DETECTING NUCLEAR SMUGGLING

Radiation monitors at U.S. ports cannot reliably detect highly enriched uranium, which onshore terrorists could assemble into a nuclear bomb

By Thomas B. Cochran and Matthew G. McKinzie

KEY CONCEPTS

- Existing radiation portal monitors, as well as new advanced spectroscopic portal machines, cannot reliably detect weapons-grade uranium hidden inside shipping containers. They also set off far too many false alarms.
- So-called active detectors might perform better, but they are several years off and are very expensive.
- The U.S. should spend more resources rounding up nuclear smugglers, securing highly enriched uranium that is now scattered overseas, and blending down this material to low-enriched uranium, which cannot be fashioned into a bomb.

—The Editors

Customs inspectors at a pier in New York City send a sealed cargo container just taken off a ship from Istanbul through a radiation scanner. A dozen new tractors seem to be inside. Although the detector senses no radiation, the inspectors open the container anyway. Their handheld units show no radiation either, so they allow the container to leave. A private hauler drives it to a small Midwestern city. There terrorist cell members remove what was their final shipment of highly enriched uranium, concealed as 10 metal washers in the tractor engines, together weighing two kilograms. Months later an improvised nuclear device with a yield of one kiloton is detonated in Los Angeles. The blast, fire and airborne radioactivity kill more than 100,000 people. Virtually all shipping into the U.S. is halted, precipitating a financial crisis. Military operations commence in the Middle East after forensics and intelligence efforts trace the plot to cells in Pakistan and Iran.

Are these terrible events far-fetched? Twice in recent years the two of us helped an ABC News team that smuggled a soda can–size cylinder of depleted uranium through radiation detectors at U.S. ports. The material did not pose a danger to anyone, but it did emit a radiation signature comparable to that of highly enriched uranium (HEU), which can be assembled into a nuclear bomb. As you read this article, the Bush administration and the U.S. Congress are likely considering spending billions of dollars for additional detectors at ports and other border crossings—detectors that would also fail to reliably spot our cylinder or a similar amount of HEU.

A crude nuclear device constructed with HEU poses the greatest risk of mass destruction by terrorists. In the aftermath of the September 11 attacks, the U.S. government sought to prevent the smuggling of nuclear weapons and materials. The U.S. Department of Homeland Security instituted what it called a "layered defense," built largely around costly radiation detectors.

Why focus on detection? The sheer number of cargo containers entering the U.S. is staggering. Containers come in different sizes, so the number is counted as the equivalent of standard, 20-foot containers, or "twenty-foot equivalent units" (TEUs). More than 42 million TEUs entered American ports in 2005. By 2007 Homeland Security had deployed hundreds of radiation portal monitors. It also asked Congress for additional, advanced machines but in October

JULIE JACOBSON *AP Photo*; PHOTOILLUSTRATION BY SCIENTIFIC AMERICAN

backed off to perform further testing on those units, in light of software problems. Although some federal officials and government contractors claim that the technology will be effective, an analysis we have conducted shows that the machines will not reliably reveal HEU. Instead the government must place a much higher priority on efforts to identify and eliminate or secure known stocks of HEU, stopping the potential problem at its source.

Easy to Hide

To wreak havoc, terrorists could steal, purchase or be given a fully assembled nuclear weapon, but that scenario is not likely. Intact nuclear weapons are generally under greater physical security than the fissile material needed to build one. A more probable route is to illicitly obtain this material—which is now scattered among many civil, military and space power facilities worldwide—and then to smuggle it into the U.S. and assemble a bomb. Two fissile materials are of primary concern: plutonium and HEU.

Less plutonium than HEU is needed to achieve a given explosive yield, but crafting a plutonium weapon requires far more complex engineering. Plutonium is also easier to detect if shipped among cargo. HEU is easier to handle, to form into a crude explosive device and is much harder to detect in a cargo container. Furthermore, a greater amount of HEU exists in more dispersed and less secured places. According to the International Atomic Energy Agency, 275 confirmed incidents involving nuclear material and criminal intent occurred globally between January 1993 and December 2006. Four involved plutonium, but 14 involved HEU. More than 40 countries harbor HEU, with the highest risk of theft being from facilities in Russia, other former Soviet states and Pakistan. And a recent Harvard University study concluded that U.S.-funded security work had not been completed at 45 percent of nuclear sites of concern in countries once part of the Soviet Union.

