NUCLEAR TRAFFICKING

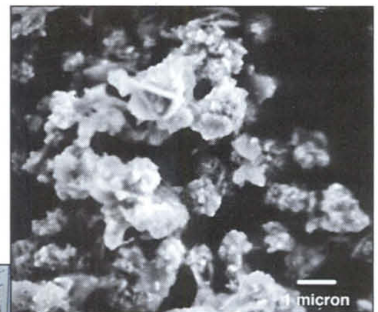
Crime and (Puny) Punishment

A seizure of highly enriched uranium on the Bulgaria-Turkey border shows that heightened vigilance and high-tech forensics are not sufficient to deter would-be nuclear smugglers

KARLSRUHE, GERMANY—In May 1999, a nervous-looking man caught the attention of Bulgarian border guards as he attempted to enter the country from Turkey. A search of his car turned up a certificate "for the purchase of uranium 235" written in Cyrillic and a lead container labeled "uranium 235." Inside was a glass ampoule filled with several grams of fine black powder that Bulgarian scientists later confirmed to be highly enriched uranium (HEU). According to press reports, Uskan Hanifi, a Turkish citizen, told police that he had bought the uranium in Moldova. He had been trying to sell it in Turkey, he explained, but having failed, he was attempting to return to Moldova.

The small amount of uranium seized at the border is far short of the quantity terrorists would need to fashion a crude nuclear bomb—that would require at least 10 kilograms of HEU, experts say. But the incident underscores the vulnerability of poorly secured research reactors, a likely source of the seized uranium. Just such a concern prompted U.S. and Yugoslav authorities to whisk 48 kilograms of unused HEU fuel from a research reactor in Belgrade last summer (*Science*, 30 August, p. 1456). But the Bulgarian case, detailed at a conference* here last week sponsored by the International Atomic Energy Agency (IAEA), also reveals an Achilles' heel of scaled-up efforts around the globe to prevent terrorists from getting their hands on materials that could be used to create a nuclear device or a radiological, or "dirty," bomb: In many countries where the potential for smuggling is greatest, authorities lack the legal tools to give convicted smugglers much more than a slap on the wrist. The smuggler in this case was given only a fine.

The case also illustrates how the latest nuclear forensic techniques are being brought to bear in tracing smuggled materials. A year after the uranium-filled vial was seized in Bulgaria, the U.S. Department of State arranged for it to be sent to Lawrence Livermore National Laboratory in California with the hope that detailed analyses could offer clues to where the sample originated. Working with several other Department of Energy labs, a team led by Livermore scientist Sidney Niemeyer uncovered a wealth of telling characteristics. Analysis by x-ray diffraction and electron microscopy revealed that the powder was particularly fine-grained uranium oxide, team member Nathan Wimer of Livermore told the meeting. The grains were strikingly uniform in size and shape, suggesting that the powder was milled in a sophisticated lab. Chemical and isotopic analyses revealed that the uranium was 73% U-235 and 12% U-236, consistent with material that had been recycled from very highly enriched nuclear reactor fuel.



Nuclear sleuthing. Livermore scientists used the IsoProbe, a state-of-the-art mass spectrometer, to precisely measure radioactive isotopes and impurities in a uranium sample seized by Bulgarian border guards. An electron microscope revealed unusually fine grains of uranium oxide, like this sample (*inset*).

Further work allowed the researchers to zero in on the process used to produce the uranium and when it was last handled. Chemical separations, thermal ionization mass spectrometry, and radiation spectrometry allowed the scientists to precisely measure the ratios of seven isotope pairs produced as the uranium decays. These ratios suggest that the material went through so-called Purex reprocessing—a chemical treatment that separates spent fuel into waste products and reusable uranium and plutonium—around the end of October 1993. The mass spectrometry also revealed that the uranium powder was loaded with impurities such as sulfur, chlorine, iron, and bromine.

Taken together, the powder's characteristics would allow scientists to match it to another sample from the same source, Wimer says. "This is quite unusual material and quite indicative" of certain types of reactor processes, he says. Theoretical models of processes that could have produced the powder's particular ratio of radioactive isotopes suggest that it is derived from fuel that was originally 90% uranium-235, Niemeyer says. The scientists concluded that the sample is consistent with material from a research reactor, most likely in the former Soviet Union, although they were unable to pinpoint the exact source.

More conventional forensic techniques corroborated the notion that the sample emanated from Eastern Europe. The ampoule—a type sometimes used to archive nuclear samples—was lined with an unusual paraffin wax tinged yellow by barium chromate, a colorant rarely used in Western countries but common in Brazil, China, India, and Eastern Europe. The label on the lead container and a piece of paper wrapped around the ampoule were both derived from a mixture of hardwood and softwood trees commonly found in Eastern Europe. And the isotopic signature of the container suggested that the lead came from a mine in Asia or Eastern Europe.

But even before the Livermore team brought its analytical firepower to bear on the sample from Bulgaria, the smuggler was long gone. He had been convicted of trafficking in controlled nuclear materials a few months after his arrest at the border. At his sentencing, however, the judge asked how much the seized uranium was worth; Bulgarian scientists replied that a lab might sell a sample of that size for legitimate purposes for $3000 to $4000. Accustomed to locking away drug smugglers who traffic in much more valuable commodities, the judge fined the man several thousand dollars and let him go, according to Alexander Strezov of the Institute for Nuclear Research and Nuclear

* Advances in Destructive and Non-Destructive Analysis for Environmental Monitoring and Nuclear Forensics, Karlsruhe, Germany, 21–23 October.

CREDITS: S. NIEMEYER AND I. HUTCHEON/LLNL

Energy in Sofia, Bulgaria.

