These photos showing the extensive damage at Fukushima were taken less than a week after the tsunami of March 11, 2011. Left: Conditions around Reactors 5 and 6. Right: The Reactor 3 building after an explosion blew off its upper floors. The explosion was triggered by the ignition of hydrogen gas created by reactor fuel overheating. Reactor buildings 1 and 4 suffered similar explosions in the days immediately following the tsunami. (Photos: TEPCO)

The quake initiated Fukushima's automatic reactor shutdown. It also cut off the reactor complex from the electric power grid. However, the tsunami that followed overwhelmed the 30-foot-high seawall that Japanese experts believed would protect Fukushima, swamped the lower floors of the reactor buildings with 15 feet of water, and permanently knocked out the reactors' emergency electric generators—and with them, their cooling-water circulation pumps. The reactors' cores containing hot nuclear fuel lost critical cooling and some (perhaps all) of the fuel became so hot it melted. Life-threatening radiation was released.

Now, more than five years later, radiation levels inside the buildings that contained the melted fuel are still lethal. The deadly fuel must be removed, but key questions still need definitive answers. Before the process of fuel removal can begin, the exact status of the fuel must be known. How much has melted? Where is it? The Japanese government, nuclear engineers, and plant operators will not have the answers until they can see inside the reactors. Yet without technology that allows them to proceed safely, the Japanese cannot begin the process.
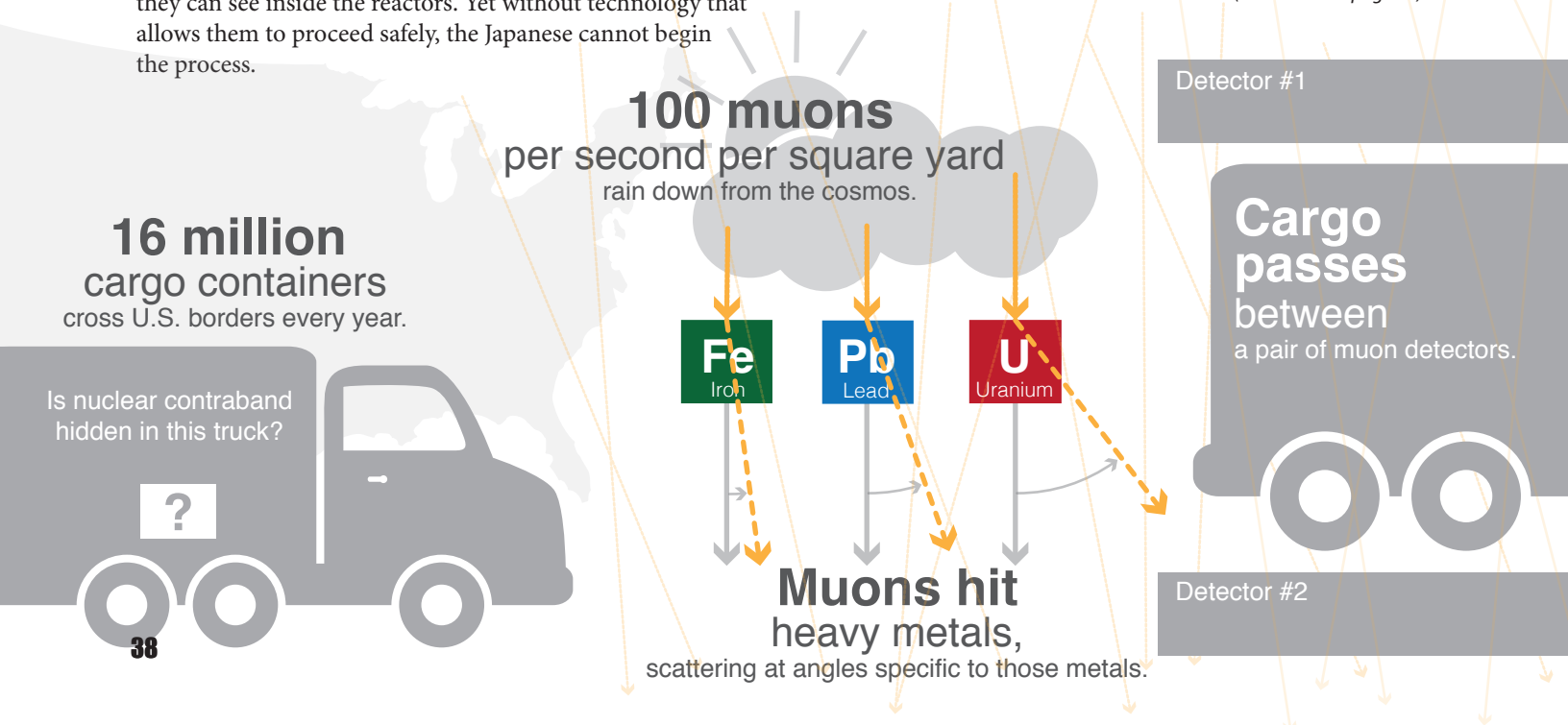
Before the process of fuel removal can begin, the exact status of the fuel must be known.

