclide content of actual fallout from a recent detonation. Finally, we then employ these techniques in producing simulated aerodynamic debris samples with realistic elemental matrix composition and radionuclide content simulating a recent uranium-fueled detonation taking place in a rural desert environment and compare it to historic fallout from the Nevada Nuclear Security Site.



Overview of the Conventional Forensic Analysis Capability (CFAC)

Samantha Lennard[1]

[1] AWE, UK

The Conventional Forensic Analysis Capability (CFAC) was opened in 2012 by James Brokenshire MP, Under Secretary for Crime and Security as a direct response to the murder of Alexander Litvinenko. It is funded by the Homeland Security Group (HSG) within the Home Office (HO) and enables exhibits that are contaminated with radiological material to be forensically examined for markers such as Hair, Fibres, Questioned Documents, Digital Information, DNA and Finger Marks. It directly supports the 'Pursue' strand of the Home Office Counter Terrorism Strategy (CONTEST).

Exhibit Handling and Case Management

Simon Laslett[1]

[1] AWE, UK

Exhibit handling and case management are critical elements in any forensic examinations or laboratory analysis undertaken in support of a criminal investigation. Maintaining and accounting for the integrity and continuity of exhibits and the collation, recording and retention of all generated material is key in underpinning and strengthening the overall evidential picture.

Recent innovation in Scanning Electron Microscope (SEM) in-situ extreme micromechanical tests for nuclear forensics

Nicholas Randall[1], and Jean-Marc Breguet

[1] Alemnis Ag, Gwatt (thun), 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. Some examples of test data will be presented where a wide range of strain rate has been combined with variable temperature in order to investigate rate effects as a function of temperature.

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.

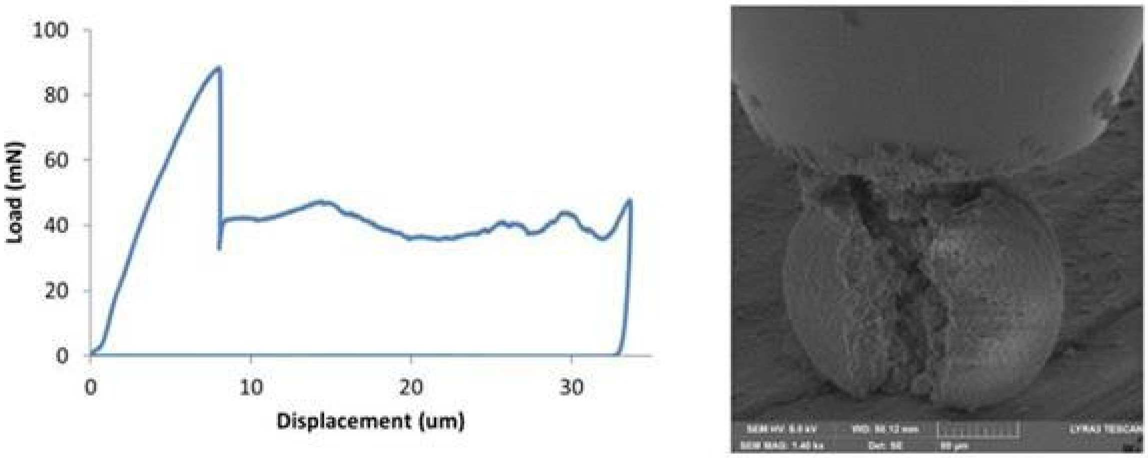


Figure 1: Example of in-situ micromechanical crush test on a nuclear fuel particle using a diamond flat punch indenter of diameter 200 μm.

