

Replacing high-risk radioactive materials remains a challenge

The medical industry is substituting x-ray sources for cesium-based blood irradiators. Other industries are also exploring alternative technologies.

A radioactive iridium-192 source capable of causing permanent injury within minutes of exposure went missing in late July, according to the US Nuclear Regulatory Commission (NRC). Prime NDT Services—a business based in Strasburg, Ohio, that uses nondestructive testing methods to evaluate the integrity of oil and gas pipelines—shipped the ^{192}Ir source from Ohio to Michigan on 12 July. Eight days later the carrier informed the company of the disappearance. Dozens of similar incidents around the US have been reported to the NRC this year.

The risks of accidental radioactive contamination and deliberate dispersal by terrorists have prompted governments worldwide to fund the search for substitutes for commercial radioisotope technology. After the 9/11 terrorist attacks in 2001, Congress tasked the National Research Council with reviewing technologies that rely on high-risk materials and recommending nonradioactive replacements that couldn't be readily weaponized.

The report, released in 2008, found that a handful of radionuclides make up the majority of high-risk sources in the US and suggested that cesium chloride sources, in particular, should be replaced. A follow-up report released in June of this year by the National Academies of Sciences, Engineering, and Medicine (NASEM) renews the call to decrease the reliance on radioactive materials.

But over the past 12 years, the US medical field, science research enterprise, and industry have increased their use of radioactive sources by 30%, according to regulatory commission data.

Targeting cesium chloride

The 2021 NASEM report focuses on the riskiest radiation sources. Blood-



MEMBERS OF DOE'S Radiological Assistance Program survey the inside of the University of Washington's Harborview Research and Training Building in Seattle after a sealed cesium-137 source was breached in May 2019. Such radiation exposure could be avoided by replacing cesium-based blood irradiators with new x-ray technology.

irradiator devices, for example, contain cesium chloride and other materials that the International Atomic Energy Agency (IAEA) defines as category 1 sources. They can cause death or permanent injury, even if someone is exposed to grams of material for just a few minutes. Category 2 sources include the americium-241 and beryllium mixture found in logging tools for oil exploration and radiometric-instrument calibration. They typically require an exposure time of hours to cause severe health conditions.

Common smoke detectors use ^{241}Am to ionize air molecules; an interruption of the resulting current indicates the presence of smoke. They're a category 5 radiation source, which the IAEA ranks as unlikely to cause any injury.

Devices with cesium-137 are commonly used in research and in the medical industry. For example, to prevent graft-versus-host disease and other transfusion-based illnesses, medical facilities routinely expose blood to ionizing radiation, which kills white blood cells. The ^{137}Cs is traditionally bonded to chloride. The resulting crystalline powder is easily handled and stored, but its high water solubility makes it easy to disperse and even capable of diffusing through concrete.

The US Department of Energy's Na-

tional Nuclear Security Administration has funded numerous efforts to replace cesium chloride blood irradiators. One promising technology uses x rays to deliver ionizing radiation to blood, and several companies now offer commercial units to the medical industry. According to a 2018 report by the nonprofit Nuclear Threat Initiative (NTI) in Washington, DC, the costs of three devices approved by the Food and Drug Administration range from \$200 000 to \$270 000.

In 2016 Emory University Hospital in Atlanta, Georgia, purchased an x-ray blood irradiator and retired its radiological one. Mount Sinai hospital in New York City followed suit in 2019, replacing all of its cesium blood irradiators. Georgia-based manufacturer Rad Source Technologies has sold devices to hospitals in the US and Saudi Arabia. Thomas Kroc, the committee cochair of the recent NASEM report, says that "the 2008 academies report did talk about the promise of x-ray technology. It has taken until now for it to really mature to the point where it's starting to emerge on the market."

