ITWG Nuclear Forensics
International Technical Working Group

ITWG
NUCLEAR FORENSICS
UPDATE
No. 3 June 2017

NUCLEAR FORENSICS: THE WAY AHEAD, A PERSONAL VIEW

KLAUS MAYER

Nuclear forensic science, as it is currently known, dates back to when the first incidents of nuclear smuggling were reported in the early 1990s. Nuclear scientists and law enforcement officials were called on to handle these, at the time, new and challenging cases. In the past 25 years significant casework experience and expertise have been built-up—on cooperation between investigators and measurement experts and on research and development. Despite these advances, nuclear forensics is still considered an emerging discipline, or a 'discipline in motion'.

The potential risks associated with radioactive materials beyond regulatory control necessitates sustained and focused efforts to refine and expand the nuclear forensic toolset. Thus, in addition to continually optimizing the interaction between law enforcement and nuclear scientists, the analytical and interpretation toolset that forms the backbone of this discipline must be further elaborated and perfected. As a practitioner involved in the field almost since its infancy, I have identified three aspects of the toolbox—technical capabilities, subject-matter expertise and research and development—that are, in my view, of the utmost priority in efforts to advance nuclear forensic science.

Technical capabilities for handling and analysing nuclear or other radioactive material must be readily available in order to provide rapid information to investigating authorities. The work to ensure such availability, however, needs to take account of existing infrastructures at the national level as well as international support that could complement national

Continued page 4

IDENTIFYING RESEARCH NEEDS IN NUCLEAR FORENSICS

VITALY FEDCHENKO

Results of a dedicated session at ITWG-21

At the initiative of the International Atomic Energy Agency (IAEA), the Nuclear Forensics International Technical Working Group (ITWG), at its 21st annual meeting in Lyon, France, on 6–9 June 2016, dedicated a session to discussing the current and future research needs of the discipline of nuclear forensic analysis.[1] The session was designed to leverage the combined expertise of over 100 meeting participants on six thematic topics: (*a*) nuclear forensic signatures; (*b*) activities after the dispersion of radioactive material; (*c*) data interpretation; (*d*) methods for bulk sample analysis; (*e*) methods for particle analysis; and (*f*) traditional forensic evidence contaminated with radioactive material. The session was organized using the so-called World Café methodology: participants were split into six groups and took turns to discuss each topic. The discussions were facilitated by a moderator for each topic, who collated the ideas that were generated.[2] A short topic-by-topic summary of the session is presented below. The ITWG is preparing a more comprehensive document that will serve as a resource for pertinent organizations in their work on establishing, reviewing or prioritizing their nuclear forensics-related research and development programmes.

Nuclear forensic signatures

A nuclear forensic signature is a characteristic, or set of characteristics, of a material in a sample that enables its comparison with reference materials or calculated values and, thus, helps to establish the sample material's provenance or history. The signature can be 'inherited' from the source material, or introduced (or erased) by chemical processing, physical manipulation (e.g. uranium enrichment) or nuclear transformation. Most signatures are added unintentionally, but some initial research regarding the intentional 'tagging' of materials has also been done in the past. Evidence from a crime scene

Continued page 5

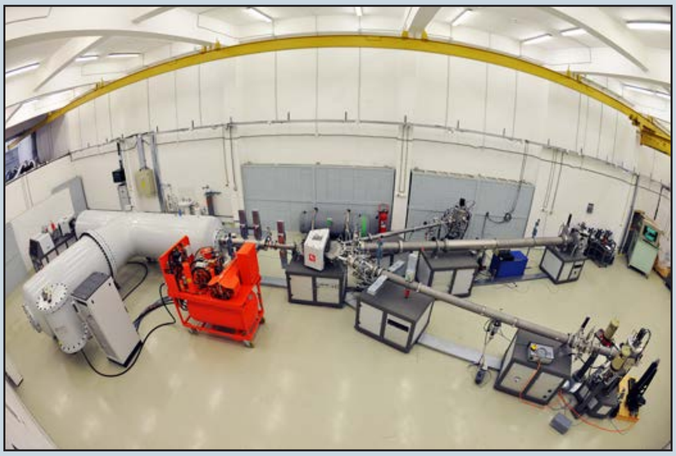

Figure 1. An Ion Beam Analysis (IBA) system with a 3 MV Tandetron Accelerator at IFIN-HH

