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NUCLEAR FORENSICS AS NUCLEAR MATERIAL ANALYSIS FOR SECURITY PURPOSES

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SUMMARY

Nuclear forensic science is normally seen as a discipline pertinent to nuclear security and intended to support investigations of illicit trafficking or nuclear terrorism cases. This view, while certainly correct in most cases, may be worth revisiting at a time when the process of the Nuclear Security Summits is over, and when the political support for nuclear security may diminish in the future in at least some key states.

Nuclear smuggling was happening before nuclear security was formally defined as a discipline, and nuclear material analysis and data interpretation techniques employed by nuclear forensic science have also been used to investigate cases not pertinent to illicit trafficking.

An argument can be made that nuclear forensics would benefit from taking stock of its roots and considering an expansion of its scope or improved awareness of and collaboration with other frameworks, such as verification of non-proliferation and disarmament treaties. The consolidation of various dimensions of nuclear forensics—or of nuclear material analysis for security purposes—would cut costs and provide new and possibly unexpected synergies between different applications.

This paper provides some background to that discussion and describes European contributions to the development of nuclear forensics as a discipline.

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INTRODUCTION

The discipline of nuclear forensic science (or nuclear forensics) has been firmly associated with combating illicit trafficking of nuclear or other radioactive materials (NORM).[1] In its broadest sense, illicit trafficking refers to criminal or unauthorized acts involving NORM outside of regulatory control, such as their 'import, export, possession, sale, delivery, movement, use, storage, disposal or transfer'.[2] The more colloquial term of 'nuclear smuggling' is also used to describe the same phenomenon, especially where nuclear materials suitable for the manufacture of nuclear explosive devices are concerned.

Illicit trafficking is a threat that is meant to be addressed by nuclear security, which is the complex of laws, regulations, institutions, systems and measures aimed at the 'prevention of, detection of, and response to, criminal or intentional unauthorized acts involving or directed at nuclear material, other radioactive material, associated facilities, or associated activities'.[3] Even though it is not stated directly in the above-mentioned definitions, both nuclear security and illicit trafficking imply that the perpetrators

[1] According to the most recent IAEA definition, the terms 'nuclear forensic science' and 'nuclear forensics' are interchangeable and are defined as the 'discipline of forensic science involving the examination of nuclear and other radioactive material, or of other evidence that is contaminated with radionuclides, in the context of legal proceedings'. IAEA, *Nuclear Forensics in Support of Investigations: Implementing Guide*, IAEA Nuclear Security Series no. 2-G (IAEA: Vienna, 2015), p. 62. For a more detailed review of the origins of nuclear forensics see Fedchenko, V. (ed.), *The New Nuclear Forensics: Analysis of Nuclear Materials for Security Purposes* (Oxford University Press: Oxford, 2015).

[2] IAEA, *Combating Illicit Trafficking in Nuclear and Other Radioactive Material*, IAEA Nuclear Security Series no. 6, (IAEA: Vienna, 2007), <http://www-pub.iaea.org/MTCD/Publications/PDF/pub1309_web.pdf>, p. 2.

[3] IAEA, Nuclear Security Series, Glossary, Version 1.3 (Nov. 2015), <https://www-ns.iaea.org/downloads/security/nuclear-security-series-glossary-v1-3.pdf>, p. 18.

involved in such 'criminal or unauthorized acts' are non-state actors. For example, the document that defined nuclear security for the first time equates it with 'measures to protect against nuclear terrorism'.[4] The 2005 International Convention for the Suppression of Acts of Nuclear Terrorism defines nuclear terrorism as a set of specific offences (listed in article 2) that can be performed by a person, explicitly excludes states and the military forces of states and mandates the criminalization of specific offences.[5]

As a result, nuclear forensics is often seen as a nuclear security tool intended to aid criminal investigation of illicit trafficking or nuclear terrorism. This view, however, while certainly correct in most cases, is not sufficiently nuanced. Nuclear smuggling was happening before nuclear security was formally defined as a discipline, and nuclear forensics techniques have also been used to investigate cases not pertinent to illicit trafficking.[6] At a time when political support for nuclear security might be diminishing, after the end of a process of Nuclear Security Summits, an argument can be made that nuclear forensics would benefit from taking stock of its roots and considering an expansion of its scope. This paper provides some background to that discussion and describes European contributions to the development of nuclear forensics as a discipline.

II. THE HISTORICAL BACKGROUND: FROM NON-PROLIFERATION TO NUCLEAR SECURITY

Before the 1990s

The threat of the illicit trafficking of nuclear or other radioactive material (nuclear smuggling) is not new. Depending on the specific definition, this phenomenon can be traced back at least as far as the alleged theft of highly enriched uranium (HEU) from a Nuclear Materials and Equipment Corporation (NUMEC) plant in the United States and its transportation to Israel in the 1960s.[7] Before the 1990s, however, the threat was low level, isolated and more relevant to the field of nuclear non-proliferation than nuclear security. The NUMEC incident was discussed as a special case of unauthorized transfer of nuclear material from one state to another, and in the most general sense belonged to the same category as the ALSOS missions—the removal of uranium-bearing compounds from Germany and Austria by the USA and the Soviet Union in 1945—or nuclear proliferation between states.[8]

The term nuclear forensics was not yet in use, but the same techniques of nuclear material analysis were being used by countries such as the USA, the United Kingdom and the Soviet Union to understand the contemporary state of nuclear proliferation, and later arms control, by applying them within the fields of technical intelligence (the monitoring of foreign nuclear weapon tests, nuclear facilities and nuclear materials production) and treaty verification (e.g. monitoring under the 1963 Partial Test-Ban Treaty).[9]

The 1990s to 2001: the rise of nuclear smuggling and the European response

Nuclear smuggling became much more common in the early 1990s. Shortly before and immediately after the break-up of the Soviet Union, reports began to appear in the former Soviet space of multiple cases of the unauthorized removal, possession, transfer or loss of nuclear and other radioactive materials, as well as sealed radioactive sources. These developments can be explained by the sharp economic decline and 'wrenching societal change' in the states of the former Soviet Union, which had large stocks of nuclear and other radioactive materials and had been using them in multiple ways and locations. This decline happened against a background of rapidly diminishing control by a disintegrating state, which meant that the people who

[4] IAEA General Conference, 'Nuclear Security: Measures to Protect Against Nuclear Terrorism', Report by the Director General, GC(49)/17, 23 Sep. 2005, <https://www.iaea.org/About/Policy/GC/GC49/Documents/gc49-17.pdf>, p. 1.

[5] United Nations, International Convention for the Suppression of Acts of Nuclear Terrorism, signed 14 Sep. 2005, entered into force 7 July 2007, <https://treaties.un.org/doc/db/terrorism/english-18-15.pdf>.

[6] Nuclear security was formally defined for the first time in 2005. IAEA General Conference (note 4), p. 1.

[7] Gilinsky, V. and Mattson, R. J., 'Did Israel steal bomb-grade uranium from the United States?', *Bulletin of the Atomic Scientists*, 17 Apr. 2014, <thebulletin.org/did-israel-steal-bomb-grade-uranium-united-states7056>; and Gilinsky, V. and Mattson, R. J., 'Revisiting the NUMEC affair', *Bulletin of the Atomic Scientists*, vol. 66, no. 2 (2013).

[8] For background see Rhodes, R., *The Making of the Atomic Bomb* (Simon & Schuster: New York, 1986), pp. 605–13.

