ITWG Nuclear Forensics International Technical Working Group

ITWG NUCLEAR FORENSICS UPDATE

No. 19 June 2021

CHAIRPERSONS' ADDRESS

Welcome to the Nuclear Forensics International Technical Working Group (ITWG) newsletter. As signs of progress against the Covid-19 pandemic emerge, the ITWG held its annual meeting on 15–18 June 2021 with more than 100 experts from nearly 35 countries participating. While it was held via Zoom—a word many of us may not have known at our last annual meeting in 2019—the event provided an opportunity to reconnect and take stock of our work in the field of nuclear forensics. One prominent feature of the virtual meeting was a panel discussion marking ITWG's 25th anniversary. The panel included past ITWG leaders and allowed us to better contextualize our work and reflect on the evolution of international nuclear forensics efforts since the mid-1990s. In addition to the annual meeting, ITWG continues its webinar series which will reconvene in July with a presentation on the Graded Decision Framework, and in September, ITWG will initiate its seventh collaborative materials exercise. In this issue of the newsletter, you will find articles about nuclear forensics efforts in Romania (page 1) and Singapore (page 3) as well as a readout of the fourth iteration of ITWG's Galaxy Serpent exercise. Finally, there is a new section to the newsletter that identifies recently published articles related to nuclear forensics. We hope this will be of interest to readers and help better connect this community.

With best regards,

Klaus Mayer and Michael Curry

NUCLEAR FORENSICS: 10 YEARS A FULL-TIME JOB

ANDREI I. APOSTOL

The threat

The threat of crimes involving nuclear or other radioactive (RN) material is real, evolving and becoming more sophisticated and diverse. The first registered cases in the 1990s and early 2000s were characterized by unauthorized possession of RN materials or associated with illicit trafficking and malicious intent. They mostly featured misguided individuals in search of personal profit or revenge. The potential for assassination or terrorist acts involving radioactive material existed, but was not generally seen as posing a major threat. In the 2000s, cases such as the 2006 Litvinenko poisoning in London using polonium-210 demonstrated both an intent to use RN materials in high-profile assassinations and a very different level of sophistication. In addition, European experience in recent years shows that nuclear security threats have diversified even further as groups associated with international organized crime learn how to use RN materials for profit. In 2018, the Romanian and German authorities discovered that organized crime groups had obtained the capability to industrially manufacture items with integrated radioactive isotopes (iodine-125), bring these to Europe from East Asia, and use them along with hand-made radiation detection equipment for illicit gambling purposes.

Contemporary nuclear forensic scientists, law-enforcement agencies and judicial authorities now face a highly diverse set of perpetrators and a wide range of RN materials, many of which are quite exotic. Some of these threats are not immediately evident. Romanian experience demonstrates that appropriate nuclear forensics investigations have to be considered for all nuclear security events involving nuclear or other radioactive material outside of regulatory control (MORC).

Implementing nuclear forensics capabilities: The Romanian success story

In the past four years, the nuclear forensics team at the Horia Hulubei National Institute for R&D in Physics and Nuclear Engineering (IFIN-HH) has responded to 12 genuine criminal cases involving RN material

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Nuclear Forensics in Romania *continued from page 1*

Figure 1. Characterization of radioactive evidence by the Romanian Nuclear Forensics Laboratory team

(see figure 1). This has not been at a steady rate of three cases per year. Rather, the number of cases has increased almost exponentially over time, resulting in eight criminal cases in the past two and a half years at the time of writing of this article.

These cases involved seizures or discoveries of radioactive sources, nuclear materials, and of evidence contaminated with radionuclides, leading to the opening of a criminal case and a detailed investigation involving national nuclear forensics capabilities and subject matter expertise.