Obtaining nuclear material is no small challenge, but the ABC News exercises showed that smuggling it into the U.S. can be a straightforward matter. In the summer of 2002 an ABC News unit successfully slipped a lead-lined steel pipe containing a 6.8-kilogram (15-pound) cylinder of depleted uranium (DU) past U.S. Customs and Border Protection by placing it inside a standard cargo container. This material is unsuitable for a weapon, but its chemical properties are

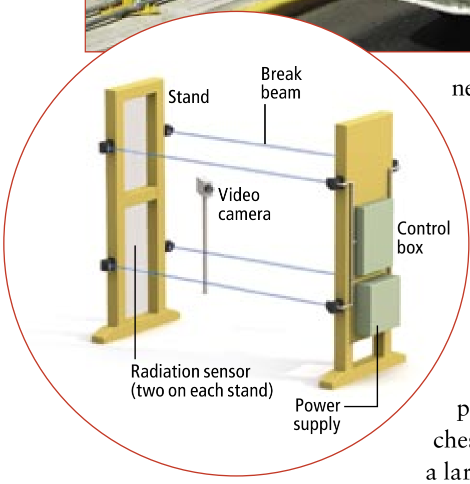
URANIUM IN A HAYSTACK

20
Length, in feet, of a typical shipping container. The volume of international shipping is measured in "twenty-foot equivalent units," or TEUs.

297 million
Number of TEUs shipped worldwide in 2005.

42 million
TEUs entering U.S. ports that same year.

6,500
TEUs arriving at the Port of New York and New Jersey on a light day; up to 13,000 on a busy day.



CURRENT PORTAL MONITORS wait to detect radiation as containers slowly pass by. Inset: Sensors on both sides can pick up radiation; a video camera identifies the vehicle.

nearly identical to those of HEU. Our organization, the Natural Resources Defense Council (NRDC), prepared the shielded cylinder. The ABC News crew placed the pipe in an ordinary suitcase and carried it on passenger trains from Vienna to Istanbul—a route chosen to simulate a terrorist journey. The news crew saw no radiation detection equipment along the way.

On reaching Istanbul, the journalists placed the suitcase inside an ornamental chest, packed alongside crates of huge vases in a large metal shipping container that left Istanbul by ship on July 10. When the container arrived at Staten Island in New York, Customs officials, part of Homeland Security, targeted it as high risk, in part because of its origin, and flagged it for more thorough screening. The machine and its operators failed to sense the uranium. ABC News aired its story on September 11, 2002, a year after the 9/11 attacks.

ABC News repeated the experiment a year later. This time the suitcase was placed inside a teak trunk that was loaded with other furniture within a container in Jakarta. The container arrived at the Port of Long Beach, Calif., on August 23. As before, this shipment was targeted and screened by Customs personnel but was allowed to proceed by truck on September 2. ABC News announced that officials once again failed to detect depleted uranium. After the story aired, Customs seized our cylinder, "disposed" of it and placed one of us (Cochran) on an air-travel watch list for several months.

Inadequate Detectors

The Department of Homeland Security began installing first-generation detector systems—known as radiation portal monitors (RPMs)—in late 2002. Despite the ABC News results, more than 800 of these machines and their successors have been placed at manned ports of entry, land border crossings, airports, seaports, and international mail and courier facilities. These machines are so-called scintillation detectors that count neutrons and gamma rays but do not measure their total energy. The instruments can therefore gauge the intensity of detected radiation but cannot measure the characteristic radiation spectrum, or signature, of a source.

To reveal radioactive material, the radiation must first be detected, but then the counts must also be discernible from those produced by harmless radioactive substances in the cargo—everything from bananas, brazil nuts and white potatoes to cat litter, aircraft parts, glass and

FRANK FRANKLIN II *AP Photo* (*top*); GEORGE RETSECK (*inset*) concrete. This natural background radiation can vary significantly depending on a container's contents. The inability of RPMs to measure a source's characteristic radiation spectrum, however, leads inevitably to false alarms from background sources, and the false-alarm rate for the current monitors is problematically high—as high as several hundred a day at certain facilities. When an alarm is triggered, Customs agents must run containers through further scans or inspect them by hand, adding considerable shipping delays and cost.

The further testing is done by a gamma-ray imaging system called VACIS, which produces an x-ray scan of the container contents. Customs officers are also equipped with small, pagerlike personal radiation detectors. Although all these sensors were present during the second ABC experiment, none of them detected the concealed uranium.

