ITWG
NUCLEAR FORENSICS
UPDATE
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CHAIRPERSONS' ADDRESS

Welcome to the Nuclear Forensics International Technical Working Group (ITWG) newsletter. With the IAEA hosting a Technical Meeting on Nuclear Forensics in Vienna (1–4 April 2019), we are eager to share this tenth edition of our quarterly newsletter, which includes several updates from the forensics community. This edition of the 'Update' includes an introduction to the IAEA Coordinated Research Project on forensics, a summary of outcomes from the third iteration of the Galaxy Serpent exercise, an article on the ITWG collaborative material exercise (CMX) series and a calendar of upcoming forensics activities. As the April Technical Meeting takes stock of forensics activities around the world and helps chart a path forward, we would like to acknowledge the longstanding collaboration between the ITWG and IAEA and the many IAEA contributions to our community in the form of training, guidance and workshops. We wish organizers and participants a productive and successful Technical Meeting.

With best regards,
Klaus Mayer and Michael Curry

IAEA COORDINATED RESEARCH IN NUCLEAR FORENSIC SCIENCE: THE ESSENTIAL CONTRIBUTION FROM THE ITWG

DAVID KENNETH SMITH

The need for international research in nuclear forensics

Scientific discovery is the bedrock of a sustainable programme in nuclear forensics: it enables the objective technical review of methods applicable to an examination of nuclear and other radioactive material encountered out of regulatory control and offers better insight into the origin and history of these materials. Furthermore, the possibility that findings from a nuclear forensics examination may be used in a legal proceeding requires the analysis and interpretation to be as close to unassailable as possible. Active collaborations are critical as they facilitate the sharing of results between states with developed nuclear forensics capabilities and other states that are presently developing those competencies. Human resource development within nuclear forensics must be pursued in order to attract and elicit new insights from the next generation of investigators in nuclear forensics science and related disciplines. Thus, efforts to advance nuclear forensics as a discipline hinge on the future of coordinated international research.

Coordinated research projects at the IAEA

The International Atomic Energy Agency (IAEA) has promoted coordinated research as part of a broader programme of assistance in nuclear forensics to member states over the past decade. Coordinated research activities at the IAEA have long been an institutional component supporting the IAEA's mandate of 'Atoms for Peace and Development' since the Agency's inception in 1957. The IAEA awards coordinated research projects (CRP) funds to advance specific scientific studies, and this assistance differs from that provided under other, often larger, initiatives to build capacities to include those of the Agency's technical cooperation programme. In any one year, more than 135 CRPs involving some 1600 research institutions worldwide are active across the IAEA in areas of isotope and radiation science as well as in radiation applications in agriculture, human health, industry and hydrology. CRPs also are a part of the Agency's programmes in nuclear energy, nuclear safety and nuclear security.

Continued page 4

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

JIM BORGARDT

About Galaxy Serpent

Galaxy Serpent is an ongoing series of virtual, web-based nuclear forensics library tabletop exercises conducted under the auspices of the National Nuclear Forensics Libraries (NNFL) task group of the ITWG. The exercises are designed to raise awareness of the technical aspects of developing and using an NNFL, provide participants with challenging problem sets aimed at advancing an NNFL's technical capabilities, and demonstrate the value of an NNFL, when appropriately utilized by subject matter experts, for answering questions in support of an ongoing nuclear forensics investigation. Each version of the exercise employs surrogate data to model a different nuclear or other radioactive material, providing participants with an opportunity to organize material characteristic data and use data analytics to identify the connections between materials and assess provenance.

The first version of Galaxy Serpent (GSv1) used repurposed data culled from the Spent Fuel Composition (SFCompo) database.[1] GSv2 used synthetic data for radioactive sealed sources in the form of simulated vendor catalogues, shipping manifests and other data streams.[2] GSv3 used surrogate trace element data for uranium ore concentrates (UOCs).[3] The exercises involved an average of 27 teams and 110 participants. In each exercise, teams were provided with realistic data that did not contain sensitive or proprietary information. The common aim of all these efforts is to embed 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 out of regulatory control 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.