The increase in the number of seizures of MORC in Romania in recent years should be seen not as a sign of growth in criminal interest in or access to RN materials, but as a change in response strategy to nuclear security events by the national authorities. This change occurred gradually. First, at the Nuclear Security Summit in 2016 the President of Romania, Klaus Iohannis, announced a commitment to strengthening national capabilities in nuclear forensics investigations.[1]

Second, the Romanian authorities have benefited from absorbing the messaging from and experience of exercises developed by the Global Initiative to Combat Nuclear Terrorism (GICNT), such as Olympus and Olympus Reloaded hosted by the Government of Romania, Destiny Elephant hosted by the Government of Thailand and Resolute Sentry hosted by the Government of Canada. All these exercises focused on cooperation between scientific and legal experts on fictional scenarios that described illicit activities involving RN materials. The exercises increased awareness among the Romanian authorities of the legal procedures that must be followed when responding to nuclear security events.

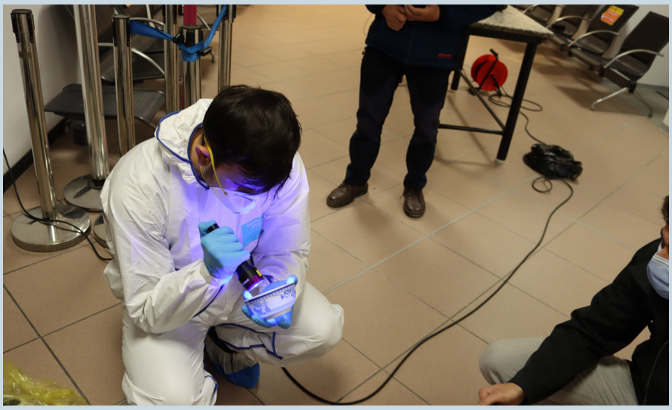
Third, the national approach began to transition from categorizing nuclear security events as an emergency and prioritizing the security of the source of radiation by transporting it to a safe location to strictly following the Criminal Procedural Code (CPC) and immediate notification of prosecutors, who in turn started to consider opening a criminal case. This opened up new opportunities for prevention.

The role of the prosecutor in criminal cases is regulated by the Romanian CPC. The prosecutor is the lead entity in a criminal case or investigation of illicit trafficking of RN material—not the police or the nuclear regulatory body or any other national authority. She/he can delegate appropriate aspects to the police to proceed with an investigation. The prosecutor decides what department of the police and which experts or specialists to work with, and can order urgent special investigative measures to commence within 48 hours and the detention of suspects for 24 hours. Prosecutors are also able to request or provide international judicial assistance and form a joint investigation team with the authorities of other states.

The initial circumstances of a case often look fairly routine or innocuous, and do not appear to require the involvement of a prosecutor or law enforcement.[2] However, certain provisions of the CPC require various non-judicial entities that have knowledge of any suspicious activities that could result in a criminal offence to report such incidents to the appropriate criminal investigation bodies. These in turn consider opening a criminal case in order to conduct a criminal investigation. The main goal of an open criminal investigation is to find the truth about the facts and circumstances of the case, and the suspect or defendant. It can often reveal the criminal intent of perpetrators and, in some cases, the involvement of organized crime. Probably the main lesson learned from the first decade of Romanian nuclear forensics practice is the importance of opening and duly conducting a proper criminal investigation as described in the national CPC whenever nuclear or other radioactive material is discovered outside of regulatory control.

Conclusions

Romania transitioned from no criminal cases opened in response to seizures of MORC to several cases every year (see figure 2). This was simply a response to national authorities starting to strictly follow the



Figures 2 and 3. Characterization of radioactive evidence by the Romanian Nuclear Forensics Laboratory team at a crime scene

existing legal framework in the National CPC and considering opening a criminal case after every seizure of MORC.

In support of these investigations, the Romanian Nuclear Forensics Laboratory (NFL-RO) of the IFIN-HH integrated all the necessary procedures described in the CPC focused on expertise, findings, the selection of experts and reporting results.[3] Today, it stands ready to assist the judicial authorities and to provide radiological crime scene management and nuclear forensics expertise that follow the rules of radiation protection and all legal provisions (see figure 3). •

NUCLEAR FORENSICS: CAPABILITY BUILDING AT THE DSO NATIONAL LABORATORIES, SINGAPORE

BOON KIN PONG AND DORIS HO MER LIN

Nuclear forensic science is the analytical examination of nuclear and radioactive materials to determine their origin and history. The outcome of the examination is important not only for law enforcement investigations, but also for rectifying vulnerabilities in nuclear security practice. Armed with information on the provenance of the nuclear/radioactive materials, authorities are able to nip threats in the bud.