[9] Fedchenko, V. (ed.), *The New Nuclear Forensics: Analysis of Nuclear Materials for Security Purposes* (Oxford University Press: Oxford, 2015), pp. 4–7.

had access to such material had a strong incentive to attempt to profit from it.[10]

The European states were quickly affected too. The earliest investigated cases of nuclear smuggling in Europe reportedly occurred in Switzerland and Italy in 1991, although it is not known whether a connection between the material in those cases and the Soviet Union was established.[11] These incidents were followed by others in Germany, the Czech Republic, Hungary and several other Central European countries. The nuclear smuggling phenomenon became so widespread that in 1995 the International Atomic Energy Agency (IAEA) established the Illicit Trafficking Database (ITDB, renamed the Incident and Trafficking Database in 2012) to record and analyse its member states' reports of illicit trafficking and other unauthorized activities involving material outside of regulatory control. This work was supplemented by other databases, which were maintained by states and academics. It seems that illicit trafficking cases 'involving unauthorized possession or other related criminal activities reached a peak in the early 1990s'.[12] Many of these cases occurred in Europe or its immediate neighbourhood, and some involved HEU and plutonium in various quantities (see table 1).

The first nuclear forensics analysis performed by the European Union (EU) was triggered by the seizure of 72 uranium pellets in Augsburg, Germany, in March 1992. The pellets were analysed at the EU Joint Research Centre's Institute of Transuranium Elements in Karlsruhe, Germany (JRC Karlsruhe). The analysis concluded that the intercepted material was fuel pellets for a Russian RBMK-type graphite-moderated nuclear power reactor, and identified two possible production plants in Russia and Kazakhstan. Material analysis was carried out using the same methods as those applied in IAEA safeguards measurements at that time. The measurement data was then interpreted, and a source attribution performed using scientists' expertise and open literature searches.[13]

The discipline of nuclear forensics had barely been named at the time. It was not yet defined, and its processes, protocols, purpose and context were not yet described. The 1992 Augsburg fuel pellets case was followed by a number of others, some involving HEU and plutonium. It became clear not only that all these features need to be developed, but also that international cooperation would be required on both the investigation of individual cases and the development of the discipline. International cooperation on the investigation of what is essentially international crime—illicit trafficking is most often understood as involving material transferred between at least two states—is advantageous from many perspectives. For example, it can provide a more complete picture or more timely information, allow the identification of additional investigative leads, increase confidence in findings, enable the determination of the origin of material and help identify the point at which regulatory control was lost.

In the mid 1990s, the laboratories involved in nuclear material analysis began to cooperate with each other, not least through the creation of the Nuclear Smuggling International Technical Working Group (ITWG), which later became the Nuclear Forensics International Technical Working Group. Since its inception, the ITWG has been jointly led by representatives of the USA and the European Commission. The first meetings of the group were convened in Livermore, USA in 1995 and in Karlsruhe, Germany in 1996. They have since continued annually.[14] The ITWG received political support when nuclear forensics was recognized as an element of response to nuclear smuggling events at the Group of Seven (G7) Moscow Nuclear Safety and Security Summit in 1996. The Group was endorsed by the Group of Eight (G8) Non-Proliferation Experts Group (NPEG) in May 1999, and by the G8/G7 Nuclear Safety and Security Group in 2005.[15]

The ITWG and its members began to develop scientific and technological applications to support investigations of illicit trafficking. Two of the founding fathers of the ITWG explained in 2002 that the group's primary goal was to 'develop a preferred approach

[10] Lee, R., *Nuclear Smuggling and International Terrorism: Issues and Options for US Policy*, Congressional Research Service (CRS), Report to Congress RL31539 (CRS: Washington, DC, Oct. 2002), <https://www.everycrsreport.com/reports/RL31539.html>.

[11] Mayer, K., Wallenius, M. and Fanghänel, T., 'Nuclear forensic science: from cradle to maturity', *Journal of Alloys and Compounds*, vol. 444–45 (Oct. 2007), pp. 50–56.

[12] IAEA, 'IAEA incident and trafficking database (ITDB)', Fact sheet, Vienna, 2016, <http://www-ns.iaea.org/downloads/security/itdb-fact-sheet.pdf>, p. 2.

[13] Mayer, Wallenius and Fanghänel (note 11), pp. 50–56.

[14] Koch, L. and Niemeyer, S., 'Status of international cooperation on nuclear smuggling forensic analysis', ITWG Unpublished document, 20 Mar. 1996.

[15] IAEA, 'Nuclear forensics support: Reference manual', *IAEA Nuclear Security Series*, no. 2, Technical Guidance (IAEA: Vienna, 2006), p. 1; Thompson, P., '15 years of ITWG: A personal view', Paper presented to the ITWG-15 Meeting, Oxford, UK, June 2010.

Table 1. Highly credible reports of incidents involving unauthorized possession of highly enriched uranium and plutonium-239, 1992–2016

Date	Location	Material	Amount (grams)	IAEA confirmed
6 Oct. 1992	Podolsk, Russia	HEU (90%)	1500	No
29 July 1993	Andreeva Guba, Russia	HEU (36%)	1800	No
28 Nov. 1993	Polyarny, Russia	HEU (20%)	4500	No
Mar. 1994	St Petersburg, Russia	HEU (90%)	2972	Yes
10 May 1994	Tengen-Wiechs, Germany	Pu	6.2	Yes
13 June 1994	Landshut, Germany	HEU (87.7%)	0.795	Yes
25 July 1994	Munich, Germany	Pu	0.24	Yes
8 Aug. 1994	Munich Airport, Germany	Pu	363.4	Yes
14 Dec .1994	Prague, Czech Republic	HEU (87.7%)	2730	Yes
June 1995	Moscow, Russia	HEU (21%)	1700	Yes
6 June 1995	Prague, Czech Republic	HEU (87.7%)	0.415	Yes
8 June 1995	Ceske Budejovice, Czech Republic	HEU (87.7%)	16.9	Yes
29 May 1999	Rousse, Bulgaria	HEU (72.65%)	10	Yes
2000	Elektrostal, Russia	HEU (21%)	3700	No
26 June 2003	Sadahlo, Georgia	HEU (89%)	~170	Yes
Jan. 2006	Tbilisi, Georgia	HEU (89%)	79.5	Yes
11 Mar. 2010	Tbilisi, Georgia	HEU (89%)	18	Yes
27 June 2011	Chisinau, Modova	HEU	4	Yes

HEU = highly enriched uranium; IAEA = International Atomic Energy Agency; Pu = plutonium.

Source: Zaitseva, L. and Steinhäusler, F., 'Nuclear trafficking issues in the Black Sea region', EU Non-Proliferation Consortium, Non-Proliferation Paper no. 39, Apr. 2014, <https://www.sipri.org/sites/default/files/EUNPC_no-39.pdf>, p. 5.

to nuclear forensic investigations that is widely understood and accepted as credible'.[16] They also described the elements of the group's work to achieve that goal: the development of procedures and protocols for the collection and preservation of evidence, and for laboratory investigation; the development of techniques for material characterization; the development of methods and tools, such as nuclear forensics libraries, to assist with the interpretation of the characterization's results; executing inter-laboratory exercises; and facilitating technical assistance to countries on request.[17] This vision of the purpose and work of the ITWG remains the same to this day. The central part of this vision began to be realized in 1997 when the ITWG started to discuss an action plan, or general guidance and a step-by-step description of a process designed to 'identify and trace back seized nuclear material from illicit trafficking'.[18] At a meeting in Vienna in June 2000, the ITWG adopted a reference Model Action Plan for the first time. The EU reportedly tested this concept with its member states, and the relevant authorities in Bulgaria, the Czech Republic, Hungary and Ukraine did the same.[19] (The first three were not EU member states at the time.)