A few national health systems have started or completed the switch. In the wake of the 2011 Fukushima Daiichi reactor accident, Japan began phasing out the use of cesium blood irradiators; 75% of the country's units have now been

replaced with x-ray ones. By 2016 France and Norway had supplanted all their cesium blood irradiators with x-ray ones.

Cobalt-60

Another common, high-risk radioisotope is cobalt-60, which is most often used to sterilize medical devices and to kill insects, fungi, and bacteria in food processing. It's effective because the panoramic irradiator that holds the source is typically housed in a shielded room and shoots 1.17 and 1.33 MeV gamma rays at items on a conveyor belt. According to the 2021 NASEM report, the US has about 72,000 category 1 and 2 ^{60}Co sources and roughly 3,200 category 1 and 2 ^{137}Cs sources.

Suresh Pillai, who studies molecular microbiology and food safety at Texas A&M University, says "to the best of my knowledge, there are no new cobalt-60 facilities being commissioned in the US." DOE has funded R&D for electron-beam sterilization technology and other replacements for ^{60}Co .

"The facts on the ground show that especially in medical device and food processing, nonradioactive machine sources are growing," says Pillai. Still, electron-beam makers face regulatory hurdles and an uphill battle against industry inertia. Operators of ^{60}Co sources and device manufacturers have a 50-year head start, and Pillai says there are not enough electron-beam suppliers. Switching from gamma-ray sterilization to electron-beam technology requires that the materials be boxed in different packaging, which is expensive and involves a significant reorganization of sterilization supply chains.

In India, blood and low-dose research irradiators that rely on ^{60}Co , which has a 5-year half-life, are being replaced by devices employing ^{137}Cs , which has a 30-year half-life. Although proponents argue that the longer half-life of ^{137}Cs translates to fewer handling and transportation operations and thus may be less risky, it's still a category 1 source. India's strategy relies on vitrified ^{137}Cs , which lacks the water solubility of the isotope's more common powdered form.

In a June 2020 paper from the Observer Research Foundation, a think tank based in New Delhi, India, Rajeswari Pillai Rajagopalan says that "while India has made a strong case for cesium-137, it could be useful for India to explore other



MORE R&D is needed to lower the cost of less risky, nonradioactive alternatives to the gamma-ray-based logging tools that the oil and gas industry uses to measure the density and porosity of rock formations. (Photo by iStock.com/sasacvetkovic33.)

replacements that might not present the same dangers as cesium-137."

In addition to technological innovation, issues associated with the supply of ^{60}Co may be helping to drive the adoption of replacements. In 2014 the amount of ^{60}Co on the global market slumped after a joint Russian-British business venture collapsed. The shutdown of an Argentinian reactor in 2016 for refurbishment further strained the global supply.

In an October 2020 presentation to the NASEM report committee, Nordion—a health science company based in Ottawa, Canada, that is a primary supplier of ^{60}Co sources—said the supply of ^{60}Co is now 5% below demand.

Well logging

Although the bulk of ^{137}Cs sources are found in the medical industry, the oil industry uses the radioisotope too. Drillers, equipped with a ^{137}Cs source housed in a data-logging tool, detect and measure the density of the surrounding rock to determine its capability for holding hydrocarbons. A second detector measures and corrects for naturally occurring radiation.

Another tool common in petroleum exploration contains an americium-beryllium source and emits neutrons in the borehole of a well to estimate the ground's porosity. The porosity characterizes the well's economic feasibility by

quantifying the ease with which hydrocarbons will flow through the rock reservoir to the well. (For more on the physical techniques used in oil exploration, see the article by Brian Clark and Robert Kleinberg, *PHYSICS TODAY*, April 2002, page 48.)

The IAEA has established protocols for the storage, transport, and use of radioactive sources in hydrocarbon exploration. Still, radioactive logging sources have been stolen—including in India in 1993 and in Argentina in 2009. Others have gone missing. In 2003 the americium-beryllium source of an oil company in Nigeria disappeared for several months before turning up in Germany.