Given the RPMs' deficiencies, Homeland Security announced in 2006 that it would acquire hundreds of second-generation radiation detectors—advanced spectroscopic portal (ASP) machines—with the price tag for total hardware alone exceeding $1 billion. The system has both gamma-ray and neutron detectors but can also perform gamma-ray spectroscopy to show a radiation signature; when applied together, the techniques are intended to lower false alarms by identifying a source as harmless radioactive cargo. In August 2007 President George W. Bush signed into law the Implementing Recommendations of the 9/11 Commission Act of 2007, which mandates that within five years *all* maritime cargo be scanned *before* it is loaded into vessels in foreign ports heading to the U.S. Many more detectors would have to be deployed.

This move is ill-advised, however, because even the ASP machines are not dependable. Their ability to reliably sense shielded HEU was not demonstrated during classified trials at the U.S. Department of Defense's Nevada test site. Moreover, the ASP machines failed to function properly, when installed at the Port Authority of New York and New Jersey, as a result of software problems. Indeed, in November 2007 the *Washington Post* revealed that Homeland Security itself had questioned the machines' effectiveness. According to the newspaper, in September 2006 auditors at the U.S. Government Accountability Office alleged that officials had greatly exaggerated the tools' capabilities. Another investigation by the accountability office a year later found that officials had overseen compromised tests of the ASP system. After petitioning Congress to allocate funds for more ASPs, in October 2007 Homeland Security chief Michael Chertoff decided to postpone certifying the new ASPs and further production until problems were resolved. When this issue of *Scientific American* reaches newsstands, Homeland Security will likely be presenting Congress with new contractor performance data on the ASP detectors. Legislators will have to decide whether to continue to fund such acquisitions in light of the machines' checkered history.

A Fair Surrogate

Homeland Security was not fond of the ABC exercises and asserted publicly that if NRDC's slug of depleted uranium had been HEU, inspectors would have identified and intercepted it. We disagree. Our analyses show that when even lightly shielded with lead and steel, depleted and highly enriched uranium have similarly weak radiation signals and would be equally hard to detect by either generation of monitor.

To compare DU with HEU, we calculated the radiation particle count and detector dose rate at various distances from shielded and unshielded samples of both and then compared these quantities with background radiation. We performed our calculations using the standard radiation analysis software employed by Los Alamos National Laboratory and common uranium radiation data supplied by Lawrence Livermore National Laboratory.

Some HEU contains extremely small concentrations of the isotope uranium 232, which is not found in natural uranium but is produced when HEU is irradiated in nuclear reactors. In the U.S. and Russia most HEU was enriched from uranium that was recovered from military fuel and thus is contaminated with trace amounts of uranium 232. Even minuscule quantities, less than one part per billion (ppb), have a telltale radiation signal.

Two significant factors can reduce an RPM's ability to detect the signal of either pure or contaminated HEU: shielding that absorbs radiation, and distance between the source and detector. When not shielded, the calculated dose rate for pure and contaminated HEU is greater than for DU. But much of the dose in both cases arises from the lower-energy part of the gamma-ray spectrum, which is readily absorbed by shielding. If the source is wrapped in a one-millimeter-thick layer of lead, the radiation dose rate from HEU with no uranium 232 is *less* than

RADIATION COMPARED

The slug of depleted uranium (DU) that we prepared and that ABC News smuggled past portal monitors is shown below. It is a good substitute for testing whether the monitors could detect highly enriched uranium (HEU) because the radiation signal from uncontaminated DU, when shielded inside a cargo container, is actually greater than that from uncontaminated HEU.

CALCULATED DOSE RATE
(microrad/hour)
two centimeters away, when wrapped in three millimeters of lead