[16] Niemeyer, S. and Koch, L., 'The nuclear smuggling international technical working group: making a difference in combating illicit trafficking', eds IAEA and Institute for Transuranium Elements (ITU), *Advances in Destructive and Non-destructive Analysis for Environmental Monitoring and Nuclear Forensics*, Proceedings of an International Conference, Karlsruhe, 21–23 Oct. 2002 (IAEA: Vienna, 2003), p. 17.

[17] Koch and Niemeyer (note 14) (paraphrased using current terminology).

[18] Koch and Niemeyer (note 14); Koch, L., 'Summary report of the International Technical Working Group (ITWG) on Nuclear Smuggling, 10–11 June 1997', Proceedings of the International Forum 'Illegal Nuclear Traffic: Risks, Safeguards and Countermeasures', Como, Italy, 12–13 June 1997, <http://unesdoc.unesco.org/images/0011/001122/112216Eo.pdf>, p. 29; and Koch, L., 'Identifying the origin and intended use of seized samples of illicit trafficking of nuclear material', Proceedings of the International Forum 'Illegal Nuclear Traffic: Risks, Safeguards and Countermeasures', Como, Italy, 12–13 June 1997, <http://unesdoc.unesco.org/images/0011/001122/112216Eo.pdf>, p. 35.

[19] IAEA (note 15), p. 1.

Thus, in the 1990s the sudden and unexpected surge in illicit trafficking of NORM spurred the creation of nuclear forensics analysis as a discipline that aims to combat the phenomenon. The EU was at the forefront of developing and promoting nuclear forensics by conducting nuclear forensics examinations, and by leading, together with the USA, the inception and development of the ITWG. It should be noted, however, that in the 1990s the policy incentive for investigating illicit trafficking cases, and therefore developing nuclear forensics, was not as clear-cut as it became after the attacks on the USA of 11 September 2001, but had more to do with prevention of nuclear proliferation than nuclear security and the prevention of nuclear terrorism. For example, the 1996 Moscow Nuclear Safety and Security Summit, attended by the G7 heads of state and government and co-chaired by the presidents of Russia and France, issued an influential declaration that, among other initiatives, announced a programme for preventing and combating illicit trafficking. The declaration stated that 'illicit trafficking of nuclear material is a public safety and non-proliferation concern'.[20] The threat of terrorism was mentioned in the subsidiary summit documents, but not in the main declaration. Nuclear security, even if mentioned in the summit's title, had not yet been defined.

Most of the contemporary publications that discussed the threats linked to nuclear and other radioactive materials found outside of regulatory control focused on such material being 'a shortcut to nuclear proliferation', which circumvented the need for a state to develop a domestic nuclear material production infrastructure in its quest to obtain a nuclear weapon capability. 'Nuclear leakage' was discussed at the time as a technical possibility that could assist nuclear proliferation and as a phenomenon that was 'likely to affect states' decisions on proliferation questions'. Some authors went so far as to suggest that nuclear leakage would not just aid the countries seen as likely proliferators in those years—Iran, Iraq, North Korea, Libya and Syria—but 'open the floodgates' of proliferation and tempt countries such as Germany, Japan, Taiwan, Turkey, South Korea and Ukraine to obtain nuclear weapons.[21] The threat that nuclear smuggling could increase the risk of nuclear terrorism was discussed seriously, but not seen as the central issue.[22]

Between 11 September 2001 and 2010

The field of nuclear security as we know it today took shape rapidly after the events of 11 September 2001, which highlighted the problem of mass-casualty terrorism. The attacks did not involve nuclear or other radioactive material, but served as a strong reminder of the possible consequences of nuclear terrorism. In January 2002 the Director General of the IAEA established the Advisory Group on Nuclear Security (AdSec), which subsequently developed the official definition of nuclear security that is currently used by the international community.[23] The official international definition of nuclear security (see above) was published by the IAEA in 2005, in an IAEA General Conference document with a title that equated nuclear security with protection against nuclear terrorism.[24] Nuclear terrorism received its own official definition in the same year, in the 2005 International Convention for the Suppression of Acts of Nuclear Terrorism (ICSANT). A comparison of the definitions 'nuclear security' and 'nuclear terrorism' confirms that the former is now understood to mean the same as defence against nuclear terrorism.

Another important development in terms of connecting nuclear security and nuclear terrorism took place at the G8 Summit in St Petersburg, Russia in July 2006. US President George W. Bush and Russian President Vladimir Putin launched the US–Russian Global Initiative to Combat Nuclear Terrorism (GICNT) in order to 'prevent the acquisition, transport or use by terrorists of nuclear materials and radioactive substances or improvised explosive devices using such materials, as well as hostile actions against nuclear facilities'.[25] The GICNT builds on the ICSANT and

[20] IAEA, 'Moscow Nuclear Safety and Security Summit Declaration', INFCIRC/509, 4 June 1996, <https://www.iaea.org/sites/default/files/infcirc509.pdf>.

[21] Allison, G. T. et al., *Avoiding Nuclear Anarchy: Containing the Threat of Loose Russian Nuclear Weapons and Fissile Material* (MIT Press: Cambridge, Mass., 1996), pp. 50–53.

[22] Allison (note 21).

[23] Anthony, I., 'The role of the European Union in strengthening nuclear security', EU Non-Proliferation Consortium, Non-Proliferation Paper no. 32 (Nov. 2013), <https://www.nonproliferation.eu/web/documents/nonproliferationpapers/ iananthony52960e48f308e.pdf>, p. 2.

[24] IAEA General Conference (note 4).

[25] G8 Summit 2006, 'Joint statement by US President George Bush and Russian Federation President V. V. Putin announcing the Global Initiative to Combat Nuclear Terrorism', St Petersburg, 15 July 2006, <http://en.kremlin.ru/supplement/4721>.

essentially helps to inform, familiarize and train the appropriate authorities in partner nations on how to combat nuclear terrorism.[26] In October 2006 the GICNT partner nations endorsed a Statement of Principles, a list of eight nuclear security objectives that they 'made a commitment to implement on a voluntary basis'.[27] Without naming it, the seventh principle in the statement concerns nuclear forensics:

> Improve capabilities of participants for response, mitigation, and investigation, in cases of terrorist attacks involving the use of nuclear and other radioactive materials and substances, including the development of technical means to identify nuclear and other radioactive materials and substances that are, or may be, involved in the incident.[28]

These documents and developments transformed the policy incentives for combating illicit trafficking. Unlike in the 1990s, nuclear smuggling had become a threat clearly associated with nuclear terrorism and therefore nuclear security. The discipline of nuclear forensics, developed by the EU, the USA and other countries since the early 1990s as a means to investigate cases of illicit trafficking, had come to be seen as a nuclear security instrument. The events of 11 September 2001 ensured that the policymaking, law-enforcement and national security communities in the USA, the EU and other states had to consider their capabilities and capacity to respond to an incident involving nuclear or other radioactive material. As a consequence, they increased their interest and investment in nuclear forensic science.