REPLACEMENT ANALYTICAL PROJECT: Detailed Design Overview and Analytical Capability

Jonathan Hawkett[1]

[1]*National Nuclear Laboratory, UK*

The Replacement Analytical Project (RAP) is concerned with the relocation of Analytical Services Laboratory (ASL) capability into National Nuclear Laboratory Central Laboratory (NNL-CL) at the Sellafield Ltd. site in West Cumbria, England. This capability consists of high active (HA) medium active (MA), special nuclear material (SNM) containment and supporting fume cupboards (low active analysis), where low active and environmental analysis will be provided by the supply chain in the most part off site. The project requires the change in purpose of some areas from non-active to active facilities, the refurbishment and modernisation of an existing facility never commissioned and a new build that will house one High Active Analytical Services Cell (HAASC), 9 medium active cells, 23 gloveboxes and supporting fume cupboards housing ca. 210 items of analytical equipment. In addition to the relocation of the analytical capability, the nature of the analysis is altering as Sellafield will stop reprocessing fuel and enter a Post Operational Clean Out (POCO) phase followed by decommissioning returning the site to brown field land. This has provided the opportunity to investigate and develop new analytical techniques. Further, there is an opportunity to conduct non-destructive analysis in containment of receipt wherever possible; (non-destructive analysis results in reduced levels of in waste, dose risk to operators and analytical uncertainties associated with handling).

This presentation will focus on the design overview for the three containment areas highlighting key design details and areas of development. It will discuss the analytical capability of the facility and detail the development work being undertaken to deploy complex techniques and instruments into HA, MA and SNM environments through our collaborative approach with Instrument Modifiers.

The analytical capability shall be discussed identifying how Sellafield Ltd. demand data has shaped the future instrumentation and what can be characterised to support decommissioning and POCO. The selection process will be demonstrated through Best Available Techniques (BAT) and As Low As Reasonably Practicable (ALARP) principles to ensure the analytical processes and instrument nuclearisation is appropriate.

This future capability will also be discussed in conjunction with the wider analytical capability provided across NNL sites and laboratories and the work being undertaken by the internal Analytical Capability & Skills Community of Practice (CoP). The CoP is attempting to identify all analytical instruments, techniques and capability across the organisation as well as the individuals with the skills and knowledge who run, support and develop them. The entirety of the current and future NNL analytical capability can be used to support nuclear forensics as a national resource.

RAP is a Programme and Partners Project (PPP) where Jacobs, Doosan, KBR and Morgan Sindall are working in partnership with Sellafield Ltd to deliver long term complex projects on site. In the example of RAP, PPP are also working closely with NNL as the final operator of the NNL-CL facility and future provider of the national analytical capability. For the Analytical Equipment Development (AED) we are collaboratively working with Aquila Nuclear Engineering, NIS Ltd. and Orano Projects Limited where they are acting as Instrument Modifiers.

Rudos Cove: An Interactive NF Exercise

Frank Wong[1]

[1]Lawrence Livermore National Laboratory, USA

An interactive session where participants will observe an evolving nuclear security event, in which radioactive material may have been smuggled into a residential area of the fictitious city of Rudas Cove. As the scenario develops, participants can actively engage in the narrated investigation through anonymous virtual polling tools. The scenario will focus on how materials from the crime and nuclear forensic measurements could possibly reveal links among people, places, events, and materials to aid a law enforcement investigation.

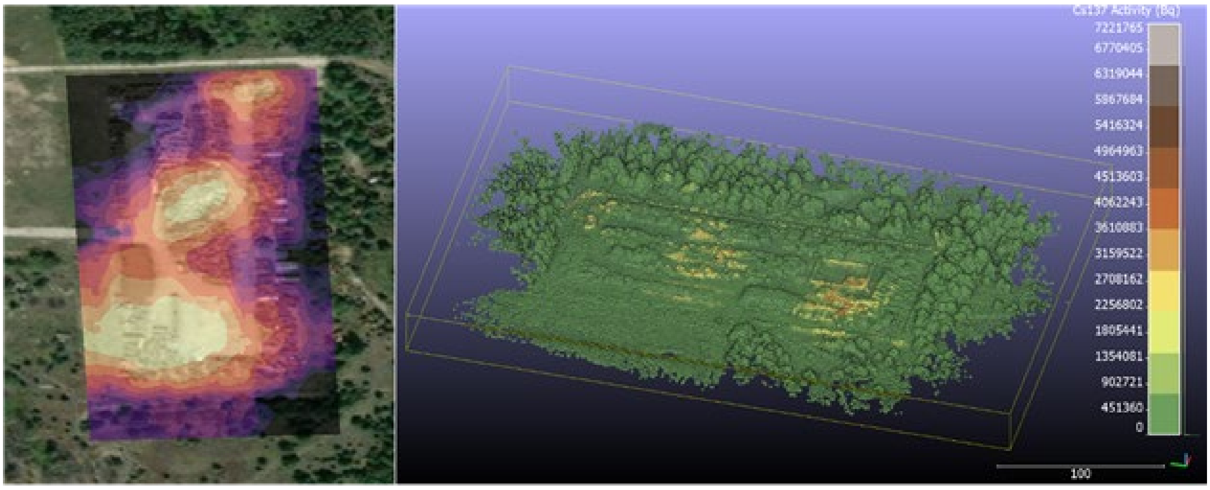
Algebraic reconstruction of gamma radiation fields in complex environments from aerial data