Despite the importance of nuclear forensics investigations following a nuclear security event, it is important to recognize that the *immediate needs* following such an event are *effective responses* to protect people, assets and the environment. This means developing a set of effective and timely responses to the available information, such as the identity, quantity, physical form and distribution of the nuclear or radioactive material. The identity of the radioisotopes and their physical form, for example, will help to identify the optimal approach to radiation protection.

DSO National Laboratories (DSO) conducts research to enhance the effectiveness of Singapore's nuclear forensics capabilities and its response to nuclear security events.

Over the past decade, DSO has built up a suite of capabilities for investigative studies of nuclear and radioactive materials. These capabilities support national response to and recovery from incidents involving radiological or nuclear materials.

Gamma-ray spectrometry in the field

In a nuclear security event, the identity of the radioisotopes is arguably the most important piece of information for both nuclear forensics and response planning. High-resolution gamma-ray spectrometry using high-purity germanium (HPGe) crystal has enabled spectroscopists to identify radioisotopes from their characteristic gamma rays. Advances in electrical cooling technology have allowed the practical deployment of these spectrometers in the field, eliminating the cumbersome logistical requirement for liquid nitrogen. However, unlike the laboratory setting where heavy lead shields can be used, interference from natural background radiation presents many challenges for the spectroscopist operating in an open environment.

To enable faster and more reliable detection and identification of suspicious radioisotopes in an open environment, DSO is developing a computer code to achieve accurate, autonomous interpretations of complex gamma spectra (see figure 1).

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Nuclear Forensics: Capability Building at the DSO Laboratories *continued from page 3*

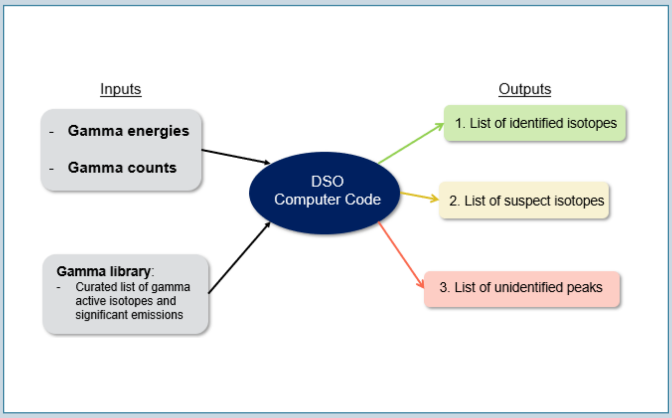

Figure 1. Development of computer code to achieve high-confidence interpretation of gamma spectra

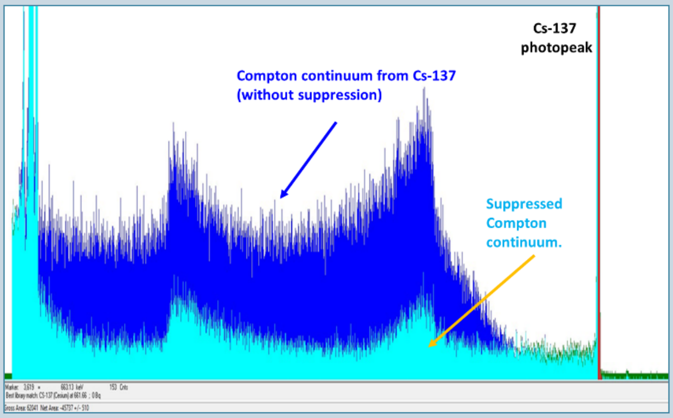

Figure 2. Suppressing the Compton scattering in the gamma spectrum can improve the detection limits for low-energy photons, such as those from nuclear materials

Activity of shielded radioactive materials

On discovery or seizure of illicit radioactive material, the 'hotness' of the material has a direct impact on its handling and management. This makes the level of activity of the radioisotope important information. While gamma-ray measurements can be used to quantify radioactivity fairly readily, these can be confused by packaging and/or shielding materials. To quantify a shielded or heavily packaged radioisotope, the extent of radiation shielding must be determined, for example, using X-ray imaging to identify shield thickness. In an emergency situation such as a potential Radiological Dispersal Device, it may not be possible to determine the level of shielding without posing additional hazards to the response team.