Nuclear forensics was born approximately a decade before nuclear security took its current shape and was defined by the IAEA. By the middle of the 2000s the emphasis on nuclear security had led to the creation of an international regulatory and organizational environment where the discipline of nuclear forensics science could begin to be defined and codified at the international level. The IAEA, its member states and the EU often repeat that 'there is an international consensus that responsibility for nuclear security within a State rests entirely with that State as it is a matter of national security'.[29] The prevalence of this position means that national nuclear security regulatory environments vary significantly from state to state. (Here, nuclear security differs from e.g. non-proliferation, where most states base their national implementation of safeguards on the same model Comprehensive Safeguards Agreement.) However, the IAEA member states recognized that 'nuclear security in one State might depend on the effectiveness of the nuclear security regimes in other States', and that there was 'an increasing need for appropriate international cooperation to enhance nuclear security worldwide'.[30] In working towards increasing the effectiveness of national nuclear security regimes and fostering the required degree of compatibility between them, the IAEA's Board of Governors approved the development of the nuclear security series of publications—a set of non-binding recommendations and guidance documents of varying levels of detail. The nuclear security series provided a platform for formalizing nuclear forensic science as a tool in the nuclear security toolbox.

In 2004 US scientists prepared a publication for future use by the IAEA, building on the years of work in the ITWG, among other things on the development of the action plan mentioned above.[31] The IAEA used this publication to prepare its own technical guidance, published in 2006 as the second document in the nuclear security series. It codifies the discipline as officially as can be done for the nuclear security purposes of the international community. Nuclear forensics is defined as 'the analysis of intercepted illicit nuclear or radioactive material and any associated material to provide evidence for nuclear attribution', where attribution refers to 'the process of identifying the source of nuclear or radioactive material used in illegal activities, to determine the point of origin and

[26] Müller, H. et al., *Non-Proliferation 'Clubs' vs. the NPT* (Stockholm: Swedish Radiation Safety Authority, Jan. 2014), <http://www.stralsakerhetsmyndigheten.se/Global/Publikationer/Rapport/Icke%20spridning/2014/SSM-Rapport-2014-04.pdf>.

[27] Global Initiative to Combat Nuclear Terrorism (GICNT), 'Statement of Principles', Oct. 2006, <http://www.gicnt.org/documents/Statement_of_Principles.pdf>.

[28] GICNT (note 27).

[29] Council of the European Union, Ad Hoc Group on Nuclear Security, 'Final report', 10616/2012, 31 May 2012, <http://register.consilium.europa.eu/pdf/en/12/st10/st10616.en12.pdf>.

[30] IAEA, *Objective and Essential Elements of a State's Nuclear Security Regime*, IAEA Nuclear Security Series no. 20, Nuclear Security Fundamentals (IAEA: Vienna, 2006), p. 1.

[31] Kristo, M. J. et al., *Model Action Plan for Nuclear Forensics and Nuclear Attribution*, UCRL-TR-202675 (US Department of Energy, Lawrence Livermore National Laboratory: Livermore, CA, 5 Mar. 2004).

routes of transit involving such material, and ultimately to contribute to the prosecution of those responsible'.[32]

The IAEA technical guidance document codifies the nuclear forensics process. In short, it works in the following way. Once a sample of nuclear (or other radioactive) material has been obtained, nuclear forensics attempts to extract useful information from it. First, the material in the sample is characterized, or measured to determine its physical, chemical, elemental or isotopic characteristics. This step yields raw data—numbers or perhaps images—that has little meaning by itself. For example, in the case of a plutonium sample it can be determined that it comprises plutonium metal with an additional 0.8 per cent by weight gallium and an isotopic composition of 93 per cent plutonium-239 and 6 per cent plutonium-240. The second step is to interpret the data obtained—the process of correlating the characteristics of the sample with information on known methods of material production, handling and use. The nuclear forensics interpretation is aided by the concept of nuclear forensics signatures, which are essentially sets of material characteristics that enable a material in the sample to be identified.[33] In the example above, all the noted characteristics taken together can be seen as a signature that suggests that the material in the sample is weapons-grade plutonium. This second step, which normally requires an experienced analyst's expertise, is expected to yield useful, meaningful information, as opposed to the raw data in the first step.

The approach envisaged in these documents and definitions implies that the purpose of nuclear forensics analysis is to feed information from the interpretation step, framed as nuclear forensics findings, into the attribution process. The attribution would then try to combine these findings with other data available from law-enforcement, intelligence and traditional forensics agencies, as well as any other source for the purpose of prosecution.

It is important to note that the process described above is often not linear, but iterative—meaning that it may require the repetition of some or all of the steps described above if something new is discovered or a new theory emerges. In addition, in the context of the judicial process the investigating authority is likely to steer nuclear forensics examinations, for example by asking the questions that in its opinion will best inform the investigation. In some cases, parts of the process described above, such as attribution, might not be required.

III. NUCLEAR SECURITY SUMMITS, THE GICNT, NUCLEAR SECURITY AND NEW ROLES, 2010–16

By the time the first Nuclear Security Summit was convened in April 2010, nuclear forensics had become an advanced scientific discipline that was aiming to provide nuclear forensic science findings for the process of attribution. Even though the discipline was addressing a number of prosecution and other law-enforcement issues, it was still often perceived as laboratory-driven. This can be seen in the way nuclear forensics was treated at the 2010 Washington Nuclear Security Summit. The changes in the perception and role of nuclear forensics have been reflected in the documents of subsequent summits.

The Work Plan of the 2010 Washington Summit announced that the participants would develop national nuclear forensics capabilities, including state-level organizational arrangements such as a national nuclear forensic library, but nuclear forensics was still filed under the 'research' category.[34] As a characteristic example, when Japan made a commitment at the 2010 Washington Summit to a three-year cooperation programme with the USA, that programme focused on research and development in the areas of nuclear material measurement, detection and forensic analysis.[35] In her summary of the outcomes of the 2010 Washington Summit, the Senior Director of the National Security Staff and US 'sherpa' to the summit, Laura Holgate, also emphasized the technological component of nuclear forensics.[36]

In its communiqué, the Washington Summit also recognized the 'role and contribution' of the GICNT, which probably provided an additional political

[32] IAEA, *Nuclear Forensics Support: Reference Manual*, IAEA Nuclear Security Series no. 2, Technical Guidance (IAEA: Vienna, 2006).

[33] For a strict definition see IAEA, *Nuclear Forensics in Support of Investigations: Implementing Guide*, IAEA Nuclear Security Series (IAEA: Vienna, 2015), p. 26.

[34] US Department of State, 'Key facts about the Nuclear Security Summit', 13 Apr. 2010, <http://www.state.gov/documents/organization/247156.pdf>.

[35] US Department of State, 'Japan's National Statement at the Washington Nuclear Security Summit', 12 Apr. 2010, <http://www.state.gov/documents/organization/246975.pdf>.

[36] Holgate, L., 'The outcomes of the 2010 Washington Summit', Remarks, US Department of State, 7 Oct. 2011, <http://www.state.gov/t/isn/rls/rm/184951.htm>.

impetus to the initiative.[37] A few months later, at its June 2010 plenary meeting in Abu Dhabi, the GICNT revised its terms of reference and established the Implementation and Assessment Group (IAG). The same plenary meeting defined nuclear forensics as one of the 'priority functional areas' of the GICNT. The Nuclear Forensics Working Group (NFWG) was established as a result at the IAG meeting in September 2010. Australia has chaired the NFWG ever since.[38] The NFWG educates policymakers and decision makers about nuclear forensic science, conducts workshops and tabletop exercises to increase their understanding of the benefits of implementing nuclear forensics capabilities and promotes the exchange of best practices.[39] The EU, most notably the JRC Karlsruhe, and many EU member states have made significant contributions to the work of the NFWG, and prepared and hosted the many multilateral GICNT events mentioned above.[40]

The NFWG produced two guidance documents: 'Nuclear Forensics Fundamentals for Policy Makers and Decision Makers' in 2012; and 'Exchanging Nuclear Forensics Information: Benefits, Challenges, and Resources' in 2015. The first document, which was published shortly before the 2012 Nuclear Security Summit in Seoul (see below), differs from previous documents in that it explicitly defines nuclear forensic science as a sub-discipline of forensic science as a whole. It takes the definition of 'traditional' forensics ('comprehensive scientific analysis of physical, biological, behavioural, and documentary evidence in the context of civil, criminal or international law') and simply specifies the kind of evidence, resulting in the following language: 'Nuclear forensics is the comprehensive scientific analysis of nuclear or other radioactive materials or of evidence contaminated with radioactive material in the context of civil, criminal, or international law'.[41]

Perhaps as a result of developments in the GICNT, nuclear forensic science was addressed in a more nuanced way at the 2012 Nuclear Security Summit in Seoul. The paragraph of the Summit's communiqué dedicated to nuclear forensics encourages combining 'the skills of both traditional and nuclear forensics through the development of a common set of definitions and standards'.[42] A number of participants, most notably France, Germany, Japan, Singapore, South Korea, the UK, the USA and the EU, mentioned activities pertinent to nuclear forensics in their National Progress Reports, many of them in the area of training and capacity building.

