NUCLEAR FORENSICS

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Summary

Nuclear Forensics is a fairly new discipline in science. It aims at providing clues on the origin and intended use of nuclear material. Such samples may arise from interception of smuggled nuclear material or from other illicit incidents involving nuclear material. To this end nuclear forensics makes essentially use of the information inherent to the material, i.e. its isotopic composition, its elemental composition, chemical impurities, macroscopic appearance and microstructure. A number of analytical techniques have been used for such investigations; for data interpretation, however, the availability of reference information or comparison samples is essential.

1. Introduction

Since the beginning of the 1990s, more than 1000 cases of illicit trafficking involving radioactive or nuclear material have been reported in the International Atomic Energy Agency (IAEA) illicit trafficking database (Figure 1). The reported seizures obviously represent only the tip of an iceberg and we have to assume that the real number of cases of illicit trafficking of nuclear and radioactive material is significantly higher. Most of the reported seizures refer to radioactive sources (such as ^{137}Cs, ^{192}Ir, ^{60}Co or ^{90}Sr) originating from medical or industrial applications.

These materials pose a radiological hazard due to their high activity. The seized samples of nuclear material were generally of higher mass, yet of lower activity as compared to medical or industrial radionuclide sources. The threat associated with nuclear material is going beyond the sheer consideration of the number of becquerels of seized samples. The radiotoxicity of the alpha emitting nuclides typically encountered in nuclear material is significantly higher than that of beta or gamma emitters usually applied in medical sources. This represents a considerable hazard if the material is handled in inappropriate ways and particularly if considered in a terrorist context. The use of nuclear material in a radiological dispersal device (colloquially referred to as a “dirty bomb”) is therefore a matter of serious concern.

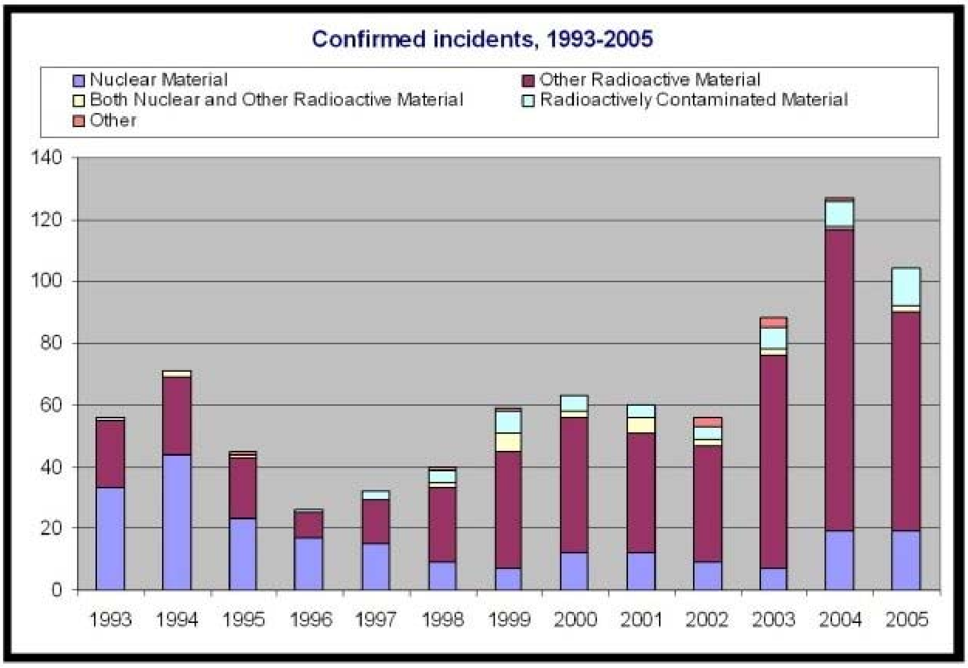

Figure 1: Number of incidents involving nuclear or other radioactive material as reported to the IAEA Illicit Trafficking Database (Source: IAEA)

Furthermore, nuclear material – if available in sufficient quantity and quality – may be used in nuclear explosive devices. Nuclear material is generally under strict control of competent national or international authorities. This control may involve accountancy and safeguards measures and is generally combined with strict physical protection of the material. However, the reported seizures of nuclear material prove that nuclear material can be diverted or stolen in some instances. This leads to the conclusion that the implementation of treaties, agreements or conventions on safeguards and physical protection has not been fully achieved or suffers from gaps. Closing these gaps and improving the control of nuclear material at the sites where theft or diversion occurred are therefore of prime importance. This, however, requires the identification of the origin of the seized nuclear material.