DSO has developed a method for quantifying directly shielded radioisotopes without the need to determine the identity of the shielding material or its thickness. The method is able to quantify the radioisotope with reasonable accuracy to support decision making on the handling and management of the radioactive source.

Compton-suppressed gamma spectrometry

Compton scattering of gamma photons is a nuisance in gamma spectrometry. It increases spectrum background noise, causing the detection limits of radioisotopes to deteriorate. The Compton continuum, which is usually more pronounced at lower energy, is particularly unfavourable for nuclear materials investigations. DSO is conducting research to discriminate Compton events from photopeak events and allow Compton events to be discarded from the spectrum. This will lead to significantly lower background noise at the low-energy region, leading to better detection limits for signatures arising from nuclear materials (see figure 2).

Enhancing mass spectrometric analysis for nuclear materials

Mass spectrometry techniques are ideal for long-lived isotopes, such as many of the isotopes associated with nuclear materials. In mass spectrometric analysis, isobaric interference and cross-talks have to be resolved. For example, the analysis of plutonium can be plagued by the presence of natural uranium interferents. Common approaches include radiochemical separation using solid phase extraction, and the use of alpha spectrometry to complement mass spectrometry results. In order to shorten the analytical time, DSO has developed a direct method that circumvents natural uranium isobaric interference from plutonium ICP-MS data. This approach significantly shortens the analysis time from days to hours.

Another approach to removing isobaric interference in mass spectrometry is to introduce reactive species into the sample stream that will selectively react and bind to the interferent. This approach was successfully demonstrated by removing Zr-90 to allow Sr-90 analysis. In this case, the reactive species binds to the zirconium ions, thereby 'red-shifting' its effective mass by the mass units of the bonded reactive species, allowing Sr-90 to be detected.

The forensics of radiological materials

Following on from the advances made in forensic science for nuclear materials, DSO is working on similar forensics studies with radiological materials. The immediate target is to identify possible characteristics of radiological materials, such as Ir-192 and Cs-137, that can be used as forensic signatures. •

ITWG LIBRARIES TASK GROUP UPDATE: SUMMARY RESULTS FROM THE FOURTH GALAXY SERPENT EXERCISE

JIM BORGARDT

About Galaxy Serpent

Galaxy Serpent (GS) is a recurring series of virtual, web-based nuclear forensics library tabletop exercises conducted under the auspices of the ITWG National Nuclear Forensics Libraries (NNFL) task group. The exercises are designed to raise awareness of the technical aspects of developing and applying an NNFL, and to demonstrate the value of an NNFL in supporting nuclear forensics investigations. They provide participants with challenging problem sets with real-world attributes. Each version of the exercise uses surrogate data to model a different nuclear or other radioactive material (RN). Teams also use data analytics to identify the connections between materials and assess provenance, answer simulated investigative questions giving a confidence level, and consider what additional nuclear forensics data would have been helpful in addressing the questions posed Teams are provided with realistic surrogate data that does not contain sensitive or proprietary information.

The common aim of all these efforts is to provide valuable experience for participants by creating datasets that feature real-world challenges, such as missing or ambiguous data, while maintaining the defining attributes of a realistic data set that is manageable in size and scope. In Phase 1 of each exercise, teams are asked to leverage their expertise to organize the data into a model NNFL that can be used for comparative analysis in the context of a nuclear forensics investigation. In later phases, teams are presented with constructed scenarios in which material outside of regulatory control (MORC) has been recovered, and are asked to answer a series of increasingly challenging questions regarding material provenance as part of a hypothetical investigation using their exercise-developed NNFL as a comparative instrument. In GSv3 and GSv4, teams were also asked to ascribe a confidence level using the draft Graded Decision Framework and to identify missing nuclear forensics data that, if known, would help answer the questions posed.