DU: 1,500
HEU: 100

CALCULATED DOSE RATE
(microrad/hour)
two meters away, for same samples

DU: 1.0
HEU: 0.1

NATURAL BACKGROUND: 2–10

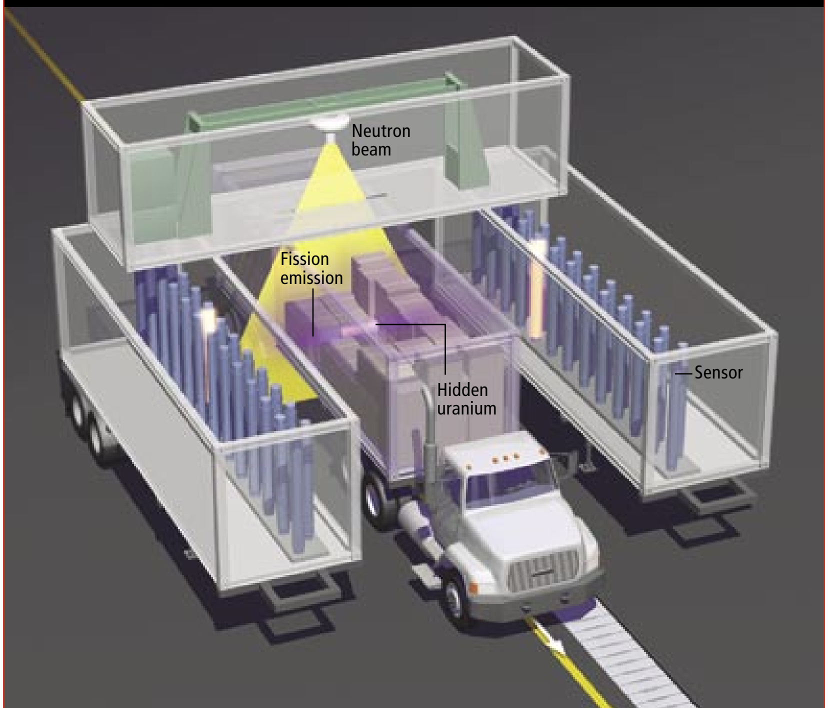
DEPLETED URANIUM cylinder, shielded in lead, was slipped past portal detectors.

COURTESY OF MATTHEW G. MCKINZIE

[NEW TECHNOLOGY]

ACTIVE DETECTION

Active detectors being developed by several laboratories could distinguish highly enriched uranium in cargo containers from other naturally radioactive materials. At issue is whether the incoming detector beam could harm people who illegally stow away inside containers and whether the public would balk if containers held food, even though imparted radiation would decay in less than a minute.



In a concept from Lawrence Livermore National Laboratory, a detector sends a low-power neutron or gamma-ray beam (*yellow*) into a passing container; if highly enriched uranium is present (*purple*), it will undergo a brief fission and emit neutrons and high-energy gamma rays, which have a short half-life decay. Sensors (*blue rods*) would distinguish each of these signals.

the dose rate of similarly shielded DU. For HEU contaminated with 2 ppb of uranium 232 and encased in the same shielding, the gamma-ray dose rate is about equal to that from DU. Public data indicate that roughly half of Russian HEU may have a uranium 232 concentration less than 0.2 ppb, and all HEU produced in Pakistan and Iran is likely free of the isotope.

For both DU and HEU, the emitted radiation decreases with distance from the source. We calculated that for lightly shielded HEU (covered by one-millimeter-thick lead) with no uranium 232, the dose rate is less than 5 percent of the background radiation at two meters; for HEU contaminated with 0.2 ppb the dose rate is less than 10 percent of the background radiation. In a typical portal monitor the distance from a standard shipping container's center to a detector on either side is greater than two meters. Thus, neither RPMs nor the newer ASPs would distinguish most shielded HEU from Russia if any were placed near the center of a container.

Our work demonstrates that DU is a good surrogate for HEU in testing Homeland Security's ability to detect smuggled nuclear weapons material. Had our test slug been HEU, the RPMs would not have detected it, and neither would have the next-generation ASPs.

Enough for a Bomb

To make matters worse, it is conceivable that terrorists could smuggle HEU into the U.S. by shipping pieces smaller than the slug we used. The question, then, is whether small pieces of HEU could be assembled into a crude bomb with substantial explosive yield.

Most modern nuclear weapons are based on implosion: conventional explosives are detonated to compress nuclear material so well that it erupts in a runaway fission chain reaction. Terrorists operating covertly are unlikely to be able to assemble such a device because of its complexity. A simpler gunlike design can be effective, however; two subcritical pieces of HEU are driven together so that they form a supercritical mass. The "Little Boy" atom bomb that was dropped on Hiroshima in 1945 brought together about 65 kilograms of HEU within a millisecond by firing one subcritical piece down a gun barrel at a second subcritical piece.

The "quality" of nuclear material since then has continued to improve, however, so much so that in 1987 Nobel laureate physicist and Manhattan Project scientist Luis Alvarez noted that if terrorists had modern weapons-grade uranium, they "would have a good chance of setting off a high-yield explosion simply by dropping one half of the material on the other half." To test that assertion, we modeled the difference between the Little Boy design and an improvised nuclear device as crude as the one Alvarez described.

