Traces of Evidence

by Lothar Koch

NUCLEAR FORENSICS & ILLICIT TRAFFICKING

In 1994, after searching the home of a known criminal, police in Baden–Württemberg, Germany found a plutonium sample — by chance. Analysis at the European Institute for Transuranium Elements (ITU) in Karlsruhe showed an alloy mixture used only for "atomic bombs."

Unfortunately, this was not an isolated incident. An IAEA databank lists other reported cases of illicitly trafficked nuclear or other radioactive materials. *(See box: Incidents of Illicitly Trafficking Nuclear and Radioactive Materials.)* Apart from the traditional concern with nuclear proliferation, the post September 11th public is now wary of a possible attack by terrorists with a nuclear or radiation dispersion device (RDD). Until now, the seized quantities have not been sufficient to manufacture a nuclear explosive device, but they might be enough to construct an RDD.

Recognizing the latent global challenge to public health and safety, the G8 States (Japan, USA, Germany, France, UK, Italy, Canada, and Russia) have called for "joint international efforts to identify and suppress illicit supply of, and demand for, nuclear material and to deter potential traffickers." One measure gaining in significance is to identify seized material and trace it back to its origin — the objective of an emerging science known as nuclear forensics.

Plan of action

Repeatedly we observe nuclear or other radioactive material of unknown origin being released into the environment or illegally possessed. This follows from:

- accidents involving dispersed material;
- illegal dumping of nuclear scrap or waste;
- releases of traces from declared or clandestine activities;
- orphaned radioactive sources;
- diverted nuclear material;
- illicit trafficking of nuclear or other radioactive material.

In investigating such incidents, questions arise regarding the intended use, the origin and – where applicable – the smuggling route of the detected material. For this purpose the Nuclear Smuggling International Technical Working Group developed a "Model Action Plan" outlining a series of steps to be taken once material is found or seized. The IAEA and ITU jointly assisted Member States in its implementation and application through a demonstration exercise. As a result of training and technical upgrading, law enforcement services in those States are now able to establish to what extent seized nuclear material might constitute an occupational hazard or public threat. If needed, scientists from the concerned States will characterize the material, together with the assistance of nuclear forensics experts at the ITU, to find out the intended use, origin and smuggling route of the seized material.

The emerging pattern

The investigation scheme for nuclear or radioactive material is not very different from classical forensics. Before preserving the evidence, officers take the necessary precautions to protect themselves and the public (under observation of the chain of custody required for that State). Traces (fibres, dust, DNA, fingerprints etc.) from contaminated surfaces are best collected in appropriate laboratories.

In which ways does nuclear forensics contribute to solving the puzzle? Nuclear forensics provides valuable clues based on the fact that in each nuclear or radioactive material the isotopic composition of ingoing chemical elements is uniquely given, and differs from that in naturally occurring elements. The pattern of isotopic abundance reflects the enrichment processes and the irradiation in nuclear reactors. While geochronology or cosmology use the same principle, in nuclear forensics there exists a wealth of artificial nuclides for which their nuclear formation is well-known. The ratio of parent/daughter nuclides reveals the elapsed time within which the nuclear reaction or a subsequent chemical treatment occurred. The abundance of radionuclides reveals the type and conditions of production.

In 1994, law enforcement at the Munich airport seized 363g of plutonium (Pu). There was, however, suspicion that the material was a "fake" — composed of previously identified sources. The analysis of the mixed uranium (U) and plutonium (Pu)-oxide particles showed that Pu was formed in an unusually soft neutron energy spectrum. This proved they were of similar age and not produced and formed from the known sources. From such endogenous information – inherently "engraved" in the material – the intended use is recognized. Yet it does not point to the geographical origin of its production. Fortunately, all nuclear and radioactive products have to be extensively characterized for quality assurance and safety. The plant specific production conditions and the varying material specification make each product unique. These specifications are systematically recorded in a database allowing forensics experts to make a match between the characterized material and a historical plant record. Such a match gives strong evidence of its origin.

Of course, at the beginning of an analysis, the history of the investigated material is unknown. Consequently, at first the analyst must determine some basic data of the material and then query historical plant records or other relevant available databases. Following the principle of diagnosis, the analyst gradually excludes proposed possible places by generating additionally requested data until eventually only one place remains as the possible origin. In other words, the analytical investigation is guided and determined by the available relevant historical data.

Tools of the trade

Nuclear forensics can rely on a variety of established and recognized methods. The analytical instrumentation and procedures used in the fabrication of radioactive and nuclear materials are not only appropriate but also indispensable to obtain information of similar quality to compare with historical plant records. The toolbox *(See box: Tools of Analytical Techniques)* summarizes the most common analytical techniques in use. They are grouped by tools related to:

- measuring weight and dimensions of materials, e.g. of a fuel pellet;
- determining the abundance of the main nuclides, e.g. enrichment of U-235;
- analysing the chemical composition;
- describing the microstructure; and
- assay of impurities.

In order to compare with available but very specific historical data, the nuclear forensics expert sometimes requires special analyses such as the surface roughness of fuel, grain size etc.