GSv4 featured a deliberate shift in focus from prior iterations of the exercise. While some multivariate techniques could be applied, GSv4 did not focus on organizing data or using multivariate analysis to do larger comparative analyses. Instead, the focus was on working with more limited datasets, statements that could be made in support of an ongoing investigation involving radioactive or nuclear material, and what additional data would help answer investigative questions with greater confidence.

Methodologies and results

GSv4 used realistic surrogate fuel pellet data based loosely on commercial power reactor fuels. Teams were provided with a hypothetical commercial power reactor pellet database for 30 reactors that included data on characteristics such as dimensions, enrichment, select trace elements and production plant or supplier of pellets. The data set was sparse as a relatively high percentage of cells had missing data but robust as sufficient data density was provided to address the questions posed in the exercise. The data was designed to reflect real-world challenges such as missing data, the non-availability of measurement uncertainties and ambiguous descriptors.

After assessing and organizing the data set in Phase 1, teams were provided with materials characteristics data for a subset of ten hypothetical fuel pellets from a cache of about 140 pellets recovered out of regulatory control in a residential garden. This data included scanning electron microscope (SEM) images for one of the pellets. In Phase 2a, a second potential site was discovered, leading to the recovery of a small bag of radioactive powder from a garden shed in a neighboring community. Teams were provided with powder data, including trace elements, uranium assay, uranium isotopics, grain size distribution and an SEM image, and asked to determine whether this

Table 1. Overview of Galaxy Serpent exercises

	Date	Teams	Participants	Material of interest	Source
GSv1[1]	Feb. 2013–Apr. 2014	18	64	Spent fuel	Spent Fuel Compositions (SFCOMPO) Database
GSv2[2]	June 2015–Jan. 2016	35	137	Rad sources	Argonne National Laboratory
GSv3[3,4]	June 2017–Feb. 2018	29	132	Uranium ore concentrate	Lawrence Livermore National Laboratory
GSv4	Sep. 2019–Sep. 2020	38	204	Fuel pellets	Lawrence Livermore National Laboratory

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ITWG Libraries Task Group Update *continued from page 5*

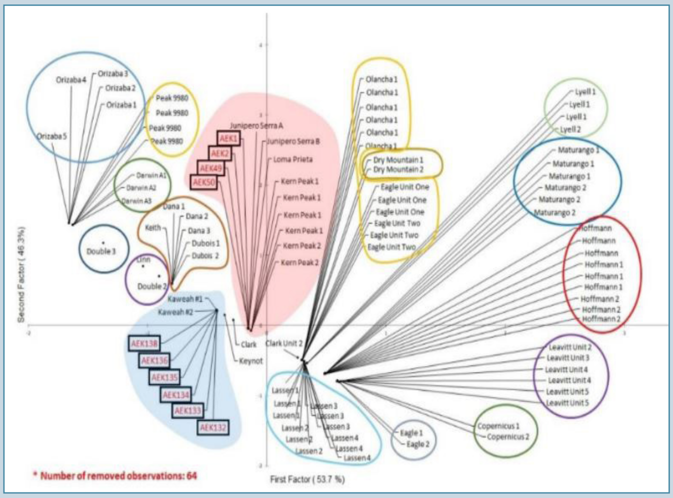

Figure 1. Pellet dimensions (height and diameter) discrimination using principle component analysis (PCA)

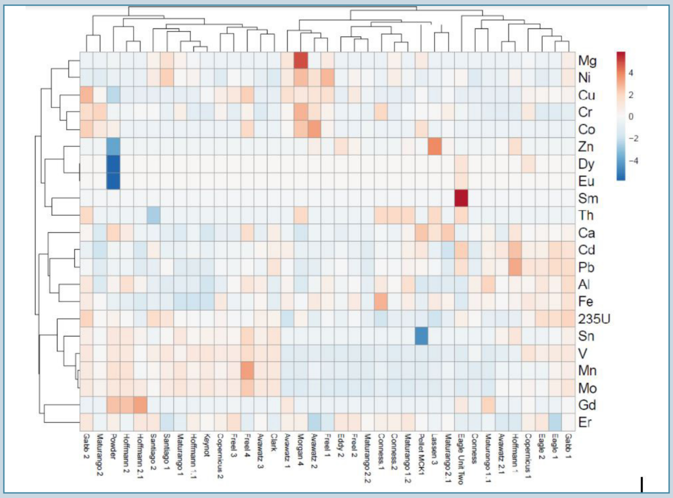

Figure 2. Reduced pellet dataset processed using the ClustVis software package

powder was consistent with pellets in their model NNFL. In Phase 2b, an alleged fuel pellet for sale on eBay was recovered. Teams were given forensics data, including photographic and SEM images of the pellet, and asked to use the data provided in the exercise as a comparative instrument to assess the consistency of this pellet with their model NNFL, the cache of pellets or the powder.