As a result, nuclear material has become a part of the forensic investigations and a new discipline – nuclear forensic science – was developed. Obviously, the questions on the origin of the material, its intended use and last legal owner need to be answered. The methodology developed in nuclear forensics may also be applied to source attribution of nuclear material in environmental samples, e.g. illegal dumping of nuclear waste, contaminated scrap metal or accidental release.

The source attribution can be achieved using the characteristics inherent to the nuclear material. For each seized sample a specific analytical strategy needs to be developed, taking into account the particular conditions of the seizure, the very nature of the material and of its packing and other evidence. The analytical strategy is based on a step-by-step approach, where experimental results are compared to information on nuclear material of known origin contained in a relational database. Based on the actual findings, the next step is defined and performed. Numerous analytical techniques are used in the investigations, including radiometric and mass spectrometric techniques as well as electron microscopy.

The samples of seized nuclear material were investigated in the early 1990s at the Institute for Transuranium Elements (ITU), later also Lawrence Livermore National Laboratory (LLNL) and other laboratories analyzed such material and contributed to the development of nuclear forensic science. The instrumentation available in the laboratories is specifically adapted for work with nuclear material. The instruments are routinely applied to nuclear material analysis in several areas, e.g. safeguards, material science, contractual work, method development, environmental studies.

Beyond the actual analytical work in the laboratory one also needs to consider the actions to be taken at the incident site (place of seizure of the material), the legal and law enforcement aspects and the question of data interpretation. The complexity of these issues – and the fact that illicit trafficking of nuclear material is a border crossing problem – call for international collaboration and for coordinated measures.

2. General Approach

Nuclear forensic investigations have to be considered as part of a comprehensive set of measures for detection, interception, categorization and characterization of illicitly trafficking nuclear material (Figure 2). As mentioned above, nuclear forensic analysis may result in important conclusions on the origin of the material and thus provide the most essential contribution to the prevention of future diversions from the same source. It is therefore crucial to ensure throughout the entire process the integrity and authenticity of the collected evidence. This requires a close collaboration between the various actors on the scene: law enforcement, radioprotection services, forensics experts and nuclear measurement experts. The International Technical Working Group on combating nuclear smuggling (ITWG) has developed a Model Action Plan (MAP) for handling cases of seized nuclear material. This action plan lays out the elements that are needed in the instance that illicit nuclear material is uncovered, e.g. incident response, crime scene analysis, collection of evidence, transportation to a nuclear facility, subsequent laboratory analysis, and then development of the case. The Model Action Plan obviously needs to be adapted to the regulatory, logistical and technical specifics in each country. A number of states have implemented the concept of the MAP and developed a dedicated handbook summarizing the responsibilities and processes relevant in response to illicit trafficking of nuclear material. Also the IAEA has taken over the concept of the MAP and promote its implementation.

3. Analytical Methodology

Like other pieces of evidence, nuclear material intercepted from illicit trafficking carries information that might be useful to illuminate the case. Obviously, classical forensic investigations may be carried out as well as nuclear forensic investigations. The preservation of evidence is of key importance for obtaining a maximum of information on the material, its history and its intended use.