<u>Dean Connor</u>[1], Euan Connolly[2], David Megson-Smith[2], Freddie Russell-Pavier[2], Kieran Wood[3], Peter Martin[2], Nick Smith[1], and Tom Scott[2]

[1]National Nuclear Laboratory, UK, [2]University of Bristol, UK, [3]University of Manchester, UK

Gamma radiation surveying is an important tool within Nuclear Forensics. For any radiometric survey, regardless of context, obtaining accurate and precise estimates of the locations and intensity of the sources is of paramount importance. However, stand-off radiometric measurements are affected by geometric dilution, signal attenuation and the complex interaction of the detector response with complicated 3D scene geometries. Each of these factors work to mask the true surface level distribution of radioactive material with a blurred representation that elongates hot spots and underestimates their true activity, meaning that resultant maps lack clarity and contain inherent, unquantified uncertainty. This is of particular concern when radiometric measurements are acquired through aerial platforms, even at low altitudes of 5 – 30 m above ground level.

We present an inversion-based approach to improving contrast and localisation accuracy within radiation maps collected by low-altitude drone systems containing small-volume, uncollimated gamma spectrometers. Through combining aerial radiometrics with 3D scanning LiDAR measurements, complex scenes around the detector throughout the survey were discretised into a hypercube of linear equations in the form Ax = b. In this format, potential source locations in the surveyed area (x) are defined by a downsampled form of the 3D scanning LiDAR data. Each of these points contributes to every radiation measurement collected by the spectrometer (b) according to a forward projection model (A), formulated from gamma propagation physics with undetermined Poisson noise. The least squares solutions of these large linear systems were calculated using Algebraic Reconstruction (otherwise known as Kaczmarz Method) combined with Tikhonov regularisation to mitigate against overfitting. The resultant maps produced from this method show vastly improved contrast, with specific 3D features being highlighted as the most likely source locations and at the correct magnitudes of activity. Ultimately making them more useful to responding operators.



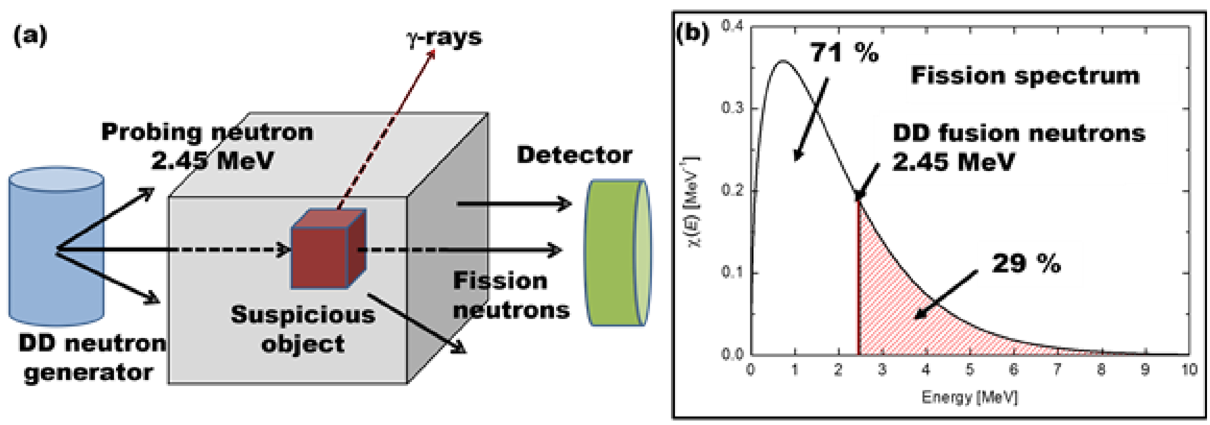
Active Interrogation System for SNM: Principle, Configuration and the First Experiment