The Netherlands reported at the 2012 Seoul Summit that it had enlisted the services of its Netherlands Forensic Institute (NFI)—an entity working in traditional forensic analysis—to initiate 'a comprehensive programme to foster cooperation among nuclear and forensic institutes worldwide'.[43] The Netherlands intended to encourage the process of closer integration of the scientific discipline of nuclear forensics as previously defined with the broader legal and law-enforcement context, as well as with the traditional forensic science and criminalistics communities. During preparations for the 2012 Seoul Summit, the NFI and the Dutch Foreign Ministry tabled a White Paper on nuclear forensics in March 2011, aimed exactly at strengthening 'the links between traditional and nuclear forensics through the development of a common set of definitions and standards'.[44] Also in the period between the 2010 and 2012 summits, the IAEA began a formal process aimed at revising the above- mentioned technical guidance document, 'Nuclear Forensics Support', published in 2006 as part of the IAEA's nuclear security series.

The process of further integrating nuclear and traditional forensics continued at the 2014 Nuclear Security Summit in The Hague. The paragraph in the summit's communiqué discussing nuclear forensics welcomed the development of pertinent traditional forensic science methods and encouraged 'connecting and enhancing traditional and nuclear forensic capabilities'. At the same summit, the Netherlands

[37] White House, Office of the Press Secretary, 'Communiqué of the Washington Nuclear Security Summit', Press release, 13 Apr. 2010, <http://www.voltairenet.org/article164964.html>.

[38] Erästö, T. and Herbach, J., *Ten Years of the Global Initiative to Combat Nuclear Terrorism (GICNT): Strengths, Challenges and the Way Forward* (SaferGlobe: Helsinki, 2016), <https://www.saferglobe.fi/wp-content/uploads/2016/06/gicnt_report_2016.pdf>, pp. 16–17.

[39] GICNT, 'Global Initiative to Combat Nuclear Terrorism', [n. d.], <http://www.gicnt.org/documents/GICNT-Brochure-Final.pdf>, p. 15.

[40] GICNT, 'Key multilateral events and exercises', June 2015, <http://www.gicnt.org/documents/GICNT_Past_Multilateral_Events_June2015.pdf>; and Erästö and Herbach (note 38), pp. 37–39.

[41] GICNT, *Nuclear Forensics Fundamentals for Policy Makers and Decision Makers*, Feb. 2012, p. 2.

[42] 'Seoul Communiqué', 2012 Seoul Nuclear Security Summit, 27 Mar. 2012, <http://en.kremlin.ru/supplement/1185>.

[43] The Netherlands, 'NSS National Progress Report', Mar. 2012, <goo.gl/djz6YL>. Note the 'and' between 'nuclear' and 'forensic'.

[44] US Department of State, 'Forensics in Nuclear Security: 2014 Gift Baskets', Joint Statement in the context of the Nuclear Security Summit, 2014.

proposed a 'gift basket' on nuclear forensics. Like other gift baskets, it took the form of a Joint Statement. Unlike many other cases, however, this gift basket presented a set of ready-to-use tools for subscribing summit participants.[45] Among the tools was a 'Nuclear Forensics Lexicon'—a glossary of pertinent terms publicly available as a mobile telephone app. Nuclear forensic science is defined there as '[a] discipline of forensic science . . . the examination of nuclear or other radioactive material, or of other evidence that is contaminated with radioactive material, in the context of legal proceedings, including national or international law or nuclear security'.[46]

Two features of the Dutch definition and the very similar GICNT NFWG definition mentioned above are significant. First, they classify nuclear forensics as a chapter of wider forensic science as traditionally applied in the criminal law. Second, and more importantly for the purposes of this discussion, they broaden the scope of nuclear forensics, allowing its application to international law beyond the nuclear security, law enforcement or criminal prosecution domains. (Note the 'or' between 'international law' and 'nuclear security'.)

Around the same time, the IAEA was finishing the revision of its 2006 nuclear forensics guidance document mentioned above. Published in 2015, the revision contained a definition of the discipline that is very similar to the one in the Dutch lexicon: 'the examination of nuclear or other radioactive materials, or of evidence that is contaminated with radionuclides, in the context of legal proceedings under international or national law related to nuclear security.'[47] A comparison of the IAEA's 2015 definition with the one from 2006, cited above, shows that the key concept of the older definition is 'analysis', as in 'laboratory analysis' or the identification and measurement of a sample's content using analytical instruments and methods. The 2015 definition retains this theme but also emphasizes law enforcement and criminal prosecution. Probably influenced by the same process that produced the GICNT and the Dutch definitions, the IAEA's 2015 definition locates nuclear forensic science as a component of a state's forensic services and as such as an integral part of legal proceedings.

The second above-mentioned feature of the Dutch definition—an attempt to avoid restricting the meaning of such legal proceedings to a state's judicial processes or even a nuclear security context—did not survive the IAEA revision process. The new IAEA definition keeps nuclear forensics in the nuclear security domain.[48]

The 2015 revision has also codified a new function of nuclear forensics—assisting in the prevention of future nuclear security events. If nuclear forensics findings could help determine that the illicitly trafficked material had been removed from a particular facility or site that was previously deemed secure, this would spur improvements in nuclear security measures there and help prevent unauthorized material removals in the future. In addition, the knowledge that a state or a group of states has a credible nuclear forensics capability could deter perpetrators from diverting or smuggling the material.[49] The same idea was underscored by the USA in connection with the 2016 Nuclear Security Summit.[50]

The final Nuclear Security Summit in Washington, DC, in 2016 significantly strengthened political support for the discipline in general and the ITWG in particular, and emphasized the need to focus on practical implementation and the sustainability of nuclear forensics capabilities. The Joint Statement, 'Forensics in Nuclear Security', 'recorded the intent' of the 30 states that signed it to 'advance nuclear forensics as a key element of effective nuclear security . . . by incorporating nuclear forensics as an important element of a nation's coordinated response'.[51] The EU and the USA, as co-chairs of the ITWG, made a separate bilateral statement at the 2016 Washington Summit, announcing that the ITWG had become 'an effective platform for nuclear forensic practitioners to raise awareness, build capacity, and identify and promote best practices', and affirming that the ITWG

45 US Department of State (note 44).

46 Netherlands Forensic Institute, 'Coming to terms with nuclear terms', 12 Mar. 2014, <https://www.forensicinstitute.nl/news/news/2014/03/12/coming-to-terms-with-nuclear-terms>.