We again used the Los Alamos software code and modeled the yield of Little Boy on publicly available design information, as well as two simple configurations of HEU in a gun assembly. Our modeling showed that, for an explosive-driven gun assembly, the minimum quantity that was required to obtain a one-kiloton explosive yield would be substantially less than the amount of HEU in Little Boy. Most disturbingly, with larger quantities, a one-kiloton yield could be achieved with a probability greater than 50 percent by dropping a single piece of HEU onto another, confirming Alvarez's statement. Designing an HEU bomb seems shock-

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GEORGE RETSECK (*illustration*); COURTESY OF THOMAS B. COCHRAN (*Cochran*); COURTESY OF MATTHEW G. McKINZIE (*McKinzie*)

EDITORS' NOTE

The authors and editors have been careful to not expose details that could help terrorists or that are not readily available in published sources.

ingly simple. The only real impediment, therefore, is secretly gathering sufficient material.

More Effective Countermeasures

Given the difficulty portal monitors have in detecting smuggled HEU, stopping any clandestine influx is crucial. The U.S. government has essentially four choices: rely on intelligence to identify and round up nuclear smugglers; eliminate HEU at its source; consolidate HEU and safeguard it; or detect HEU as it crosses international borders. Wise policy would pursue all these avenues in a balanced way, based on their effectiveness and cost. The current U.S. approach, however, is far too reliant on the dubious detectors. The federal government does have programs to "blend down" excess Russian military stocks of highly enriched uranium into low-enriched uranium and to replace HEU fuel in research reactors with low-enriched fuel. The U.S. is also helping to improve the physical security of some Russian HEU stocks. But the government has not given these programs, which do not fall under Homeland Security, the same high priority as portal monitor programs.

As trials have shown, neither RPMs nor ASPs are currently able to provide reliable protection. Homeland Security does support research on other advanced detection schemes, such as active detection systems that bombard a container or vehicle with low-energy neutrons, creating a telltale gamma-radiation signal. Last year Lawrence Livermore unveiled a prototype that it claims can detect lightly shielded uranium pieces of less than one kilogram, with a low false-alarm rate [*see box on page 102*]. Rapiscan Systems in Torrance, Calif., is developing a similar scheme. The technology would have to be commercialized and its costs significantly reduced, however. Concern by the public, and by shippers, that cargo contents would be exposed to the gamma rays produced would also have to be addressed, even though the energy levels are very low and the radiation dissipates within an hour. Lawrence Livermore has said it could have a system ready for commercial evaluation by 2009.

Congress is likely now debating whether it should continue to support the troubled, multibillion-dollar ASP program. With RPMs and ASPs, Customs agents might catch an amateur terrorist attempting to smuggle HEU, but they are unlikely to catch a sophisticated agent like 9/11 terrorist Mohamed Atta. The U.S. government should instead place a much higher policy priority, and in some cases spend more funds, on securing and eliminating HEU sources worldwide. The government should also seek a global ban on the commercial use of HEU, such as isotope production for medical applications and experiments on nuclear reactor designs, most of which can be performed with low-enriched uranium or in particle accelerators. To protect the U.S. from terrorist nuclear attack, the country should forge a larger, more effective strategic plan centered on eliminating access to weapons-grade material. ■

ABOUT 40 KILOGRAMS (88 pounds) of highly enriched uranium identified in Swierk, Poland, is returned to Russia in August 2006 for decommissioning, a move prompted by the International Atomic Energy Agency.

INTERNATIONAL ATOMIC ENERGY AGENCY *Ho/AP Photo*

BETTER PLAN

Radiation monitors at U.S. ports are insufficient for preventing terrorists from amassing highly enriched uranium for a nuclear bomb. We maintain that the country should therefore enhance protective actions, some now under way. Chief among them:

- Identify and round up nuclear smugglers.
- Secure known sources of poorly guarded HEU and ship it back to its country of origin for elimination.
- Blend down excess Russian stocks of HEU into low-enriched uranium.
- Replace HEU fuel in research reactors with low-enriched fuel.
- Seek a global ban on the commercial uses of HEU, such as medical applications, most of which can be pursued with low-enriched uranium.

—T.B.C. and M.G.McK.

MORE TO EXPLORE

Thwarting Nuclear Terrorism. Alexander Glaser and Frank N. von Hippel in *Scientific American,* Vol. 294, No. 2, pages 56–63; February 2006.

Securing the Bomb 2007. Matthew Bunn. Harvard University and Nuclear Threat Initiative, September 2007.

Looking for Hidden Materials. Dennis Slaughter in *Nuclear News,* page 43; November 2007.

Radiation Detectors for Border Are Delayed Again. Robert O'Harrow, Jr., in *Washington Post,* page A1; November 20, 2007.

The Illicit Trafficking Database, maintained by the International Atomic Energy Agency, lists unauthorized activities involving radioactive materials: **www.iaea.org/NewsCenter/News/2007/itdb.html**