<u>Mahmoud Bakr</u>[1], and Tom Scott[1]

[1] *South West Nuclear Hub, School of Physics, University of Bristol, Bristol, United Kingdom*

Non-destructive inspection systems are mandatory to prohibit terrorist threats and the smuggling of special nuclear materials (SNM) at airports and seaports. For decades, investigating SNMs such as Pu-239 and U-235 has been the primary concern of many countries' nuclear security. This work describes experimental results from a prototype test of the world's first-of-its-kind, portable active interrogation system for non-destructive detection of SNMs. The present system is based on the utilisation of threshold energy neutron analysis, comprising a portable DD (2.45 MeV) neutron generator of 5×10^7 n/sec intensity to actively interrogate materials coupled with arrays of tensioned metastable fluid detectors (TMFDs). If fissile material is present, prompt fission neutrons are emitted with average energy around 2 MeV and ~30% having energies higher than the energy of the DD source neutrons. The experiments with the prototype were carried out using 10 kg and 20 kg natural uranium (NU) metal samples placed inside the inspecting volume of 1 m × 1 m × 1 m. A set of 30-minute measurements with and without NU at a DD neutron source intensity of ~10^6 n/sec were repeated tens of times. The experimental neutron count rates with NU are seen clearly higher than those without NU. Utilising the experimental count rates, probabilities of detection (PD) and false alarm (PFA) were then evaluated. For this assessment, the DD neutron source intensity and the inspection time were set at 5×10^7 n/sec and <90 sec, respectively. From the arising results, PD was calculated as ~98.7 % for detecting 10 kg NU (containing ~70 g of U-235) and >99% for 20 kg NU (containing 140 g of U-253) with PFA < 5 %, which is encouraging when compared with the target PD > 90 % and PFA < 5 % stated in ANSI standards. The portable active interrogation system, experimental conditions and results will be discussed at the conference.

