GAO

A self-contained irradiator in a medical facility. About 1100 irradiators, nearly all containing cesium-137, are used in US hospitals, blood banks, and universities for research and for treatment of blood.

ramic irradiators account for 98% of the total radioactivity in all US civilian radiation sources, Harrington said.

Still, panoramic devices are thought less likely than self-contained irradiators to be targeted by terrorists due to their lack of portability and accessibility and the less readily dispersed ^{60}Co metal, says Charles Ferguson, president of the Federation of American Scientists and an authority on radiological materials.

Other potential sources of dirty-bomb materials include radiography cameras used in industry for nondestructive testing and other purposes and typically containing iridium-192. Numerous thefts of those portable devices from trucks and shipyards have been reported over the years. Thieves may have hoped to sell the cameras for scrap and probably aren't aware that they contain radioactive substances, says Ferguson, who has consulted for the NNSA on radiological source security.

In the aftermath of the 9/11 terrorist attacks, the NRC ordered that the cameras be secured by at least two locks during transport. The NNSA is currently working with device manufacturers to develop a GPS-based tracking system for radiography devices and portable sources known as well loggers, used in oil and gas drilling. The agency plans to transfer the technology to one or more commercial manufacturers next year.

Although more recent numbers aren't available, the NRC reported in 2002 that over a six-year period, US businesses and medical facilities had lost track of nearly 1500 pieces of equipment that contained radiological materials. Around 90% of those were small items such as gauges and medical isotopes that decay quickly and posed little or no threat, says Ferguson.

Worldwide, the International Atomic Energy Agency typically receives several hundred reports annually of sources either missing or caught at border crossings, Ferguson says.

A psychological threat

The damage from a dirty bomb is likely to be more economic and psychological than physical, experts say. Because any radioactive material in an explosive device would be dispersed over a wide area, the amount of exposure to an individual would be small. Indeed, the larger the explosion, the less harmful the dose will be, notes Ferguson. But cleaning up and decontaminating the area around a dirty bomb would take years and cost hundreds of millions of dollars, he says. Until that process is completed, the contaminated area would be uninhabitable. If detonated in Wall Street or some other financial area, it could cause significant damage to the economy, Ferguson adds.

Public funding has been financing the NNSA-installed building security upgrades, an agency spokesperson says, because the improvements go above and beyond NRC requirements and "there is no legislative or regulatory driver" that requires the sites to pay for them. The NNSA did not respond to a request to provide the total amount that has been spent for the upgrades.

"If you consider what would happen if one of these devices was broken into and radioactive material dispersed, a potential cost of maybe $1 billion for an event depending on where it takes place, and we spend maybe $10 million, if that, to strengthen these protections, it's a good investment," says Ferguson.

High-risk defined

The NNSA considers two classes of materials to be of high risk. Category 1 materials would likely cause permanent injury to a person in contact with them for more than a few minutes, and exposure to them for a few minutes to an hour would probably be fatal. Category 2 materials are harmful to a person exposed to them for a period of minutes to hours, and exposure lasting from hours to days could be fatal. Some 554 of the US buildings with radiological sources hold category 1 materials, and security upgrades have been completed at 273 of those, according to Harrington.

The threshold quantity of material considered dangerous varies according to whether it is an alpha, beta, or gamma emitter, notes Ferguson, due to the varying degree of risk each form of radiation presents to human health. For americium-241, an alpha emitter used in portable well-logging equipment, 2 curies is considered high risk, he says. For ^{137}Cs, which undergoes beta decay, 100 curies presents a comparable health threat.

At their 2005 summit, the Group of Eight nations agreed to tighten their export controls and improve tracking of radiological sources, a move that has led to greater awareness of the chemicals' transport between nations. At the third biennial Nuclear Security Summit, held in the Netherlands in April, 53 nations committed to secure all of their radiological sources. The US joined 21 other nations in pledging to increase protections for all category 1 materials within two years.

David Kramer

Canada CHIMEs in on dark energy

Teasing out signal from galactic noise is the biggest challenge in using diffuse neutral hydrogen to study the changing structure of the universe.

What is the expansion history of the universe? That is what the Canadian Hydrogen Intensity Mapping Experiment (CHIME) is designed to determine. Located at the Dominion Radio Astrophysical Observatory about 400 km northeast of Vancouver, British Columbia, CHIME is slated to begin operating in late 2015.

Unlike other approaches to mapping the structure of the universe as a function of time (see, for instance, the article by Josh Frieman in PHYSICS TODAY, April 2014, page 28), CHIME won't look for details about individual galaxies. Instead, the idea is to measure the 21-cm line of neutral hydrogen, which traces the positions of galaxies and, in turn, the distribution of matter. The experiment is sensitive over the redshift range of 0.8–2.5, which corresponds to the period from about 7 billion to 11 billion years ago.

