STR/AFP/GETTY

Moldovan police examine suspected radioactive uranium-238 in August 2010.

Expand nuclear forensics

Characterizing nuclear materials deters illicit trafficking and terrorism, but more scientists, techniques and collaborations are needed, says **Klaus Mayer**.

Since the International Atomic Energy Agency (IAEA) implemented its Incident and Trafficking Database in 1995, around 2,300 events involving illicit nuclear or other radioactive materials have been reported. Although most cases involve lost or orphan radioactive sources containing, for example, cobalt-60 or iridium-192 for medical or industrial applications, 10–15 incidents per year concern nuclear materials turning up out of regulatory control.

Uranium and plutonium are most worrying because, as well as posing a radiological hazard, they may be indicative of proliferation or nuclear terrorism. The sorts of things seized are scrap metal contaminated with grams of enriched uranium or kilograms of natural uranium, gram-sized samples of uranium metal, and uranium fuel pellets. In 1994, 300 grams of plutonium oxide powder were intercepted at Munich airport in Germany.

Officials detect unlawful nuclear materials at borders, seaports and airports or in state territories by measuring radiation directly or acting on tip-offs from police or intelligence work. Whenever such a sample is intercepted, agencies want to know: which laws have been broken? When and where was the material produced? What was the intended use? Where was the material stolen or diverted? Is more of it at large? Nuclear-forensic scientists try to answer these questions.

The chemical and physical signatures of a radioactive material — from its appearance and microstructure to its elemental and isotopic composition — shed light on its origin and history. For example, the isotope ratios of strontium impurities in a sample of natural uranium may indicate whether it was mined in Australia or Namibia. The presence of daughter products from nuclear decays reveal the production date of the material, and products, such as uranium-236, of neutron reactions indicate that it was irradiated in a power plant.

Nuclear forensics is a small and specialized field that has matured since the early 1990s. But progress is still too slow. Although the number of scientific publications in the discipline has risen from a handful in 2001, it still numbers only a few dozen a year.

States worldwide need to implement nuclear-forensic capabilities — both nationally and internationally — through greater collaboration. To boost the robustness of the methods, and thence their credibility, new forms of analysis and signatures for nuclear materials need to be developed. Nuclear-forensic data need to be archived securely and more experts must be trained. Otherwise smugglers and terrorists might evade prosecution.

A few years ago in a European country, a radiation detector at a scrap-metal recycling facility triggered an alarm. A piece of steel in a shipment from south Asia had ▶

a greenish deposit that a rapid on-site measurement showed was natural uranium.

A sample was sent to our nuclear-research laboratory in Karlsruhe, Germany, where my team and I identified the green material as uranium tetrafluoride, an intermediate product of uranium processing encountered typically during isotope enrichment. Dating suggested that it was produced in 1978. But chemical impurities, in particular the pattern of the rare-Earth elements (including lanthanum, neodymium and samarium), indicated that the uranium came from a sandstone subtype found not in the suspected country of origin, but in China, Australia, Niger or the Czech Republic (see 'Chemical impurities').

Uranium production in the suspected country had, according to the literature, started in the late 1970s from a different type of sandstone. Further literature studies revealed that in the same period, uranium-ore concentrate from Niger, fitting the seized sample's characteristics, was imported into the suspected country. Thus, the origin and history of the material showed that uranium processing and isotopic enrichment had already been achieved at a very early stage in the country's nuclear activities.

NUCLEAR FINGERPRINT

Chemical and physical signatures vary through the nuclear fuel cycle: from uranium ore to uranium fuel pellets used in power reactors, natural uranium to weapons-usable, highly enriched material, and spent nuclear fuel to separated plutonium. The variety of materials reflects the diverse geological and geographic origins of natural uranium, and the technological processes that could have been applied add to the diversity.

Analysis methods must be tailored to the material and signature under investigation. Uranium and plutonium samples, for instance, contain different chemical impurities that require different treatments.

