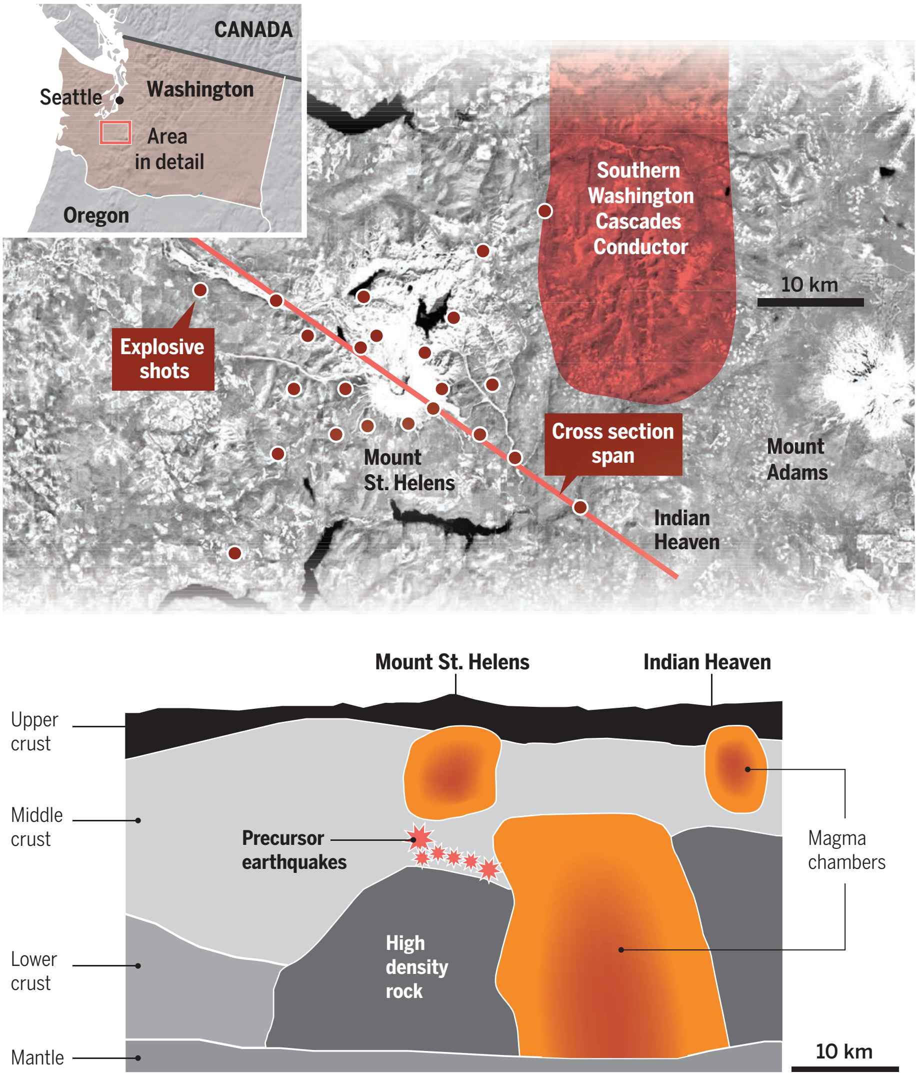
is a minor part of the system," he says.

Another question is how extensive the deepest magma chamber is. Since the 1980s, geoscientists have puzzled over magnetic and electrical measurements suggesting that a layer of rock with unusually high electrical conductivity extends all the way from Mount St. Helens north to Mount Rainier, 75 kilometers away. The layer, called the Southern Washington Cascades Conductor (SWCC), could arise from highly conductive deep ocean sediments that have since turned to rock. But a controversial 2009 study suggested a magma body could also be responsible for the signal—and might be feeding Mount Rainier as well. Levander says the idea that the deep chamber could be the southern end of the SWCC is "tantalizing." The iMUSH team is analyzing data collected by electrodes and magnetometers stuck in more than 100 locations to better understand the SWCC.

Kate Miller, a geophysicist at Texas A&M University in College Station who is not affiliated with iMUSH, says the results at Mount St. Helens will be a boon to volcanologists who want to model the movements of magma through Earth's crust. "You're actually seeing it in action," she says. "Now, you can go in and model the plumbing system." ■

Plumbing a volcano

Last year, researchers set off 23 explosive shots near Mount St. Helens and monitored 3500 seismometers for reflections from under the volcano. The experiment revealed magma chambers, and the deepest one could explain a puzzling underground zone of high electrical conductivity called the Southern Washington Cascades Conductor.