Figure 2. An Accelerator Mass Spectrometry (AMS) system with a 1 MV Tandem Accelerator at IFIN-HH

DEVELOPMENT OF NUCLEAR FORENSICS AT IFIN-HH, ROMANIA

ANDREI I. APOSTOL AND NICOLAE MARIUS MARGINEAN

Romania's geostrategic position

The Black Sea region is currently one of the most vulnerable regions in terms of the illicit trafficking of nuclear and radioactive materials. Situated in the western part of this region, Romania is positioned between three major geostrategic areas: (*a*) the countries that used to form the Soviet Union, (*b*) the Middle East and (*c*) Western Europe.

The number of illicit trafficking cases in the Black Sea region reported to the IAEA's Incident and Trafficking Database (ITDB) stands as proof that nuclear security—as a means to prevent, detect and respond to materials out of regulatory control—is of paramount concern, and that practical steps need to be taken at all levels to ensure it.

From idea to practice

In the context of the increasing threat of illicit use or trafficking of nuclear and radioactive materials in Romania, scientists from the Horia Hulubei National Institute for Research and Development in Physics and Nuclear Engineering (IFIN-HH) decided to develop nuclear forensic capabilities not only as part of the response to possible illicit activities, but also as a tool to prevent a potential radiological incident. IFIN-HH was a natural choice: it is the largest research institution in Romania with widely recognized expertise in the field of nuclear physics, and its activities cover a range of areas in fundamental and applied research. These include experimental nuclear physics, material analysis using nuclear techniques, medical physics, radiation processing, radioactive waste management, the decommissioning of nuclear facilities in applied physics as well as collaborations on experiments and theoretical physics with the European Organization for Nuclear Research (Conseil Européen pour la Recherche Nucléaire, CERN) in fundamental research.

Since the majority of the necessary equipment and know-how to do this work was already in place, the IFIN-HH researchers decided to support nuclear forensic science by making best use of the existing infrastructure to develop new methods of analysis and increase the precision and accuracy of existing methods.

In February 2015, a small group of IFIN-HH physicists began research and development of analytical methods using available particle accelerators and the multiple gamma-spectrometry systems applicable to nuclear material analysis.[1] The existence of state-of-practice research capabilities at IFIN-HH—most notably access to the Accelerator Mass Spectrometry (AMS) system with a 1MV Tandetron Accelerator and an Ion Beam Analysis (IBA) system with a 3MV Tandetron Accelerator—is a major advantage in seeking to achieve the proposed goals (see figures 1 and 2). Nonetheless, some methods of analysis were missing.

To address this, IFIN-HH submitted an application for funding to the European Union's 'Competitiveness Operational Programme, 2014–2020' in August 2015. Awarded €2 million in April 2016, the project earmarked funds for the procurement of additional equipment and the establishment of Romania's first national nuclear forensics laboratory. Implementation of the project began in March 2017, and it is estimated

Continued page 3

Development of Nuclear Forensics at IFIN-HH, Romania *continued*

that IFIN-HH will have a fully equipped, functional laboratory by the end of 2018.

Nuclear Forensics in the Nuclear Security Summit context

In recognition of its commitment to nuclear security, Romania was invited to join the Nuclear Security Summit (NSS) process in 2012. During the last summit of this kind—which took place in Washington, DC, on 31 March–1 April 2016—Romania was again represented at the highest level. As part of its contribution to the NSS process, Romanian President Klaus Iohannis made a number of unilateral commitments on initiatives the country will take to consolidate nuclear security.[2] One of these commitments refers to strengthening national capabilities in nuclear forensics investigations. In this context, the efforts and accomplishments of the IFIN-HH on nuclear forensics are much appreciated at the national level, as they meet the need to fulfil the high-level commitments made by Romania.