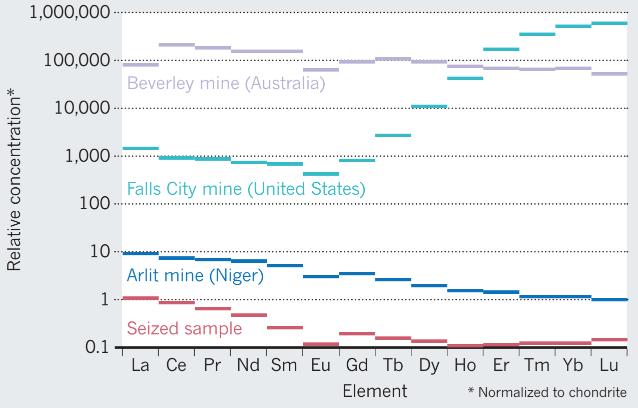
Nuclear-forensic interpretations build on a variety of measurements — including mass spectrometry, electron microscopy, α or γ spectrometry and radiochemical separations — that yield a broad spectrum of material parameters. These range from obvious characteristics such as uranium enrichment or pellet dimensions to more sophisticated information including metallic impurities or grain-size distribution.

Age is derived from ratios of progenies of radioactive parent nuclides. Most other signatures are comparative, referenced against samples of known provenance. Some reference data, such as the rare-Earth-element patterns studied by isotope geologists, are openly published. Information such as the grain-size distribution in uranium fuel pellets can be provided only by the producer.

There are broader challenges in nuclear forensics: new analytical methods need to be validated, the robustness of some signatures needs to be demonstrated and the interpretational techniques need to be substantiated.

CHEMICAL IMPURITIES

The signature of rare-Earth elements in natural uranium differs depending on the type of ore from which the uranium is mined. The concentration profile of a seized sample of nuclear material matches the sandstone type of a mine in Arlit, Niger, corroborating information that the material originates from the country.



SOURCE: Z. VARGA, M. WALLENIUS & K. MAYER *RADIOCHIM. ACTA* **98**, 1–8 (2010)

There is no centralized international nuclear-forensic database. Indeed, it is fiercely resisted by many nations, for understandable reasons. Data characterizing nuclear materials and processing histories are sensitive and may be classified. Sensitivities can be commercial (in the case of nuclear fuels) or security-related (for weapons-grade uranium or plutonium). Any compilation of data on nuclear material must be secure.

A decentralized approach is gaining acceptance. The concept of national nuclear-forensic libraries, a combination of databases and physical sample archives that allows states to control their own nuclear-materials data, is being promoted by the IAEA, headquartered in Vienna, and the Global Initiative to Combat Nuclear Terrorism (GICNT). Although few countries have taken official steps, Ukraine is developing such a library, as are some others in the European Union and southeast Asia. Comparing signatures of seized material against stored information will reveal whether the material is of domestic origin. Private queries to other states could help to identify the legal owner of the material in confidence.

Yet at the same time, skilled radiochemists, nuclear physicists and nuclear engineers with hands-on experience in the nuclear fuel cycle and in production or analysis of nuclear material have become a rarity, as a report by the American Physical Society and the American Association for the Advancement of Science highlighted (see go.nature.com/ckflpx).

Capacity building in nuclear forensics is the key issue in forming a global response to illicit trafficking and nuclear terrorism. Effective deterrence does not necessarily imply investing enormous budgets to establish sophisticated laboratories. Measurements of a few parameters may provide enough information for law-enforcement purposes. The isotopic composition of uranium or plutonium, for instance, can be determined using portable γ-spectrometry instruments, which cost about US$130,000.

GROW EXPERTISE

Building a nuclear-forensic workforce requires a scientific education in chemistry or physics with specialization in radiochemistry, nuclear engineering or nuclear physics. Hands-on experience working with nuclear material and analytical techniques comes next. Opportunities for graduate and postgraduate students to specialize in nuclear forensics should be offered through university courses and through internships and placements in nuclear laboratories.

Training programmes should be harmonized and coordinated around the world. National and international exercises would demonstrate and develop competencies, and check interagency cooperation and levels of preparedness. Curricula and materials could be reviewed by the Nuclear Forensics International Technical Working Group — a gathering of nuclear forensics practitioners, including scientists and law enforcers, founded in 1995 on the initiative of the Group of Eight (G8) countries.

Mechanisms need to be developed to ensure the security and sharing of information about nuclear materials held in national databases. The GICNT should promote national nuclear-forensic libraries. The IAEA, with its expertise in assisting states with nuclear security, is well positioned to provide technical guidance.

In March 2014, the international Nuclear Security Summit will try to enhance international cooperation to prevent malicious use of nuclear material. These discussions must call on the 53 participating nations to increase awareness of the opportunities that nuclear-forensic science offers to ensure nuclear security around the globe. ■

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