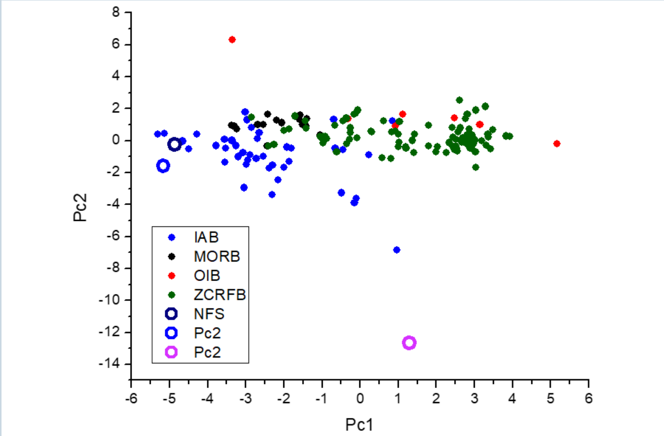

Figure 1. Sample plot of average concentrations of a subset of elements for the four UOC classes (solid lines) and the three unknowns (dotted lines).

Methodologies and results

GSv3 employed surrogate UOC data derived from geochemical data on basalts. The data set was composed of four classes of UOC (named IAB, MORB, ORB and ZCRFB) and a number of records that provided a manageable data set without sacrificing defining attributes. The data set included elemental concentrations but no uranium isotopic data, as participants were told to assume natural uranium composition. The data set also included missing data by design. Measurement uncertainties were not provided as variation within each of the classes was assumed to be much greater than any analytical uncertainties.

[1] Borgardt, J. D. and Wong, F. M. G., 'Galaxy Serpent: A web-based tabletop exercise using the concept of national nuclear forensics libraries', *Journal of Nuclear Materials Management*, vol. 42, no. 4 (Summer 2014), pp. 4–11.

[2] Borgardt, J. D., Canaday, J. and Chamberlain, D., 'Results from the second Galaxy Serpent web-based table top exercise utilizing the concept of nuclear forensics libraries', *Journal of Radioanalytical Nuclear Chemistry*, vol. 2, no. 311 (Feb. 2017), pp. 1517–24.

[3] Marks, N., 'Designing and validating the Galaxy Serpent 3 dataset', *ITWG Update*, no. 6 (Mar. 2018), pp. 6–7.

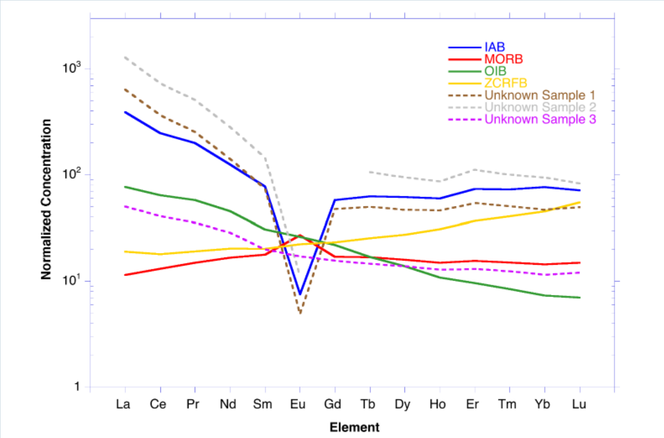

Figure 2. Sample plot employing a particular statistical technique, applied to a 17-element subset of the full data set for the four UOC classes (filled circles) and the three unknowns (open circles), suggesting that two of the unknowns are consistent with one of the classes and the third is inconsistent with all four of the classes.