International cooperation and ITWG exercises

IFIN-HH researchers are actively involved in the activities of the Nuclear Forensics International Technical Working Group (ITWG), such as the ITWG annual meetings, the Galaxy Serpent 2 Exercise and the fifth Collaborative Materials Exercise (CMX-5). The Data Review Meeting for CMX-5 was held in Bucharest in April 2017.

IFIN-HH's nuclear forensics experts are also involved in the Global Initiative to Combat Nuclear Terrorism (GICNT). In this context it is worth noting the contribution made to Table Top Exercise Olympus, 19–21 October 2016, which Romania organized under the GICNT umbrella in partnership with INTERPOL. Nuclear forensics expertise was also provided in 2017 during the GICNT Implementation and Assessment Group meeting in New Delhi, and the Magic Maggiore Workshop at the European Commission's Joint Research Centre (JRC) in Ispra, Italy.

As a follow-up to Exercise Olympus in 2016, Romania is planning to organize a practical exercise focused exclusively on nuclear forensics in 2017. The Romanian Ministry of Foreign Affairs will coordinate the event in close collaboration with the GICNT and with technical support from IFIN-HH. It will be aimed at nuclear forensics experts from the region.

One outcome of the rapid development of Romania's nuclear forensic capabilities is that the country stands ready to share its experience and expertise with other states in the region. As a result, two memoranda of understanding have been signed: one with Moldova and the other with Hungary.

Furthermore, IFIN-HH has been invited to collaborate with international organizations. A Practical Arrangement between the IFIN-HH and the IAEA in nuclear forensics and an amendment to the existing Collaboration Agreement with the JRC dedicated to strengthening scientific collaboration between the JRC Karlsruhe and IFIN-HH have been proposed. All these agreements are dedicated to strengthening bilateral and multilateral collaboration, enhancing technical and scientific support, and improving the exchange of lessons learned, best practices and relevant information. •

[1] Apostol, A. I. et al., 'Ion beam analysis of elemental signatures in uranium dioxide samples: importance for nuclear forensics', *Journal of Radioanalytical and Nuclear Chemistry*, vol. 311, no. 2 (2016), pp.1339–46; and Apostol, A. I., Pantelica, A., Sima, O. and Fugaru, V., 'Isotopic composition analysis and age dating of uranium samples by high resolution gamma ray spectrometry', *Nuclear Instruments and Methods in Physics Research Section B*, vol. 383 (Sep. 2016), pp. 103–108.

[2] Statement for the press by the President of Romania, Klaus Iohannis, delivered at the end of the Nuclear Security Summit in Washington, DC, 1 Apr. 2016 (in Romanian), <http://www.presidency.ro/ro/ media/agenda-presedintelui/declaratia-de-presa-a-presedintelui-romaniei-domnul-klaus-iohannis-sustinuta-la-finalul-summitului-privind-securitatea-nucleara-din-washington-d-c-statele-unite-ale-americii>.

Nuclear Forensics: The Way Ahead, a Personal View *continued*

capabilities—as and when required. This means that future efforts to advance the state of the art must focus on establishing and sustaining the capacity of all countries' technical capabilities to perform rapid initial identification and basic characterization of material found outside of regulatory control. Work must also continue to build strong international partnerships and networks to assure reach-back (i.e. prompt access for first-responders or law enforcement personnel to appropriate subject-matter experts) and analytical support.