47 IAEA (note 1).

48 Some practitioners have pointed out that there is also a difference between nuclear security and the requirements for criminal prosecution in the way a case must be investigated, and that one may take precedence over the other depending on the details of the particular case.

49 IAEA (note 1), p. 6.

50 White House, Office of the Press Secretary, 'Joint Statement on Forensics in Nuclear Security', Fact sheet, 6 Apr. 2016, <http://www.nss2016.org/document-center-docs/2016/4/1/fact-sheet-joint-statement-on-forensics-in-nuclear-security>.

51 'Joint Statement on Forensics in Nuclear Security', Joint Statement in the context of the 2016 Nuclear Security Summit, 5 Apr. 2016, <http://www.nss2016.org/document-center-docs/2016/4/1/joint-statement-on-forensics-in-nuclear-security>.

'will continue to serve as the authoritative international technical forum for nuclear forensic practitioners'.[52]

IV. THE CURRENT WORK OF THE ITWG AND THE EUROPEAN CONTRIBUTION

The Nuclear Forensics International Technical Working Group (ITWG) is an informal and unaffiliated association of practitioners professionally involved in the discipline of nuclear forensics analysis.[53] The group comprises scientists, law-enforcement officers, first responders, representatives of nuclear regulators and other competent national authorities, affiliated contractors and international organizations. In essence, this group is a focal point for the nuclear forensics community as it exists today. It is steered by its co-chairs, who represent the EU and the USA, as well as an Executive Committee, which currently consists of representatives from the UK, Singapore and France.

The ITWG continues to develop the same five elements of nuclear forensics analysis set out by its founders in 2002. This is done through the work of five task groups, whose areas of responsibility roughly correspond to those five elements: evidence collection, exercises, guidelines, National Nuclear Forensics Library, and outreach and training.[54]

The Evidence Collection Task Group develops procedures for the collection and preservation of evidence at the scene of a nuclear security event, and produces guidelines on specific aspects of this work, such as on evidence collection in a radiological or nuclear contaminated crime scene.[55] Over the approximately 20 years of its existence, the Exercises Task Group has conducted five collaborative material exercises (CMXs), previously known as Round Robin exercises. Laboratories that elect to participate receive the same specially prepared sample of nuclear material, which they analyse using available methods. The CMXs are meant to provide learning experiences for laboratories and to identify laboratory methods and techniques ready for operational use or worthy of further development. The first CMX involved plutonium oxide (1996), the second investigated HEU oxide (2001), the third HEU metal (2010) and the fourth low-enriched uranium nuclear fuel pellets (2015). The fifth is currently under way. A sixth CMX is planned for 2018.[56]

The Guidelines Task Group develops and publishes consensus-driven guidelines on the destructive and non-destructive analysis techniques widely used for the characterization of nuclear forensics samples, as well as on specific aspects of nuclear forensics interpretation (e.g. signatures and material age determination). The National Nuclear Forensics Library Task Group is developing the concept of national nuclear forensics libraries (a prospective tool for nuclear forensics interpretation) and conducts virtual table-top exercises that challenge participants to compare information from samples of interest with known materials used, produced or stored as part of the nuclear fuel cycle. The Outreach and Training Task Group works to publicise the work of the ITWG to states, organizations, laboratories and individuals that have expressed an interest in nuclear forensics. Since the ITWG is expected to 'facilitate technical assistance to countries on request' and promote best practice, wide international dissemination is crucial. The ITWG has launched a public website, <www.nf-itwg.org>, and a quarterly newsletter, *ITWG Nuclear Forensics Update*.

The institutions of the EU and its member states have been active in the development of nuclear forensics since the early 1990s, not least by making various contributions to the ITWG. The ITWG is co-chaired by a representative of the EU JRC. As described above, JRC Karlsruhe was involved in investigating the earliest nuclear smuggling cases about 25 years ago, and in giving the discipline of nuclear forensic science its name. Since then, the EU member states and other countries have continued to detect or intercept nuclear and other radioactive material outside of regulatory control. A significant part of this material has been sent to the JRC for nuclear forensic analysis. By 2016, JRC Karlsruhe had analysed material connected to about 60 incidents, providing support to the

[52] 'EU–US Nuclear Forensics International Technical Working Group (ITWG) Joint Statement', 2016 Washington Nuclear Security Summit, 1 Apr. 2016, <http://www.nss2016.org/document-center-docs/2016/4/1/eu-us-nuclear-forensics-international-technical-working-group-itwg-joint-statement>.

[53] Nuclear Forensics International Technical Working Group Website, 2017, <http://www.nf-itwg.org>.

[54] Smith, D., 'The ITWG: 20 years of science supporting law enforcement and nuclear security investigations', *ITWG Update*, no. 1 (Dec. 2016), p. 7.

[55] ITWG, 'ITWG Guideline on Evidence Collection in a Radiological or Nuclear Contaminated Crime Scene', 2012, <http://www.nf-itwg.org/pdfs/ITWG-INFL-EVID.pdf>.

[56] Smith (note 54), p. 7; Schwantes, J. and Marsden, O., 'The ITWG Exercise Task Group', *ITWG Update*, no.1 (Dec. 2016), p. 6.

competent authorities in the EU and the European neighbourhood.[57]

In addition to the investigation of real cases, the JRC has consistently invested in advancing its nuclear forensics capabilities, as well as in education, training and assistance within and outside Europe. It has its own dedicated research and development programme that aims to improve the 'toolset and methodology' of nuclear forensics.[58] This programme has focused on further development of a central concept of the discipline: nuclear forensic signatures.[59] JRC Karlsruhe has participated in two IAEA Coordinated Research Projects, both related to the study of signatures: (*a*) Application of Nuclear Forensics in Illicit Trafficking of Nuclear and Other Radioactive Materials; and (*b*) Identification of High Confidence Nuclear Forensics Signatures for the Development of National Nuclear Forensics Libraries.[60] In the first, JRC Karlsruhe established that some trace elements found in the uranium ore concentrate and their isotopic composition can be used as indicators of origin (type of ore deposit) and of the chemical processing (type of chemical plant) that led to its production. In the second, the JRC examined how the signatures identified in the first Coordinated Research Project survive or are erased from the material while going through further stages of the front-end of the nuclear fuel cycle, from uranium ore to UF_6 before enrichment.[61]

It is safe to say that since the early 1990s JRC Karlsruhe, alongside US laboratories, has maintained one of the most advanced and influential nuclear forensics capabilities in the world. It is the leading nuclear forensics laboratory in Europe, but certainly not the only one. A number of European countries, most notably France, the UK and Sweden, were maintaining a significant capability in the area of analysis of nuclear and other radioactive materials for national security purposes well before the 1990s; and more European countries developed a nuclear forensics capability in response to the increase in the number of illicit trafficking cases in the 1990s and 2000s. This capability is difficult to measure because it is multifaceted and does not necessarily have to rely on the facilities and personnel of just one country, especially in an EU context. For example, a state may choose to maintain only the limited capabilities required to respond to a nuclear security event, and instead rely on the advanced nuclear forensics capabilities of neighbouring countries or the EU. One way to illustrate the nuclear forensics analysis capabilities of European countries is by listing which laboratories have participated in the ITWG and in its Round Robin/CMX exercises (see figure 1).