A magma connection

Precursor earthquakes to the volcano's 1980 eruption may have indicated that the lower chamber was filling the upper one with magma.

NUCLEAR POWER

Thorium seen as nuclear's new frontier

Unsung reactor fuel is more abundant than uranium and, proponents say, safer

By **Pallava Bagla**, *in Mumbai, India*

In the 1950s, U.S. nuclear scientists proposed building a fleet of nuclear-powered bombers. That was probably a bad idea. But through decades of technological fits and starts, it has led to what many nuclear experts think could be a very good idea: reactors burning an unheralded radioactive element, thorium.

Compared with uranium, the standard reactor fuel, thorium is more abundant and harder to divert to weapons production, and it yields less radioactive waste. But thorium can't simply be swapped in for uranium in standard reactors. Taking up the engineering gauntlet, several nations are pursuing a complex, largely untested technology that is a distant descendant of that fanciful nuclear powered airplane: thorium reactors in which the fuel is dissolved in a bath of molten salt.

Driving the interest in thorium is the latest in a string of accidents involving uranium-fueled power reactors. The meltdowns at the Fukushima Daiichi Nuclear Power Plant in Japan in March 2011 prompted many countries to take operating reactors offline and to scale back or scuttle plans to build new ones. But after a pause for safety reviews, China and India are gearing up for major nuclear power expansions. They and some other nations are taking a close look at thorium as a nuclear fuel, the theme of a conference here last month that drew participants from 30 countries. India even plans to have a thorium power reactor running within 10 years.

"I'm really excited," says Matthias Krause, a nuclear power expert at the International Atomic Energy Agency in Vienna. In an industry dominated by graying men, Krause says it was refreshing to see "bright young faces and new ideas" at the conference.

Thorium is three to four times more abundant than uranium in Earth's crust. It holds little appeal for would-be bomb-

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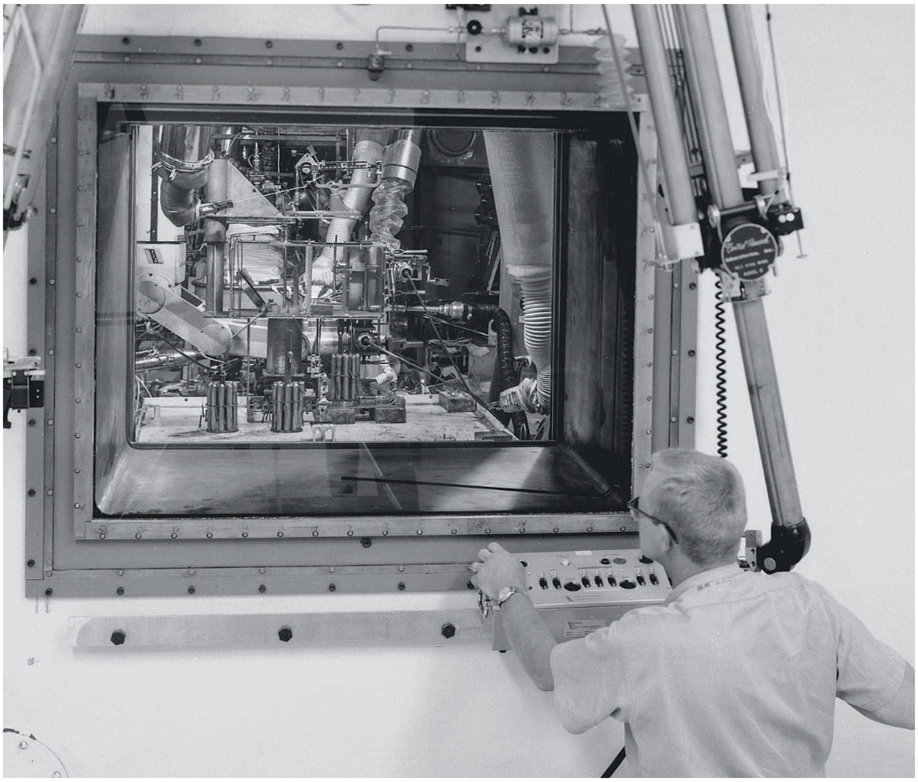
makers: Daughter isotopes, born as thorium naturally decays, are highly radioactive, emitting gamma rays that would fry weapon electronics and make thorium-derived bombs cumbersome to store. At the same time, thorium-based fuels yield much less high-level radioactive waste than uranium or plutonium, and molten-salt reactors are touted by their backers as meltdown proof.