The most surefire way to mitigate such risk would be to use an alternative, nonradioactive technology for petroleum exploration. One substitute device detects scattered x rays to measure a rock formation's density and porosity. But its accuracy is not as high as a ^{137}Cs logger, the data it collects require correction, and it isn't as widely available as radioactive devices.

The oil industry favors radioactive well-logging tools because of their stable radiation output, relatively low cost, and small footprint: They can operate in a tight, high-temperature space without an additional, bulky power supply. "If you've got something that still has 10 years of service life left and the alterna-

tive is not significantly less expensive, then there's going to be very little push to give up that service life," says committee cochair Kroc.

Ioanna Iliopulos, a senior consultant at NTI, says the oil industry is extremely competitive. "There are a few big companies and a lot of mom-and-pop shops, and expanding funding for alternative technologies has not been a priority due to narrow profit margins."

One size doesn't fit all

Health-care providers and researchers, particularly in some low-income countries in Africa, need financial support to purchase nonradioactive devices. They also lack qualified operators for the instruments and reliable, uninterrupted power supplies.

Cultural and social concerns also influence whether radioactive materials get replaced. Hubert Foy, a committee member of the 2021 NASEM report, is the founding director of and senior research scientist at the African Centre for Science and International Security in Accra, Ghana. He says it's important to ensure buy-in from users and the community. "I've seen that the technology is not being fully utilized within the developing-country community," he says. "I would have loved to see in the academies report an assessment of the infrastructure and cultural implications of the adoption and use of alternative technology."

Laura Holgate, a vice president at NTI, says, "More can be done about the regulatory setting and environment so that those who do make the change have a benefit." She says that leadership from the White House could spur a government-industry partnership, where government agencies, nuclear regulators, and business leaders could talk in a noncompetitive environment about the alternative technologies and how to overcome the challenges to adopting them.

For radioactive sources without a ready alternative, Holgate says, "you really need to have security levels consistent and commensurate with the threat to human health and the economic, operational, and societal impacts." Strong security measures, such as having cameras, providing access control, and always having two people execute critical procedures, are far from universal, she adds.

Jennifer Elster, a research scientist at

Pacific Northwest National Laboratory, notes that "avoiding the security costs and end-of-life costs associated with removal and disposal of radioactive material is likely to be a strong incentive in considering alternative technologies."

Enhanced security, however, doesn't necessarily protect against an insider adversary. "One of the things that is of rising concern to NTI and others is the growth of domestic extremism, not just in the US but abroad," says Holgate. "There have been statements by extremist groups about ambitions to build dirty bombs."

Edwin Lyman, director of nuclear power safety at the Union of Concerned Scientists in its Washington, DC, office, is less convinced of the danger. "I've been a dirty bomb skeptic for a long time. This concern was elevated in part to distract attention from the more serious issue of the potential for nuclear terrorism from the theft of materials that could be used in a nuclear bomb. Nonetheless, radiological materials can pose serious risks, and it is a worthwhile goal to seek safer substitutes where feasible."

Holgate, Iliopulos, and Lyman agree that the IAEA categorization could be

improved. A source's risk is determined by the amount of radioactivity it emits within a given exposure duration. But that classification has limitations. The possibility of a terrorist stealing radioactive materials may have a low probability, for example, but the prospect's high socioeconomic consequences makes some radioactive sources, such as ^{137}Cs , more dangerous than the IAEA presumes.

The 2021 NASEM report calls for the IAEA and the US NRC to rethink materials categorization to include probabilistic health effects, such as increased long-term cancer risk, and the economic and social effects of a radiological dispersal event. Lyman approves of the recommendation but says it's challenging: "The problem with these hard-to-quantify threats is that you can't mobilize public opinion and policymakers unless something terrible happens."

Despite the challenge, Lyman says, "every vulnerable source that's replaced or removed and every gram of plutonium that's secured is incremental progress, and it builds up over the years."

Alex Lopatka **PT**

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