CHIME will consist of five parallel, parabolic, cylindrical, mesh reflectors, each 100 m long and 20 m wide. The mesh cells are a couple of centimeters across; the design withstands rain,

MARK HALPERN

This pair of radio antennas is the warm-up for the Canadian Hydrogen Intensity Mapping Experiment. CHIME team members have climbed up to a platform at the focal line of one of the reflectors.

prevents snow accumulation, is cheaper than a solid surface, and works like a mirror for the 37- to 75-cm radio wavelengths of interest. CHIME has no moving parts; with axes aligned north–south, the experiment will sweep the sky day and night as Earth rotates. The focal line for each trough will be fitted with 256 receivers. "The backend computations are a real challenge," says Keith Vanderlinde of the University of Toronto, whose group is building an onsite correlator to perform digital interferometry. He is one of the experiment's nine co-investigators.

The experiment is being built for less than Can$12 million (roughly $11 million). The Canadian Foundation for Innovation is putting in 40% of the funding, another 40% comes from provincial agencies, and universities and industry are providing 20%.

Commercial components

It's possible to build CHIME at that low price, and to deal with the vast amounts of data it will produce, thanks to the huge global demand for cell phones and video games. Cell phones have driven the development of quiet, room-temperature amplifiers. The signal from every feed, or receiver, has to be amplified. Historically, the high cost of cryogenic cooling made a single-dish design, with only one receiver, advantageous, says Vanderlinde. "We can now amplify signals from each feed independently and collect the data from the distributed system."

For number crunching, CHIME exploits the development of graphics processing units (GPUs), which for linear algebra are cheaper and faster than central processing units. "We buy top-end, off-the-shelf graphics cards. Instead of generating fancy graphics, we convert signals to images that we add up over time," says Vanderlinde. The underlying operation is to multiply matrices. "That's how to project from three dimensions to two dimensions, as is done in video games. But it's also how to run correlations to form images of the sky. Mathematically, they're the same operation."

Each of CHIME's 1280 receivers—256 on each of the 5 reflectors—records radio waves about a billion times a second. In total, the data will roll in at terabytes per second. The data are digitized, transformed into frequency space, and juggled in real time to be fed to the GPUs.

"A gnat's eyelash"

Since last fall the CHIME team has been testing data collection and computation on a smaller version of the experiment. The "pathfinder" is made up of two reflectors 36 m in length. The main challenge is to subtract out the signals from our own galaxy. "What we have on our side," says Kris Sigurdson of the University of British Columbia, who does data analysis and interpretation, "is that we understand the physics that generates the foreground. It comes from synchrotron emission, which is smooth as a function of frequency, so we think it's possible to distinguish it from the 21-cm signals."

Miguel Morales of the University of Washington is not involved in the experiment, but uses the 21-cm line to look further back in time to the epoch of reionization. "CHIME is trying to do something new," he says. "They have to get everything right. And they have to understand their instrument to a gnat's eyelash. That precision makes it hard. But the payoff is huge."

One payoff would be to see if general relativity holds on cosmological scales. Another big question that CHIME is poised to get at is whether dark energy is a cosmological constant—that is, does its density remain constant as the universe expands? Other experiments have glimpsed earlier and later times. But, says Matt Dobbs of McGill University, "there is a key gap when dark energy went from inconsequential to dominant. I want to see if that follows Einstein's cosmological constant."

Heavenly sound

China has a similar 21-cm survey experiment in the works. At its envisioned full size, Tianlai (Chinese for "heavenly sound") will have the same dimensions as CHIME. A remote, radio-quiet site in Xinjiang province in northwestern China has been chosen, but construction hasn't yet started. The project so far has around $2 million from the country's Ministry of Science and Technology, the Chinese Academy of Sciences, and the National Astronomical Observatory, says Xuelei Chen, a cosmologist at the observatory. "We are scaling Tianlai by the amount of funding we get." The plan is to start with a pilot project of three antennas, each 40 m long and 15 m wide.

A slew of other experiments aimed at decoding dark energy are at various stages of proposal and planning. *Euclid*, a satellite that the European Space Agency plans to launch in 2020, will probe the expansion history of the universe and the evolution of cosmic structures. The Hobby-Eberly Telescope Dark Energy Experiment at the McDonald Observatory in west Texas is set to start a galaxy survey later this year using emission lines from ionized hydrogen to pinpoint individual galaxies. When the Square Kilometre Array gets going in South Africa and Australia, it will dwarf CHIME in sensitivity—but that's still years away (see the story on page 25). And the Large Synoptic Survey Telescope and a continuation of the Sloan Digital Sky Survey will both probe dark energy at optical wavelengths.

Not much is known about dark energy, says Morales, "so you want to measure the size of the universe at several different ages, and then let the theorists fight it out. I think CHIME has a good chance of being the first to get really good measurements." And, although CHIME was conceived as a single-purpose experiment, inroads are anticipated in other areas, such as pulsars, gravity at large scales, galaxies, and fast radio bursts.

Toni Feder