In Europe and its neighbourhood, Armenia, Austria, Azerbaijan, Belarus, Belgium, Bulgaria, Czech Republic, Finland, France, Georgia, Germany, Hungary, Israel, Italy, Lithuania, Luxembourg, Moldova, Netherlands, Poland, Romania, Russia, Serbia, Slovakia, Spain, Sweden, Switzerland, Turkey, Ukraine and the UK, as well as the European Commission and EUROPOL, have all participated in the work of the ITWG. Laboratories from Austria, the Czech Republic, France, Germany, Hungary, Lithuania, Moldova, Poland, Romania, Russia, Sweden, Turkey and the UK have participated in the Round Robin/ CMX exercises.[62]

Nuclear forensics as nuclear material analysis for security purposes

The Nuclear Security Summits and the 2006 GICNT have given a powerful political impetus to nuclear forensics. However, the last summit was held in 2016. How should the discipline of nuclear forensics develop in the future? Nuclear forensics will remain an important tool for nuclear security, helping to investigate incidents of illicit trafficking and attribute any nuclear terrorism event that involves an explosion or other dispersion of radioactive material. Other than contributing to national and international security, what other functions can be performed by nuclear forensics?

[57] European Commission, 'EU Efforts to Strengthen Nuclear Security', Joint Staff Working Document, SWD(2016) 98 final, Brussels, 16 Mar. 2016, p. 23.

[58] European Commission (note 57), p. 23.

[59] On the importance of that concept and placing it in the context of nuclear forensic analysis, see: Niemeyer, S. and Koch, L., 'The historical evolution of nuclear forensics: a technical viewpoint', *Proceedings of the International Conference on Advances in Nuclear Forensics*, IAEA-CN-218-117, <http://www-pub.iaea.org/MTCD/Publications/PDF/ SupplementaryMaterials/P1706/Plenary_Session_1A.pdf>, p. 6.

[60] IAEA, 'Application of Nuclear Forensics in Combating Illicit Trafficking of Nuclear and Other Radioactive Material', TECDOC no. 1730, <http://www-pub.iaea.org/MTCD/Publications/PDF/ TE-1730_web.pdf>.

[61] Varga, Z. et al., "Propagation of impurities at the front-end of fuel cycle", Proceedings of the IAEA International Conference on Nuclear Security: Commitment and Actions, 7 Dec. 2016, <https://conferences. iaea.org/indico/event/101/session/16/contribution/166.pdf>.

[62] 'Meet the ITWG participants', *ITWG Update*, no. 1 (Dec. 2016), p. 3.

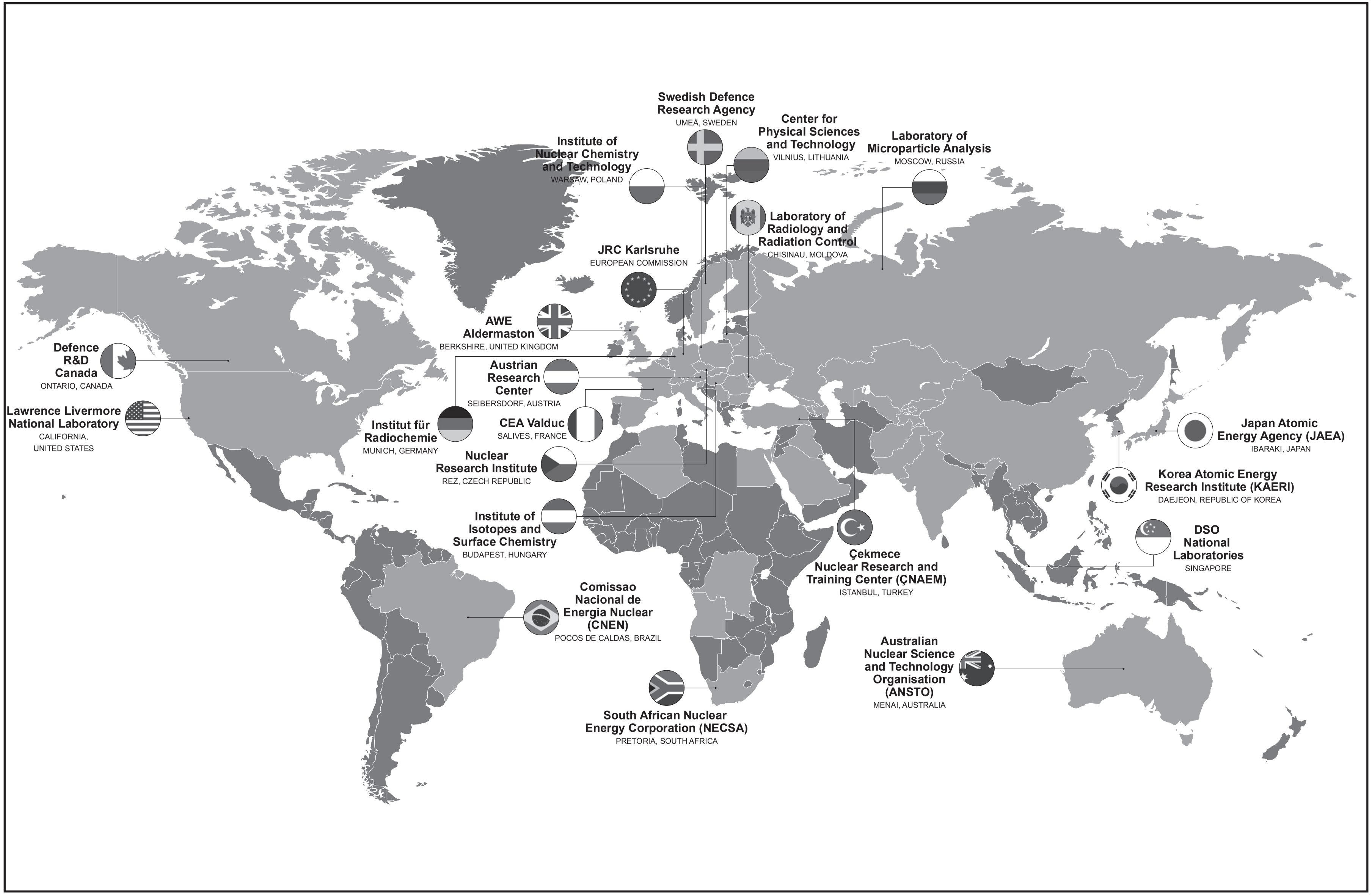

Figure 1. Map of Nuclear Forensics International Technical Working Group (ITGW) participants

Note: National flags indicate countries with laboratories participating in collaborative material exercises (CMXs).

Source: 'Meet the ITWG participants', *ITWG Nuclear Forensics Update*, Dec. 2016, <http://www.nf-itwg.org/newsletters/ITWG_Update_no_1.pdf>, p. 3.

A number of suggestions have been made in the literature in recent years of how to expand nuclear forensic analysis into new areas of international security.[63] These suggestions are based on an understanding that there are no material analysis or characterization techniques, or even methods of interpretation of their results, that are unique to nuclear forensic science, safeguards, national technical means of treaty verification or any other application.

The current IAEA definition of nuclear forensics can be broadened even beyond what was suggested by the Netherlands in the Nuclear Forensics Lexicon (see above). The Oxford English Dictionary defines 'forensic' as 'pertaining to, connected with, or used in courts of law; suitable or analogous to pleadings in court'.[64] More broadly, 'forensics' is understood in the specialized literature as 'the application of science to law'.[65] Although such definitions refer mostly to national laws, they could also be interpreted as including international law, regulations and, in particular, treaties. It could be argued that the term can be expanded even further to include the implementation of policies. Policies and laws are normally designed to achieve the same goals and differ only in the degree to which they are codified and enforced.