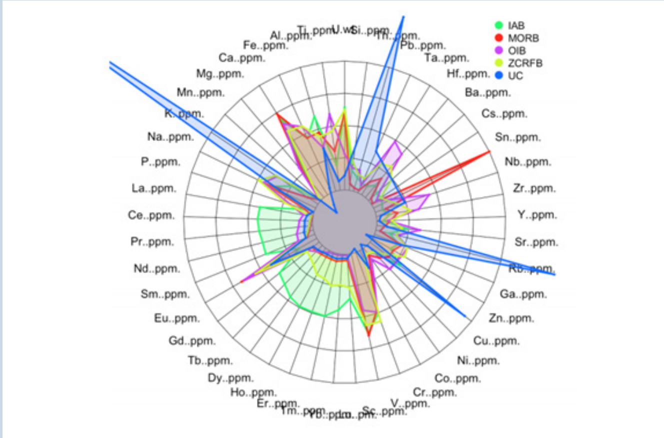

Figure 3. Plot submitted by a team showing a statistical assessment applied to the four classes of UOC data provided and the third unknown (in blue), providing evidence it is not consistent with material in the model NNFL.

After assessing and organizing the data set in Phase 1, teams were presented with data for three hypothetical barrels of UOC recovered out of regulatory control. In Phase 2a, teams were asked to determine whether material in any of the barrels was consistent with those in the other barrels. In Phase 2b they were asked to use the data set organized in Phase 1 as a comparative instrument to assess the consistency of material in the each of the barrels with the four affinities represented in the surrogate UOC data.

Of the 29 teams participating in this exercise, 22 submitted informational reports. Teams employed a wide variety of statistical tools to answer the questions posed. These methods varied in their specific approach but shared a common goal of examining and leveraging elements of a data set to identify characteristics that make it possible to discriminate between the classes within a data set. Thus, when data for an unknown is similarly analysed, it is possible to determine whether the unknown is, or is not, consistent with belonging to one of these classes. Figures 1–3 show examples of some of the many techniques employed. Teams dealt with missing data in different ways. At least three of the teams reported using data imputation to populate these fields, but it is likely that additional teams may have done so but not explicitly noted this in their reports. In Phase 2a, all the reporting teams found, as anticipated by the exercise organizers, that two of the unknowns were of common provenance, while the third was not consistent with the other two unknowns. In Phase 2b, all the reporting teams found, as anticipated, that the two similar unknowns were consistent with one class of UOC in the model NNFL. In addition, 17 of the 22 teams reported, as anticipated, that the third unknown was not consistent with any class of UOC represented in the model NNFL; the other five teams identified this unknown as being consistent with a different UOC class. The reports submitted indicate that relying on just one methodology suggests a consistency with an affinity in the model NNFL that other methods would not have confirmed.

Looking ahead

In the GSv3 exercise, as in past versions, teams employed a variety of analytical methodologies that produced consistent findings. The exercise was a structured opportunity for teams to build and hone their expertise, and the results from the exercise illustrate the value that an NNFL that includes subject matter experts, provides as a comparative tool for assessing the consistency of material found out of regulatory control with an existing NNFL. NNFLs can play a vital role in supporting investigative efforts that involve nuclear or other radioactive material out of regulatory control. A fourth version of the exercise is planned for late 2019. It will feature a greater focus on the role of an NNFL and expert interpretation, in answering investigative questions and generating investigative leads to support of a nuclear forensics investigation. •

IAEA coordinated research in nuclear forensic science… *continued*

Coordinated research encourages the acquisition and dissemination of new understanding, methodologies and technologies involving nuclear and radiation science that can be used by all IAEA member states. It is important that CRP findings be available to all member states through open publication and technical exchange. The IAEA solicits and evaluates two types of proposals for inclusion in a CRP: research agreements and research contracts. Research agreements are unfunded and represent institutes in developed member states; research contracts are funded and represent institutes in developing member states. Approximately 15 research institutes (e.g. universities, national laboratories, nuclear and radiation science organizations or centres) propose their own topics under the title of one CRP and subsequently work together over the 3- or 4-year duration of the CRP. Each individual proposal requires a chief scientific investigator. The chief scientific investigator is the single point of contact between the IAEA and the ongoing research and must represent the research through progress and final reports to include participation in periodic IAEA research coordination meetings.