Of the 38 participating teams, 30 submitted the initial, partial report and 34 submitted complete informational reports. The pandemic interrupted the exercise, introducing a four-month pause, and presented a challenge for several teams. Teams used a wide variety of statistical tools and comparative analyses to answer the questions posed. In Phase 1, teams primarily focused on isotopic composition, elemental composition and dimensional analysis (see figure 1) as discriminating factors to determine reactor provenance with the model NNFL. Teams generally identified the pellets as consistent with the Kaweah Gap pellet producer, and the Junipero Serra A, Junipero Serra B and Kaweah 1 reactors. In Phase 2a, teams generally identified the powder as consistent with the Sierra Nevada pellet producer and the Hoffman 2 reactor in their library, and noted that additional data such as density, specific isotopic ratios, complete rare elements and uranium age dating might be helpful in answering the questions posed. Figure 2 gives one example of the variety of analyses teams used in Phase 2a. In Phase 2b, teams generally identified the hypothetical eBay pellet as a non-conforming pellet, possibly from a reject pile from the Kaweah Gap pellet producer consistent with pellets designed for Lyell 1. Teams identified that data such as O:U ratio, specific elemental compositions, and radioisotope pairs such as 234U–230Th and others

NOTABLE PUBLICATIONS ABOUT THE WORK OF THE ITWG, NUCLEAR FORENSICS AND RELATED DISCIPLINES

- Kroeger, E. A., Rupp, A. and Gregor, J., 'Misuse of a medical isotope: 125I labeled playing cards in Germany, a case study', *Health Physics*, vol. 119, no.1 (July 2020), pp. 128–132.
- Thompson, N. B. A., Gilbert, M. R. and Hyatt, N. C., 'Nuclear forensic signatures of studtite and α-UO3 from a matrix of solution processing parameters', *Journal of Nuclear Materials*, 544, 3 Dec. 2020.
- Thompson, N. B. A. et al., 'Nuclear forensic signatures and structural analysis of uranyl oxalate, its products of thermal decomposition and Fe impurity dopant', *Journal of Radioanalytical and Nuclear Chemistry*, 327, 6 Jan. 2021.
- Keatley A. C. et al., 'Uranium isotope variation within vein type uranium ore deposits', *Applied Geochemistry*, published online, 12 May 2021.

for age dating would be useful to better answer the questions posed.

Looking ahead

As in past versions, teams employed a variety of analytical methodologies and dealt with the real world challenges built into the exercise design in different ways. The exercise design led to common findings on some questions but a greater diversity of responses on others. This diversity was largely attributable to the embedded ambiguities in the data provided and the degree of assigned confidence. The exercise was a structured opportunity for teams to build and hone their expertise. The results illustrate the value of an NNFL that contains subject matter experts, and as a comparative tool for assessing the consistency of MORC with national material holdings. NNFLs can play a vital role in supporting investigative efforts involving nuclear or other radioactive MORC.

A fifth version of the exercise is in development with a planned start date of the spring of 2022. It will feature a greater focus on establishing the consistency or inconsistency of a sample with national material holdings and attributing a level of confidence to conclusions. It will also focus on the role of a library throughout different phases of an investigation, rather than summative findings, to understand how the library influences each stage of the forensics examination, shapes subsequent analyses and provides valuable feedback to law enforcement. •