Subject-matter expertise is key to both the successful analysis of any seized material and interpretation of results. Yet, in an era characterized by an ageing nuclear workforce and limited job opportunities for young nuclear scientists, the transfer and preservation of fuel cycle-related knowledge has become a challenge. Much of the expertise required for nuclear-forensics interpretation ranges well beyond textbook knowledge (i.e. making use of tacit knowledge) and draws on first-hand information and benefits from hands-on experience. The deficiency in this area needs to be countered by offering budding scientists a broad education in the nuclear sciences—including measurement techniques and fuel-cycle knowledge—that enables them to specialize during postgraduate studies. Moreover, a comprehensive nuclear sciences programme should be maintained at the national, regional or international level. Such a programme should include specific technical training, interdisciplinary exchange and professional advancement opportunities to ensure that the 'nuclear forensic workforce' can offer the best possible support to investigating authorities.

Research and development has been essential to understanding the correlations between measurable material properties and the material's history (i.e. nuclear forensic signatures), including the chemical and physical processes that changed the material during its movement through the nuclear fuel cycle. These signatures help trace material outside of regulatory control back to its origin. The development of accurate and sensitive analytical methods ensures that useful signatures can be measured efficiently. While these signatures appear well established for materials at the front end of the nuclear fuel cycle, in particular uranium ore concentrates, continued effort needs to be invested in improving understanding of the signatures of enriched uranium and plutonium. To this end, a compilation or inventory of the processes used in the nuclear fuel cycle should be pursued. This would perfectly complement a national nuclear forensics library[1]. While the library would be descriptive in nature, its combination with the fuel-cycle processes inventory would offer a cognitive view, allowing nuclear forensic scientists to understand how signatures are generated and propagated—or wiped out. In addition, non-nuclear radioactive materials (i.e. industrial or medial sources containing radionuclides such as Cs-137 or Co-60) should be given increased attention. In particular, efforts to develop protocols and methods for sampling and analysing post-dispersion material must be prioritized and invested in.

The evolving threats of illicit nuclear trafficking and nuclear terrorism call for continued efforts to further perfect the nuclear forensic toolset. Success in this area, in my view as a long-term practitioner, can only be achieved if the ideas outlined above are purposefully pursued. A focused exercise to identify future research topics in nuclear forensics was undertaken at the 21st annual meeting of the International Technical Working Group (ITWG-21) in Lyon, France, on 6–9 June 2016. In a joint effort, more than 100 experts from around the world elaborated this impressive and detailed list of subjects (see Fedchenko, this issue). The list will also be presented at ITWG-22 in Karlsruhe, Germany. It is my hope that the three areas discussed above—technical capabilities, subject-matter expertise and research and development—will be among the key organizing principals going forward. •

[1] A national nuclear forensics library is an organized collection of information (on certain material characteristics), and in some cases samples, about nuclear and other radioactive material produced, used or stored within a state which serves for supporting nuclear forensic investigations.

UPCOMING TRAININGS AND MEETINGS

- GICNT Plenary, Tokyo, Japan, 1–2 June 2017
- JAEA / ISCN International Symposium on Nuclear Forensics and Regional Cooperation, Tokyo, Japan, 5 June 2017
- GICNT Nuclear Forensics Working Group meeting, Karlsruhe, Germany, 26 June 2017
- European Commission Joint Research Center Topical Meeting on Presenting Nuclear Forensic Evidence in Court, Karlsruhe, Germany, 27 June 2017
- ITWG-22 Annual Meeting, European Commission Joint Research Centre, Karlsruhe, Germany, 28–30 June 2017
- IAEA Technical Meeting on Nuclear Forensics Cooperation with African States, Vienna, Austria, 11–13 July 2017
- IAEA Nuclear Forensics Seminar, Russian Federation, 4–8 September 2017
- IAEA Regional Training Course on Practical Introduction to Nuclear Forensics, Budapest, Hungary, 2–6 October 2017
- IAEA Regional Training Course on Practical Introduction to Nuclear Forensics, Sydney, Australia, 16–20 October 2017
- IAEA Regional Training Course on Introduction to Nuclear Forensics, Pretoria, South Africa, Q4 2017 (TBC)

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.