Muon vision

That's where Los Alamos National Laboratory comes in. Los Alamos scientists have created a new type of penetrating "vision" that can detect nuclear materials, such as uranium and plutonium, hidden inside very thick layers of concrete and steel. This so-called muon vision (see "What is Muon Vision?" page 39) uses cosmic ray muons, which are always present and which, unlike x-rays, are harmless to humans.

Muon vision has already been commercialized. Los Alamos and California-based Decision Sciences International Corporation (DSIC) have worked together to create a unique

16 million
cargo containers
cross U.S. borders every year.

Is nuclear contraband hidden in this truck?

?

100 muons
per second per square yard
rain down from the cosmos.

Fe Iron
Pb Lead
U Uranium

Muons hit
heavy metals,
scattering at angles specific to those metals.

Detector #1

Cargo passes
between
a pair of muon detectors.

Detector #2

What Is Muon Vision?

Muons are subatomic particles created when very high-energy cosmic-ray particles from outer space collide with atomic nuclei in the upper layers of the Earth's atmosphere. Once created, muons travel at nearly the speed of light and rain down on the Earth's surface from random locations and in random directions; every second, 100 muons hit each square yard of the Earth's surface. Their tremendous energy enables them to penetrate most objects and even travel hundreds of feet into the Earth's crust. Yet, muons compose fewer than 10 percent of all background radiation and are harmless to people.

Muons continuously scatter as they move through material; they scatter more in very heavy materials than in lighter materials. Uranium and plutonium, which are heavy, cause the largest scattering angles, albeit no more than a few degrees. Lighter elements, such as iron, cause smaller angles, and even-lighter elements, such as oxygen, cause little or no scattering. So, measuring the scattering angle reveals the identity of the material that caused the scattering. Just as important, the angle also reveals the location of the material. In that way, muons can be used to "see" materials deep inside closed containers . . . or inside damaged reactors.

Los Alamos's unique muon vision measures muon scattering and "sees" materials otherwise hidden from view. To interrogate the inside of a shipping container, Decision Sciences International Corporation (DSIC) has commercialized muon vision. DSIC uses two specially designed detectors placed above and below the container. The system records a muon's path through the top detector (before it enters the container) and then measures its path through the bottom detector (after it exits the container).

Highly sophisticated software then traces the entry and exit paths back to where they meet inside the container—the point of intersection is the location of a material. If the lines meet at a very slight angle, the muon struck a lighter element. If the lines meet at a larger angle, the muon struck a heavy material.

By detecting enough scattered muons, the computer software can also identify the shape of the heavy material—a particularly important feature if a material has melted. The software can even translate the data into a real-time, 3D digital image, color-coded to indicate different heavy materials. As shown in the infographic below, a lead box can be differentiated from smuggled uranium within it and from the sacks of cement that surround it inside a shipping container.

~Necia Grant Cooper

Computer constructs the muon pathways.

Points of intersection are then measured and marked with a 3D color-coded pixel.

uranium

ALERT!!!

In a minute or less, potential threats can be detected.