UPCOMING TRAINING COURSES AND MEETINGS*

- ITWG Annual Meeting, Virtual, 15–18 June 2021
- ITWG Webinar: Graded Decision Framework, Virtual, 20 July 2021
- ITWG Webinar: Subsampling Protocols for Solid Objects and Powders—Approaches to Subsampling Actinide-containing Solids, Virtual, 10 August 2021
- IAEA International Training Course on Practical Introduction to Nuclear Forensics, Budapest, Hungary, TBD September 2021
- ITWG Webinar: Analytical plan—What to Measure on What Items, Including Subsampling Protocols for Solid Objects and Powders, Virtual, 14 September 2021
- IAEA International Training Course on Introduction to Nuclear Forensics, Bangkok, Thailand, 27–30 September 2021
- ITWG Webinar: Rad Source Identification, Virtual, 12 October 2021
- NuFor 2021 (Nuclear Forensics Conference), London, England, 13–14 October 2021
- IAEA Regional Training Course on Nuclear Forensics for Association of Southeast Asian Nations (ASEAN) Members, Daejeon, Republic of Korea (ROK), 18–22 October 2021
- ITWG Webinar: Fuel Cycle (Mining and Milling, Conversion, Enrichment, Pelletization, Different Reactor Types) and Nuclear Forensic Signatures Related to Different Processes, Virtual, 9 November 2021
- 12th International Conference on Methods and Applications of Radioanalytical Chemistry (MARC XII), Kailua-Kona, Hawaii, United States, 3–8 April 2022
- IAEA Technical Meeting on RCSM and Nuclear Forensics, IAEA Headquarters, Vienna, Austria, 11–14 April 2022

*Please check directly with the event organizer on the status and dates for implementation of the individual events listed above.

Dates and locations of IAEA training courses and meetings will be officially confirmed with host member states; participation in IAEA training courses and meetings is by nomination and in accordance with established IAEA procedures.

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* For reference information related to this article, click various corresponding footnote numbers.

NUCLEAR FORENSICS

Nuclear forensics is an essential component of national and international nuclear security response plans to events involving radioactive materials diverted outside of regulatory control. The ability to collect and preserve radiological and associated evidence as material is interdicted and to conduct nuclear forensics analysis provides insights to the history and origin of nuclear material, the point of diversion, and the identity of the perpetrators.

THE NUCLEAR FORENSICS INTERNATIONAL TECHNICAL WORKING GROUP

Since its inception in 1995, the Nuclear Forensics International Technical Working Group (ITWG) has been focused on nuclear forensic best practice through the development of techniques and methods for forensic analysis of nuclear, other radioactive, and radiologically contaminated materials. The objective of the ITWG is to advance the scientific discipline of nuclear forensics and to provide a common approach and effective technical solutions to competent national or international authorities that request assistance.

ITWG PRIORITIES AND ACTIVITIES

As a technical working group, the priorities for the ITWG include identifying requirements for nuclear forensic applications, evaluating present nuclear forensic capabilities, and recommending cooperative measures that ensure all states can respond to acts involving illicit trafficking and unauthorized possession of nuclear or other radioactive materials. An objective of the working group is to encourage technical peer-review of the nuclear forensic discipline. These goals are met through annual meetings, exercises, and informal and formal publications.

Outreach is a primary goal of the ITWG. The working group disseminates recent progress in nuclear forensic analysis and interpretation with the broader community of technical and security professionals who can benefit from these advancements. Affiliated international partner organizations include the International Atomic Energy Agency (IAEA), the European Commission, the European Police Office (EUROPOL), the International Criminal Police Organization (INTERPOL), the Global Initiative to Combat Nuclear Terrorism (GICNT) and the United Nations Interregional Crime and Justice Research Institute (UNICRI).

ITWG MEMBERSHIP

Nuclear forensics is both a technical capability as well as an investigatory process. For this reason the ITWG is a working group of experts including scientists, law enforcement officers, first responders, and nuclear regulators assigned by competent national authorities, affiliated contractors, and international organizations. The ITWG is open to all states interested in nuclear forensics.

ITWG participating states and organizations recognize that radiological crimes deserve thorough investigation and, when warranted, criminal prosecution. The ITWG encourages all states to possess the basic capability to categorize nuclear or other radioactive materials to assess their threat. As an international group, the ITWG shares its expertise through its membership to advance the science of nuclear forensics as well as its application to nuclear security objectives.

http://www.nf-itwg.org/

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