If it is possible to imagine the results of the nuclear forensics interpretation stage—nuclear forensic findings—being fed not into the specific stage of attribution, but into a more general stage of the reconstruction of an event of interest, the discipline can then be expanded from nuclear security applications or criminal investigation. The reconstruction stage can be defined as the process of combining the information produced by nuclear forensics interpretation with all other available information, for example from forensic analysis of the non-nuclear evidence associated with the sample or from intelligence sources, to determine as full a history as possible of the nuclear or radioactive material or an event. In that case, nuclear forensics can be seen as a broad discipline of nuclear and other radioactive material analysis for security purposes, and can be defined as the 'analysis of a sample of nuclear or other radioactive material and any associated information to provide evidence for determining the history of the material'.[66] This definition is meant to encompass all the other definitions discussed above. This approach makes it possible to list the applications where material analysis or characterization techniques and interpretation methods very similar to or exactly the same as those used in nuclear forensic science can be used in future or have already been used under a different name (see table 2).[67]

Not all of the tasks listed will be politically or publicly acceptable to a state that is considering expanding its nuclear forensics capabilities. The list, however, can represent a useful menu for a state that is considering investing in its future nuclear or other radioactive material analysis capabilities. Apart from few special cases, no country can justify dedicating an advanced, well-equipped laboratory solely to nuclear forensics analysis for the purposes of nuclear security. Such a facility would be idle for most of the time. For this reason, states prefer to assign some or all of the functions of nuclear forensic science to an existing laboratory working in a related field. The consolidation of various dimensions of nuclear forensics—or of nuclear material analysis for security purposes—in one laboratory would cut costs and provide new and probably unexpected synergies between different applications.

63 Mayer, K. and Glaser, A., 'Nuclear forensics', eds J. F. Pilat and N. E. Busch, *Routledge Handbook on Nuclear Proliferation and Policy* (Routledge: London, 2015); Fedchenko (note 9); and Fedchenko, V., 'Nuclear forensic analysis', *SIPRI Yearbook 2008*, pp. 415–27.

64 *Oxford English Dictionary*, vol. IV (Oxford University Press: Oxford, 1978), p. F-438.

65 Saferstein, R., *Criminalistics: An Introduction to Forensic Science*, 4th edn (Prentice Hall: Englewood Cliffs, NJ, 1990), p. 1. Also quoted in Moody, K. J., Hutcheon, I. D. and Grant, P. M., *Nuclear Forensic Analysis* (CRC Press: Boca Raton, FL, 2005), p. vi.

66 Fedchenko (note 9), p. 6.

67 For a discussion of a similar approach see Mayer and Glaser (note 63).

Table 2. Applications of nuclear forensic science methods to nuclear security and treaty verification

Framework	Typical sample form, content (and source)	Information to be inferred on the material or item's history
Non-proliferation and disarmament		
NPT (environmental sampling for safeguards)	Particles (on swipes from material handling areas), air, water, sediments, vegetation, soil, biota	Age, production process (consistency with declaration)
Partial Test-Ban Treaty	Particles and gases (weapon debris)	Nuclear explosive origin of debris, their age and location, especially if leaked from an underground test
CTBT (IMS and on-site inspections)	Particles and gases in air (weapon debris)	Nuclear explosive origin of debris
Fissile Material (Cut-Off) Treaty (if and when negotiated)	Noble gases (reactors, isotope production or reprocessing facilities)	Origin and age of nuclear and fuel cycle effluents
	Bulk graphite samples (shut-down plutonium-producing reactors)	Reactor's lifetime plutonium output
Nuclear security		
Attribution in an illicit trafficking case	Nuclear or radioactive materials, items or bulk form (nuclear fuel cycle facilities)	Age, production process, manufacturer
Nuclear terrorism event attribution	Particles and gases (weapon debris), particles (RDD), human body, excretions and remains (RDD and poisoning)	Design features of explosive device, material used, explosion yield, device and material origin
Nuclear intelligence or radiation protection		
Monitoring of foreign explosions	Particles and gases (weapon debris)	Explosive device's characteristics, total radioactivity of fallout
Monitoring of foreign facilities and materials	Noble gases (reactors, isotope production or reprocessing facilities)	Nuclear material production, early warning of nuclear and radiation accidents or nuclear terrorism events
	Particles in man-made media (e.g. wine or clothing), air, water, sediments, vegetation, soil and biota	

CTBT = Comprehensive Nuclear-Test-Ban Treaty; IMS = International Monitoring System; NPT = Non-Proliferation Treaty; RDD = Radiological Dispersal Device.

Source: Fedchenko, V., *Nuclear Material Analysis for Forensic and Other Security Purposes*, Institute of Nuclear Materials Management, 53rd Annual Meeting of the Institute of Nuclear Materials Management (INMM 53), Orlando, FL, 10–14 July 2012 (INMM: Deerfield, IL, 2012), p. 4.

ABBREVIATIONS

CMX	Collaborative material exercise
CTBT	Comprehensive Nuclear-Test-Ban Treaty
EU	European Union
GICNT	Global Initiative to Combat Nuclear Terrorism
G7	Group of Seven
G8	Group of Eight
HEU	Highly enriched uranium
IAEA	International Atomic Energy Agency
IMS	International Monitoring System
ITWG	Nuclear Forensics International Technical Working Group
JRC	Joint Research Centre
NFWG	Nuclear Forensics Working Group
NORM	Nuclear or other radioactive materials

EU Non-Proliferation Consortium

The European network of independent non-proliferation think tanks

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A EUROPEAN NETWORK

In July 2010 the Council of the European Union decided to create a network bringing together foreign policy institutions and research centres from across the EU to encourage political and security-related dialogue and the long-term discussion of measures to combat the proliferation of weapons of mass destruction (WMD) and their delivery systems.

STRUCTURE

The EU Non-Proliferation Consortium is managed jointly by four institutes entrusted with the project, in close cooperation with the representative of the High Representative of the Union for Foreign Affairs and Security Policy. The four institutes are the Fondation pour la recherche stratégique (FRS) in Paris, the Peace Research Institute in Frankfurt (PRIF), the International Institute for Strategic Studies (IISS) in London, and Stockholm International Peace Research Institute (SIPRI). The Consortium began its work in January 2011 and forms the core of a wider network of European non-proliferation think tanks and research centres which will be closely associated with the activities of the Consortium.

MISSION

The main aim of the network of independent non-proliferation think tanks is to encourage discussion of measures to combat the proliferation of weapons of mass destruction and their delivery systems within civil society, particularly among experts, researchers and academics. The scope of activities shall also cover issues related to conventional weapons. The fruits of the network discussions can be submitted in the form of reports and recommendations to the responsible officials within the European Union.

It is expected that this network will support EU action to counter proliferation. To that end, the network can also establish cooperation with specialized institutions and research centres in third countries, in particular in those with which the EU is conducting specific non-proliferation dialogues.

http://www.nonproliferation.eu

FOUNDATION FOR STRATEGIC RESEARCH

FRS is an independent research centre and the leading French think tank on defence and security issues. Its team of experts in a variety of fields contributes to the strategic debate in France and abroad, and provides unique expertise across the board of defence and security studies.
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PEACE RESEARCH INSTITUTE IN FRANKFURT

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INTERNATIONAL INSTITUTE FOR STRATEGIC STUDIES

IISS is an independent centre for research, information and debate on the problems of conflict, however caused, that have, or potentially have, an important military content. It aims to provide the best possible analysis on strategic trends and to facilitate contacts.
http://www.iiss.org/

STOCKHOLM INTERNATIONAL PEACE RESEARCH INSTITUTE

SIPRI is an independent international institute dedicated to research into conflict, armaments, arms control and disarmament. Established in 1966, SIPRI provides data, analysis and recommendations, based on open sources, to policymakers, researchers, media and the interested public.
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