Principle of the active integration system for SNM



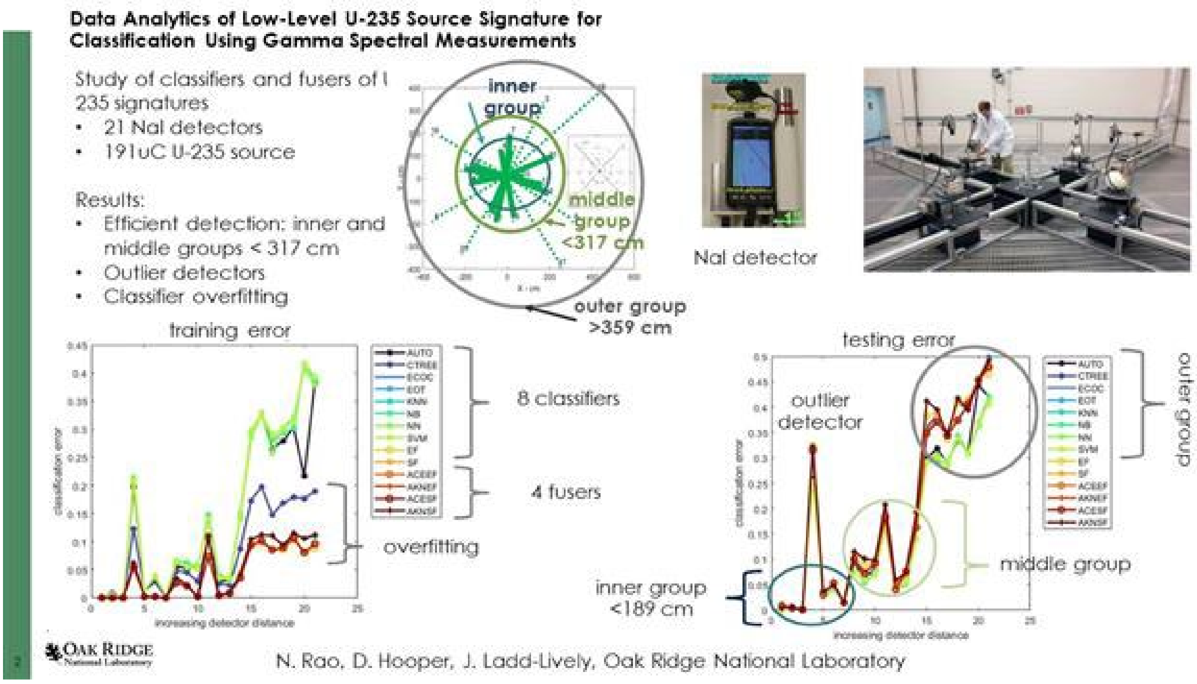
Energy spectrum of fission neutrons

Data Analytics of Low-Level U-235 Source Signature for Classification Using Gamma Spectral Measurements

Nageswara Rao[1], David Hooper[1], and Jennifer Ladd-Lively[1]

[1]*Oak Ridge National Laboratory, Oak Ridge, United States*

Signatures associated with the detection of low-level U-235 sources are studied from a data analytics perspective, using NaI gamma-ray spectral measurements from detectors located at various distances from the source material. Measurements collected at a shielded facility under controlled, exploratory configurations are utilized, wherein the source is introduced via a conduit into a formation of 21 hand-held class NaI detectors. They are deployed over a 6 x 6 meters area in the formation of two concentric circles and one spiral, and they form the inner, middle and outer groups based on the distance to source located at the center. The activity levels in the gamma spectral regions associated with U-235 material are estimated as counts and are used as features to train the classifiers for detecting its presence. Eight different classifiers are trained and tested using the background and source measurements collected over multiple experimental runs. As expected, the classifier performance improved overall as measurements from the detectors closer to source or multiple detectors are used, due to the increased effective sensor capture area. They also revealed unexpectedly low performance by some detectors and classifiers that are identically utilized and configured as others. Three types of information fusion strategies are studied based on using two spectral region features, fusing eight classifiers of diverse designs, and fusing multiple detectors located at different positions around the source. This study provides two main qualitative insights: (i) the fusion of measurements from multiple detectors leads to an overall improved classification performance, least in the inner group, most in the outer group, and in between for the middle group; and (ii) several classifiers and fusers achieve lower training error but result in much higher generalization error, indicating over-fitting by these typically complex methods.



A Novel 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 forensics 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. In-situ detection also enables 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 the counting of photons arising from the Cherenkov Effect (for high energy beta emitters) or via liquid scintillators. Therefore photon transport through a microfluidic system is a key area to target for improvement and development to reduce analysis time and achieve the best limit of detection. Numerical modelling, coupled with non-radiogenic and radiogenic testing has been used to assess the impact of bulk design features on photon transmission and detection through microfluidic systems; enabling improved designs to realise better counting efficiency and overall platform design. A prototype radioanalytical LoC system integrated with a detection system has been developed, manufactured and undergone initial testing with ^{90}Sr. Our work established the capability to reduce material consumption and the requirement for specialist facilities needed for handling radioactive materials during the initial characterisation process. This constitutes a proof of concept and the first step toward robust in-situ microfluidic detection for pure β emitting radionuclides that is capable of integration with autonomous platforms to enable remote detection and monitoring.

Organic semiconductor radiation alpha and neutron detectors

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In recent decades organic electronics have entered mainstream use in consumer electronics found in households around the world. I will discuss radiation sensors based on organic semiconductor technology, and in particular applications related to detection of hadronic radiation. This includes α particles, thermal and fast neutrons. The environmental stability of these devices is also discussed.

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