Nuclear forensics coordinated research projects: 2008 to the present

Nuclear forensics represented the inaugural coordinated research undertaken by the IAEA Division of Nuclear Security within its programme of nuclear security assistance. Two nuclear forensics CRPs have now been completed and a third has recently commenced. These CRPs represent a progression from more general studies of non-destructive and destructive analyses relevant to nuclear forensics to subsequent and more specific studies that improve the implementation of nuclear forensics in support of law enforcement and nuclear security investigations.

The first nuclear forensics CRP was entitled 'Application of Nuclear Forensics in Combating Illicit Trafficking of Nuclear and Other Radioactive Material' [IAEA Tracking J02001] and ran from 2008 to 2012. The focus of the work was to develop technical capabilities to help member states stem the illicit trafficking of nuclear and other radioactive materials first reported in the early 1990s. The CRP concentrated on application of nuclear forensic analytical techniques that can assist in the identification of the origin of nuclear and other radioactive material and in determinations of the history as well as the routes of transit of such trafficked material. Also studied were other techniques to include traditional forensic science techniques (e.g. fibers, DNA, fingermarks) to exploit evidence contaminated with radionuclides as relevant to potential criminal prosecutions. The CRP returned results for improved procedures and techniques for (1) the categorization of seized material at site; (2) the preservation of evidences and guidelines and techniques for transportation of evidence; (3) the characterization and nuclear forensics investigations; (4) nuclear forensics interpretation; and (5) the provision of nuclear forensics support to requesting IAEA member states. Participating chief scientific investigators came from Australia, Brazil, the European Commission, Germany, Greece, Hungary and the Republic of Korea. Results were published in IAEA TECDOC 1730 (2014).

The second nuclear forensics CRP was entitled 'Identification of High Confidence Nuclear Forensics Signatures' [IAEA Tracking J02003] and ran from 2013 to 2016. The focus of this work addressed the data characteristics (i.e. signatures) for each stage of the nuclear fuel cycle and for the manufacture of radioactive sources. Studies promoted research into novel signatures that are indicative of nuclear processing and are important to nuclear forensics interpretation (e.g. application of high precision, high abundance sensitivity mass spectrometry; stable isotope systematics; optimized use of radiogenic isotopes and rare earth trace elements). The research differentiated signatures imparted naturally from those that are introduced as a result of production and manufacturing processes of nuclear materials during milling, isotopic enrichment, fuel manufacture and reactor operations. Research findings highlighted the role of new analytical techniques to include nuclear and radioactive material age dating (i.e. time of production); morphology studies of nuclear materials bearing on origin and history; the role of modelling to identify the origin of spent nuclear fuels as well as the application of rare earth elements to differentiate uranium ores and concentrates. Additionally, the research enabled investigators with diverse knowledge of the nuclear fuel cycle to share insights into recommended techniques and methods to measure and predict these signatures and therefore build confidence in the conclusions drawn from an examination. Participating chief scientific investigators came from Australia, Brazil, Canada, the European Commission, Greece, Hungary, India, Indonesia, South Africa, and Sweden. Results were published in IAEA TECDOC 1820 (2017).

The third, and current, CRP is titled 'Applying Nuclear Forensic Science to Respond to a Nuclear Security Event' [IAEA Tracking J02013] and commenced in 2019. The goal of this research is to promote consistent and scientifically defensible implementation of a nuclear forensics examination in concert with national laws and international legal instruments by linking nuclear science with investigative requirements. This research will yield enhanced methods to document and collect evidence, to identify nuclear and other radioactive materials that pose a nuclear security threat, and to process traditional forensics evidence contaminated with radionuclides. Furthermore, the project will contribute to improved quantitation of results using reference materials and sensitive techniques to measure small samples and particles. The findings will support better understanding and use of nuclear forensic science by law enforcement and other investigators. States will benefit from better implementation of validated procedures and methods that are consistent with the requirements of a successful criminal prosecution. Of interest is the use of gamma ray spectrometry and other techniques to increase the speed, accuracy and precision of categorization and characterization for states to optimize their existing nuclear forensics capabilities. Additional topics include the use of small sample techniques (including electron and ion microbeam) to limit complicated bulk sample digestions in the laboratory. The CRP includes study of trace impurities and isotope ratios of sealed radioactive sources used in industry and medicine. Experiments for this CRP may also probe the application of digital technologies for nuclear forensics (e.g. for centralized registration and cataloguing of evidence collected at a nuclear security event, establishing a chain of custody and disseminating the categorization results) as well as study digital evidence taken from radiologically contaminated devices. The IAEA has received proposals from more than 15 chief scientific investigators from around the world; these proposals are presently being evaluated as part of an institutional technical review.