Identifying Research Needs in Nuclear Forensics *continued*

contaminated by radioactive material may also be analysed for identifying signatures.

The ITWG experts agreed that the analysis of multiple signatures strengthens confidence in nuclear forensic conclusions. They proposed that more research is needed to identify and validate more material parameters with potential for use in signatures. The ITWG participants suggested about 25 pertinent research topics, and grouped them in five broad categories:

- Signatures in nuclear material (e.g. rare earth element patterns, geolocation signatures, reagents used in uranium processing);
- Signatures in radioactive sources (e.g. research into exploiting isotope ratios and trace impurities in medical or industrial sources);
- Signatures in associated evidence (e.g. signatures in packaging or containers, radiation-induced changes in glass, analysis of sealed packages with unknown contents);
- Potential improvements in measurement techniques; and
- Other assorted, potentially useful research topics (e.g. morphological signatures, leveraging existing datasets to generate signatures, etc.).

Response in post-dispersion scenarios

The ITWG participants were asked to reflect on the nuclear forensics-related aspects of a response to a nuclear security event that involved the dispersion of radioactive material into the environment (i.e. post-dispersion scenarios). The experts were asked to comment on specific areas pertinent to such a response, which generated a large number of suggestions for further research:

- Safety of the public and of response personnel (e.g. development of safety procedures, including for cases of dispersed alpha- and beta-emitters, the presence of which is much harder to detect than gamma-emitters);

Continued page 6

Identifying Research Needs in Nuclear Forensics *continued*

- Tools for sample collection (e.g. new swipe materials, remotely controlled collection tools, air sampling);
- Procedures and methodologies for sample collection (e.g. determination of the kinds of samples for collection, sampling methodology, locating the dispersed radioactive material); and
- Debris analysis and data interpretation after collecting samples (e.g. reconstruction of the dispersal device, analysis of the materials' origin, methods of accounting for fractionation of different elements dispersed in the environment).[3]

Data interpretation

Data interpretation techniques and skills are key to transforming technical nuclear forensics data into information that is viable with regard to judicial proceedings and investigative questions. A variety of subject-matter experts contribute to data interpretation, such as those familiar with: (*a*) the production and use of the materials being investigated; (*b*) data quality control; (*c*) the models, tools and data resources used for comparative analyses; and (*d*) methods for appropriate communication of findings to the public and policymakers. The ITWG participants made a number of suggestions to improve data interpretation pertinent to those four areas, most notably:

- Material characteristics: reaching community consensus on ranking materials signatures in terms of the confidence by which that signature can be relied on, or developing methods for quantifying 'qualitative' evidence, such as on morphology of materials;
- Data quality: verifying data integrity and accuracy; determining the role of available quality-control data; understanding the use of data of varying quality;
- Comparative analysis techniques: choosing applicable and fit-for-purpose techniques; ensuring consistency of comparative parameters; standardized units; and
- Communication of findings: connecting findings with the questions raised by law enforcement; proper incorporation of uncertainty concepts into conclusions, finding an appropriate and effective way to state assumptions, limitations and degree of confidence.

Methods for bulk analysis

When focusing on methods for bulk analysis, the participants were asked to generate ideas on how to improve bulk analysis techniques for nuclear forensics purposes.[4] In defining 'bulk', the moderator suggested that participants should focus on samples ranging from a few milligrams to a few tens or hundreds of grams. The moderator also suggested that participants consider how established techniques using advanced instrumentation might be developed for application to more widely available (and less expensive) instruments. The discussion focused on six major areas:

- Gamma spectrometry (e.g. when it is useful or appropriate to apply gamma spectrometry and non-destructive analysis in general for nuclear forensics purposes);
- Morphology and microstructure (e.g. the need to create an index of physical and morphological characteristics for the identification of bulk powders);
- Analytical references and databases (e.g. improved use of reference materials for comparison purposes, including traceability to national standards);
- Determination of material age (e.g. the use of quadrupole or single-focusing mass spectrometers in bulk age-dating);[5]
- New techniques (e.g. use of neutron activation analysis in nuclear forensics); and
- General laboratory approaches (e.g. compilation of expert knowledge about the details of nuclear forensic analysis, including detailed information about the equipment, materials and reagents used in the analysis).