As in classical forensics and geo-cosmology, nuclear forensics employs chemical analysis as well as optical and electron microscopy. Of particular importance are mass spectrometric techniques. Some of these are also common in trace analysis of natural elements (e.g., spark source or plasma induced mass spectrometry, sputter or laser ablation mass spectrometry); but in nuclear forensics the decisive information is gained from the measured changes in isotopic abundance. For nuclides with high specific radioactivity, radiometric techniques, and notably alpha and gamma spectrometry, are suitable means of analysis. Particles, even entailing weakly active isotopes, are effectively characterized by electron microscopy paired with secondary-ion mass spectrometry. Relevant instrumentation combines high spatial resolution with very good sensitivity of chemical detection and high (isotopic) mass resolution.

TOOLS OF ANALYTICAL TECHNIQUES FOR NUCLEAR FORENSICS

For bulk material	Dating	Radiotoxicity	Use	Origin
Optical microscopy			X	X
Gamma or alpha spectroscopy	X	X		
Inductively coupled plasma MS*	X	X	X	X
Glow discharge MS*		X		
Microprobe				X
Electron microscopy+EDX**				X
X-ray diffraction				X
Thermal ion MS* + isotope dilution	X	X		X
For particles				
Electron microscopy				X
Secondary ion MS*	X	X		X

*MS = mass spectrometry **EDX = energy-dispersive X-ray analysis

Cases in point

Two earlier incidents analysed at ITU and listed in the IAEA database illustrate the use of nuclear forensics.

In Ulm, Germany, police found 202 radioactive pellets in a bank safe. The shape of the pellets identified them as nuclear fuel of a light water reactor type. Analysis showed a U-235 enrichment of 4.38% which indicated that they were intended for reload. The impurities met the specifications of the two nuclear fuel fabrication plants in question that produce such pellets. In this situation one needed additional information – even technically less significant – on impurities (such as a nearby caustic plant causing a characteristic Sodium (Na) content in the ppb range) or on differences in the fabrication techniques such as the roughness of the fuel surface. It was the latter which finally identified the plant of origin due to its known wet grinding, which gives a smoother surface than the dry grinding employed elsewhere.

Secondary ion mass spectrometry is used to measure the U-235 enrichment of particles in swipes to detect clandestine U enrichment in environmental samples collected by the IAEA. This powerful technique also found 87.8% U-235 particles in a radioactive stainless steel piece from a scrap yard of a metal refining plant. It turned out to be a fast reactor fuel assembly recognized by its shape. The usual U-235 enrichment for fast reactors is 19% – non-weapons useable. Therefore it was concluded that this assembly was a prototype for a known, less powerful testing reactor. The pyrochemically produced fuel was already removed by unprofessional abrasive cutting of the pins. It was interesting to note then that the removed fuel was illicitly trafficked in batches through several States before seized by police. Samples of all the seized materials were identical in U-235 enrichment and impurities.

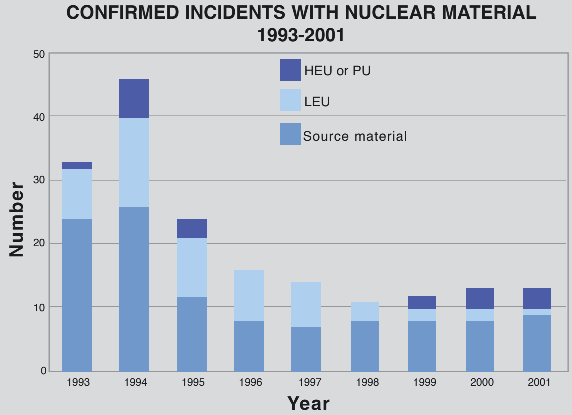
Scratching the surface

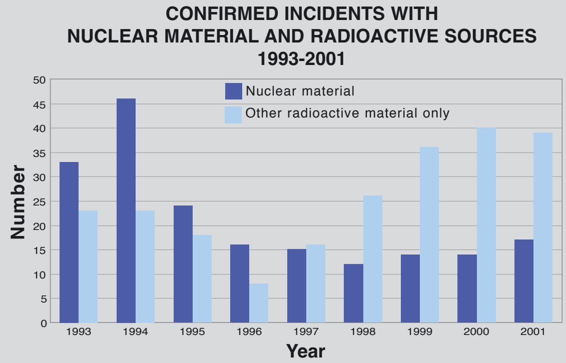
There is still need for new methods to reveal the history of an unknown nuclear or radioactive material. Research and development underway must look for more accurate analytical techniques and more conclusive interpretation of the results to read the endogenous information implicit in the material. In the future, it should become easier to distinguish between different U-235 enrichment processes, reconstruct the operation history of a reprocessing plant from its waste, and recognize the process steps of a material fabrication.

Appropriate analytical instruments and techniques are in wide use. However, only a few laboratories have a license to handle nuclear or radioactive materials. For this reason, the IAEA is considering setting up an international forensic laboratory network that would serve Member States in the characterization and identification of unknown material. Scientists would be able to attend network labs in order to observe the investigations of material seized in their State.

Historical data play a vital role in the determination of the material's origin. Since access to such information is limited due to legal constraints, commercial sensitivity or national security concerns, it has been proposed to arrange for a network of databanks for query purposes only. Analytical examinations would be guided through the network until the results show a match in a database. Whether the result becomes public should be of less concern, as long as the last legal owner can recognize the material and close the loophole.

INCIDENTS OF ILLICITLY TRAFFICKING NUCLEAR AND RADIOACTIVE MATERIALS





Source: IAEA Databank

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