Linking the ITWG and the IAEA in coordinated research

The scientific contribution from the ITWG to the IAEA's coordinated research activities in nuclear forensics remains essential. As an informal association of nuclear forensics practitioners, the ITWG is a forum for current advancements in evidence collection, guidelines for analysis, national nuclear forensics libraries, and methods ultimately used in case work. Recently at the 2016 ITWG-21 Annual Meeting in Lyon, at the request of the IAEA, the ITWG convened a 'World Café Session' to solicit research needs from the ITWG membership. Outcomes included a roadmap for research to include the topics of nuclear forensics methodologies (chemical, isotopic, particles and bulk analysis), classical forensics involving evidence contaminated with radionuclides, nuclear forensics interpretation (data quality and national nuclear forensics libraries) as well as post-dispersion applications (sample collection and radionuclide fate and transport). The IAEA used the findings of the session to inform the priorities of its most recent CRP. An article by Vitaly Fedchenko in ITWG Update 3 (2017) provides further details of this ITWG special session and these outcomes.

Meeting needs through IAEA coordinated research in nuclear forensics

The IAEA has incorporated coordinated research as part of its fundamental programme of assistance to member states for more than 10 years. As important as the novel findings of each research project is the opportunity afforded by the CRP to bring investigators together to focus on advancing the science of nuclear forensics over the 3-to-4-year span of each CRP topic. By combining the contributions of different investigators and subject matter experts, access to unique laboratory infrastructure and distinct requirements for nuclear forensic science, coordinated research in nuclear forensics continues to flourish. •

TRENDS IN NUCLEAR FORENSIC ANALYSES: 20 YEARS OF COLLABORATIVE MATERIALS EXERCISES

JON M. SCHWANTES

Collaborative materials exercises (CMXs) are one of the primary ways ITWG works to identify and socialize best practices in the fields of nuclear forensic laboratory analysis and nuclear forensic interpretation. Since the first CMX in 1999, a total of 25 countries and the European Commission have participated in ITWG materials exercises. This series of exercises is designed to be a learning experience for participating laboratories, not a performance test. The exercises target questions that scientists are likely to be asked by investigators and prosecutors. For example, is it dangerous due to its radioactivity? Is its possession illegal? How was the material produced? Where and when did it escape regulatory control? What was the route from the point of loss of control to where it was seized by authorities? Can it be linked to other materials, persons, places or things?

The ITWG completed its fifth and largest CMX in 2017. It is currently in the midst of its sixth CMX, which promises to be as large as the one in 2017, with participating laboratories from 19 countries and one multinational organization (see figure 1 for a map of laboratories that have participated in ITWG CMXs).

Over the ITWG's 20-year history of CMXs, a number of trends in nuclear forensic analysis have emerged. First and foremost, the number of participating laboratories has more than tripled, from 6 participating labs during CMX-1 to over 20 for CMX-6. The number and breadth of analytical techniques participating labs have applied to these exercises has also dramatically increased in recent exercises (see figure 2). In the past two decades, new techniques have emerged in every category of analysis. Emerging technologies within physical