Methods for particle analysis

Mirroring the previous technical area, participants were asked to propose ways to improve analysis of individual particles.[6] It was agreed that the difference between bulk and particle analysis should be better defined. The suggestions were grouped into the following categories:

Continued page 7

Identifying Research Needs in Nuclear Forensics *continued*

- Use of previously underutilized methods, or methods that can be better publicized and shared with the rest of the nuclear forensics community;
- Better dissemination and analysis of existing information pertinent to microparticle analysis for nuclear forensic purposes;
- Methods of processing the results of microparticle analysis (e.g. better characterization and interpretation of particle morphology);
- Improvement of microparticle collection procedures in cases of unusual and especially radioactive matrices;
- Use of methods of microparticle analysis for the development of new signatures (e.g. better understanding of grains in fuel pellets);
- Development of sampling techniques for microparticle analysis;
- Ensuring the quality of analytical procedures and increasing confidence in conclusions; and
- The application of micro-analytical methods to georeferencing (e.g. in the measurement of the O-18/O-16 isotope ratio in uranium oxide particles).

Traditional forensic evidence contaminated with nuclear or other radioactive material

The sixth thematic area focused on identifying the challenges associated with traditional forensic evidence that is contaminated with radioactive material. The participants reviewed research and development needs, operational aspects and radiation protection issues.

- Crime scene operations in a radioactive environment (e.g. conditions under which the evidence cannot be accepted by a traditional forensics laboratory; effects of decontamination on traditional evidence; handling of explosives contaminated by radioactive materials);
- Laboratory analysis of evidence contaminated with radioactivity (e.g. conducting traditional forensics using remote handling; encouraging interactions of traditional forensic examiners with nuclear experts).

Although the discussions were held on six discrete areas, it is notable that all of them identified common connections. This makes sense given that a solid nuclear forensics investigation is dependent on all its stages operating seamlessly with a full understanding of the flow of samples, information and data. •

[1] This newsletter feature was prepared on the basis of Mayer, K. and Curry, M., 'Research needs in nuclear forensics', Notes from the ITWG-21 World Café Session, rev.11, 27 June 2016.

[2] The sessions were moderated by: L. Keegan (Australian Nuclear Science and Technology Organisation, Australia), D. Chamberlain (Argonne National Laboratory, USA), S. LaMont (Los Alamos National Laboratory, USA), M. Kristo (Lawrence Livermore National Laboratory, USA), V. Stebelkov (Laboratory of Microparticle Analysis, Russia), and J. Blankenship (FBI Laboratory, USA).

[3] Fractionation is an enrichment of one component of a mixture relative to another in a chemical or physical process occurring in the environment. In the context of nuclear forensic analysis, this term covers a number of processes, in addition to radioactive decay, that lead to different condensation rates of chemical elements after dispersion. In geochemistry, the phase transitions of water between vapour, liquid and ice result in isotopic fractionation of hydrogen and oxygen.

[4] Bulk material is material in loose form—such as liquid, gas or powder, or in a large number of small units (e.g. pellets or pebbles)—that is not individually identified for the purposes of analysis. Bulk analysis is analysis of either an entire sample or a portion of the sample to determine the average properties of the measured portion.

[5] The age of radioactive material is the time elapsed since the most recent separation or chemical purification.

[6] Particle analysis is analysis of environmental samples in which micrometre-sized particles are removed from the samples for analysis involving the measurement of the size and the morphology of the particles, and their elemental and isotopic composition.

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/