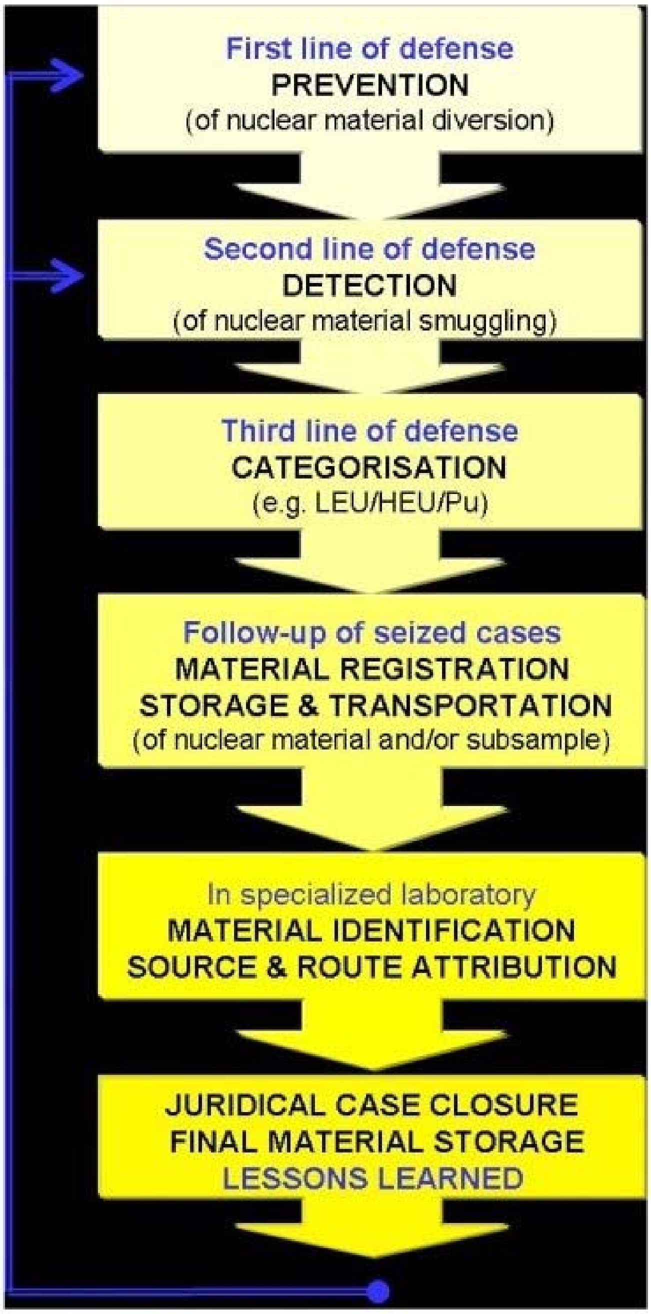

Figure 2: The basic elements in combating illicit trafficking are prevention, detection and response. Nuclear Forensics is of principal importance in the response process.

3.1. Classical Forensic Investigations

Classical forensics is a well established discipline with roots reaching far back in the past. In the present context we want to focus on forensic investigations that are carried out on nuclear or radioactive material. The analytical techniques that are applicable refer to investigations of the packing material, of associated materials and of traces (hair, fiber, cells, fingerprints) associated with the radioactive material. Results of such classical forensic investigations provide information that is complementary to the clues obtained from the nuclear forensic analysis. Hence, it will help to establish a more complete picture of the case.

Figure 3: Glove-box for taking fingerprints from contaminated items. The pieces of evidence are exposed to cyanoacrylate vapor in the chamber inside the glove-box.

The challenges encountered in classical forensics of preserving the evidence and of analyzing the meaningful traces are further complicated by handling problems due to the radiological hazard arising from the material. Such investigations call upon the vast forensics experience available in the laboratories of the police and simultaneously require special installations (e.g. glove-boxes) for handling radioactive samples. This particular area of forensic science is at its very beginning. To date only few cases have been reported where classical forensic evidence was taken from contaminated items or from an actual radioactive specimen. Figure 3 shows a glove-box with a special installation where cyanoacrylate vapor is used for visualizing fingerprints, a standard technique applied in forensics laboratories for non-soaking materials (e.g. plastic, metal). The glove-box also allows taking DNA samples from contaminated items, isolating the material, and extracting the DNA while leaving the contamination behind. In the example given in Figure 6 where a piece of contaminated scrap metal was seized, the exotic composition of the alloy (determined by SEM/EDX) and its particular geometry helped to identify Russia as the origin of the material. In another case, highly enriched uranium (HEU) was seized in Bulgaria. The nuclear forensic analysis of the material was supported by investigations on the non-nuclear materials, i.e. the lead container, the wax and the paper attached to container and the glass ampoule containing the HEU powder. The colorant of the wax, the wood fiber in the paper, the lead isotopic composition and the antimony content in the lead provide useful forensic clues, i.e., consistently pointing at an Eastern European origin.

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Biographical Sketches

Klaus Mayer obtained his PhD in analytical and radiochemistry from the University of Technology of Karlsruhe, Germany. He has been working on nuclear material analysis since then. His interest focuses on accurate measurements of nuclear material for safeguards verification purposes and on the development and improvement of measurement techniques. The emphasis of his work is currently in the area of nuclear forensics. This comprises the interaction with classical forensics and the development of a comprehensive response plan to incidents involving nuclear or other radioactive material. He is co-chairing the Nuclear Smuggling International Technical Working Group (ITWG). He is a member of the German Chemical Society (GDCh) and of the Institute for Nuclear Material Management (INMM). He participated to numerous IAEA consultants group meetings in the areas of nuclear safeguards and of nuclear security.

Maria Wallenius received her MSc in Radiochemistry at the University of Helsinki, Finland in 1994. She worked at the University of Helsinki as a research scientist in the safeguards project (Determination of uranium content, isotopic composition and impurities in fresh nuclear fuel by various techniques) and then moved to the Institute for Transuranium Elements (ITU) in 1996 to study for a PhD in Radiochemistry ("Origin determination of reactor produced plutonium by mass spectrometric techniques: Application to nuclear forensic science and safeguards") which she obtained in 2001. She continued at the ITU as a research scientist developing new methods using mass spectrometry (especially using TIMS and ICP-MS) in the field of safeguards and nuclear forensics.