The catch is that thorium itself is not fissile. Ratan Kumar Sinha, former chairman of the Atomic Energy Commission (AEC) of India, compares the element to wood that's too soggy for a fire. Thorium must be converted into fissile material much like "wet wood needs to be dried in a furnace," he says. That means bombarding thorium with neutrons to transmute it into fissile uranium-233, either in a conventional solid fuel reactor or in a molten salt reactor (MSR).

India, with the world's largest known thorium reserves, launched a research effort in the mid-1980s. Since 1996, it has been running the Kamini research reactor, the only one in the world that uses uranium-233; that fuel is made by irradiating thorium in another research reactor.



Once written off as a Cold War dead end, Oak Ridge National Laboratory's thorium-powered molten salt reactor, which ran for 5 years in the 1960s, may soon be recast as a trendsetter.

The government plans to open an institute devoted to the element in Visakhapatnam, in southern India, says Sekhar Basu, the new chairman of the AEC of India. Thorium's debut in a commercial reactor may come next year, after India commissions the Prototype Fast Breeder Reactor in Kalpakkam in southern India. The reactor will generate most of its electricity from plutonium, but eventually engineers plan to swaddle its core with a thorium blanket, spawning uranium-233 that will fission to produce small amounts of energy.

Construction of the first reactor to rely largely on thorium is due to start soon at Tarapur, on the Arabian Sea. Slated for completion in the next decade, the 300-megawatt (MW) reactor will burn a mix of thorium, uranium, and plutonium, with about 60% of the power coming from thorium dioxide pellets. That's only the beginning, says Sinha, who calls thorium "the gateway to powering India's economy."

> ***Thorium is "the gateway to powering India's economy."***
> **Ratan Kumar Sinha**, former chair, Atomic Energy Commission of India

Norway may be the first to follow in India's footsteps with thorium as a solid fuel. Since 2013, it has been testing a mix of thorium and plutonium in a research reactor in Halden as potential fuel stock for Europe's light water power reactors.

China is betting on liquid thorium, a concept first explored at Oak Ridge National Laboratory in Tennessee in the 1950s as a stepchild of the aircraft reactor program. Thorium MSRs remain seductive in part because of their potential safety advantage: In case of an accident, the fluoride salts of thorium and uranium circulating in the core can simply be drained into a storage tank, stopping the fission chain reaction. The Chinese Academy of Sciences's Thorium Molten Salt Reactor Center of Excellence in Shanghai is developing a 10-MW pilot MSR to start running by 2022 and a 100-MW demonstration plant, to be commissioned around 2030, says Hongjie Xu, who is leading the effort.

The European Commission, too, is taking a hard look at the technology. Last year, it launched a 6-year safety assessment of MSRs. Jiri Krepel, a reactor physicist at the Paul Scherrer Institute in Villigen, Switzerland, predicts that the report will highlight the advantages of thorium, from fuel production to waste management. It "offers a paradigm shift in reactor safety," he says.

Even the United States is getting back in the game—in a small way. A startup called Flibe Energy in Huntsville, Alabama, is developing a liquid-fluoride thorium reactor that hews closely to Oak Ridge's MSR design. Flibe's executive director, Benjamin Soon, envisions small, 10- to 50-MW MSRs being deployed in remote locations for power generation.

Some engineers in Europe and Japan think thorium-fueled MSRs could also be ideal tools for neutering stockpiled plutonium and high-level nuclear waste. The reactors spew high fluxes of neutrons, which could transmute plutonium and waste into radioactive elements with shorter half-lives and potentially generate power as well. The commission has allotted €5 billion to build just such a thorium-fueled test facility in Belgium, called Myrrha, which could be running by 2020.

Yet the disaster-scarred track record of uranium reactors casts a long shadow on thorium, too. Ever since the United States during the Cold War went whole hog into uranium, "the world has been paying a price for the wrong technology choice," argues Jean-Pierre Revol, president of the international Thorium Energy Committee in Geneva, Switzerland. But he and others say that thorium, at long last, is making up for lost time. ■

Pallava Bagla is a science journalist in New Dehli.

PHOTO: OAK RIDGE NATIONAL LABORATORY