Bulgarian and U.S. officials are still hoping to discover exactly where the sample came from and whether a larger cache exists that the smuggler and his associates were hoping to sell on the black market. But that will require more political cooperation. Although scientists at the original reactor could certainly identify the sample, there is not enough publicly available information to make a conclusive match. "Unless the responsible country is forthcoming, there is not going to be a resolution" to the question of the sample's origin, Wimer says.

In the absence of such cooperation, several meeting participants suggested that the development of a database of known nuclear and other radioactive sources, perhaps coordinated by IAEA, could help trace seized materials. Although secrecy could thwart the development of a comprehensive database, says Lothar Koch of the European Commission's Institute for Transuranium Elements in Karlsruhe, IAEA or another organization could at minimum seek to convince countries to identify matches if presented with details of a suspicious sample.

Stronger links between the scientific community and law enforcement are another vital line of defense against nuclear trafficking. In another case described at the meeting, a bus at the Presevo border crossing between Macedonia and Yugoslavia triggered a recently installed radiation detector. A search revealed a suspicious container with Chinese lettering. Later analysis revealed that it contained highly radioactive cobalt-60. The border guards evacuated the bus, but then they allowed everyone to go—missing the chance to determine who might have been exposed to potentially dangerous levels of radiation from the cobalt-60, not to mention allowing the smuggler to escape.

"The scientific problems are important," Strezov said at the meeting's closing session, "but more important are law enforcement personnel. They are on the front line." Well-trained police and laws with teeth are just as important as high-tech analyses for preventing the stuff of nuclear nightmares.

—GRETCHEN VOGEL

EVOLUTIONARY BIOLOGY

Evo-Devo Enthusiasts Get Down to Details

Researchers seek out variation among individuals to help them understand development's role in evolution

Some researchers are turning Theodosius Dobzhansky's famous quote, "in biology, nothing makes sense except in light of evolution," on its ear. Evolution, it turns out, makes no sense except in light of biology—developmental biology, to be precise. Ever since Darwin formalized the idea that species change through time in response to their environments, researchers have been debating how this happens. Does evolution proceed in leaps, possibly through sudden, major genetic changes? Or do new organisms arise slowly, through the gradual accumulation of more subtle genetic perturbations?

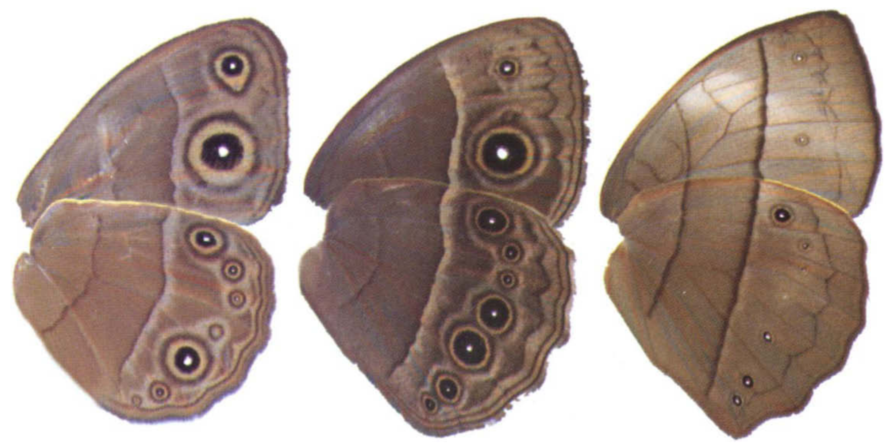
Today many researchers from a field that melds evolutionary and developmental biology—evo-devo—are turning their attention away from dramatic evolutionary events and toward seemingly mundane ones. They hope their work will eventually help explain how subtle genetic changes can sometimes make evolution appear to skip ahead, possibly even reconciling the positions of those who champion large-scale changes with the positions of those who pay heed to more minor variations. Their studies of butterfly eyespots, nematode sex determination, and cavefish eyes, for example, are yielding insights into how the same mechanisms might underlie both types of evolution.

Evo-devo work hasn't always had such a mechanistic bent. When developmental biologists began delving into evolution more than a decade ago, they tended to focus on the big picture: so-called macroevolution. The early emphasis was to survey a broad range of organisms, chasing down developmental genes common to them all. That such genes existed was a startling revelation, suggesting that organisms' body plans were more highly conserved across species than people suspected.

For a while, researchers were taken with trying to figure out how such similar genes could underpin the development of wildly different creatures. But that approach has proven limited. "You can collect lists of conserved genes, but once you get those lists, it's very hard to get at the mechanisms [of evolution]," explains William Jeffery, an evolutionary developmental biologist at the University of Maryland, College Park. "Macroevolution is really at a dead end." The lists gave no insight into how, in the end, organisms with the same genes came to be so different. And given the evolutionary distance between, say, a fruit fly and a shark, "there isn't really an experimental manipulation to let you get at what the genes are actually doing," says Rudolf Raff, an evolutionary developmental biologist at Indiana University, Bloomington (IUB).

The solution, say Jeffery and others, is to focus on genetically based developmental differences between closely related species, or even among individuals of the same species. This is the stuff of microevolutionists, who care most about how individuals vary naturally within a population and how environmental forces affect this variation.

In adopting a microevolutionary approach, these evo-devo researchers are placing themselves smack in the middle of the ongoing debate about how evolution proceeds. The fundamental question, Maryland's Eric Haag points out, is whether the mutations that result in real novelty are the same mutations that happen day to day or



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Spotting genetic diversity. Butterfly eyespots have the normally hidden potential to shrink or expand in just a few generations.