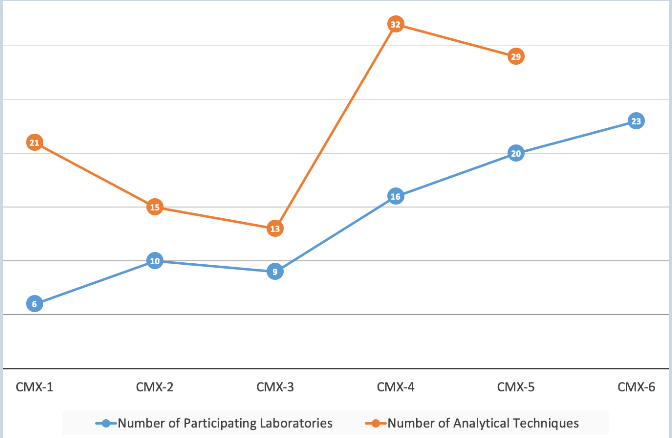

Figure 2. The number of laboratories participating in the CMXs and the measurement techniques used

Figure 1. Laboratories that took part in the ITWG Collaborative Materials Exercises

characterization during nuclear forensic analysis include the use of transmission electron microscopy (TEM), scanning electron microscopy-electron backscatter diffraction (SEM-EBSD), optical profilometry, and atomic force microscopy. Powder X-Ray diffraction (PXRD) was first used in CMX-4 and is now widely utilized within the community for phase identification. Additional techniques for phase identification in nuclear forensics are emerging, including optical microscope spectroscopies (such as infrared (IR) and Raman) as well as quantitative PXRD techniques like Rietveld refinement. An increasing number of nuclear forensic laboratories are also exploiting techniques capable of quantifying isotopic heterogeneity within solid phase materials such as secondary ion mass spectrometry (SIMS) and, more recently, laser ablation-inductively coupled mass spectrometry (LA-ICP-MS). However, not all trends in nuclear forensic analysis have been positively correlated in time over the history of CMXs.

A decreasing number of labs, for instance, are utilizing alpha spectrometry and ICP-optical emission spectroscopy (ICP-OES). In the case of alpha spectrometry, this technique is most likely being abandoned for more rapid and non-destructive techniques like gamma spectrometry or more precise techniques like mass spectrometry that can be accomplished in similar timeframes. In the case of ICP-OES, the decrease in the use of this technique seems to be inversely correlated to the greater adoption of ICP-MS, a similar, but more precise technique.

The identification and widespread acceptance of emerging technologies is a reminder that nuclear forensic analysis is still a young science. Developing an ability to interpret microstructural features or trace contaminants within a bulk phase or the extent of isotopic heterogeneity within special nuclear materials begins with that first step: the adoption of capable analytical techniques. Once adopted, the next step for the community will be to fully understand the capabilities and (more importantly) limitations of these new techniques. In other words, to gain the experience necessary to accurately interpret analytical results within the context of a nuclear forensics investigation. CMXs have served, and continue to serve, as a vital mechanism for maturing nuclear forensic science. •

UPCOMING TRAININGS AND MEETINGS

- IAEA ‘Nuclear Forensics: Beyond the Science’ Technical Meeting on Nuclear Forensics, Vienna, Austria, 1–4 April 2019
- GICNT Nuclear Forensics Working Group meeting, Helsinki, Finland, 23–25 April 2019
- JRNC 2nd International Conference on Radioanalytical and Nuclear Chemistry (RANC 2019), Budapest, Hungary, 5–10 May 2019
- 3rd International Conference ‘CBRNE–Research & Innovation’, Nantes, France, 20–23 May 2019 (www.cbrneconference.fr)
- IAEA 2nd Regional Seminar on Introduction to Nuclear Forensics (Russian-speaking), Moscow, Russia, 27–31 May 2019
- ITWG CMX-6 Data Review Meeting, Warsaw, Poland, 3–5 June 2019
- ITWG-24 Annual Meeting, Bucharest, Romania, 25–27 June 2019
- Nuclear Forensics Summer School, Kyiv, Ukraine, 9–13 September 2019 (Co-organized by Institute for Nuclear Research (KINR), EC-JRC and NNSA-NSDD)
- EC-JRC Nuclear Forensics Training Course for Balkan Countries, Novi Sad, Serbia, 24–26 September 2019

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

CONTENTS

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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