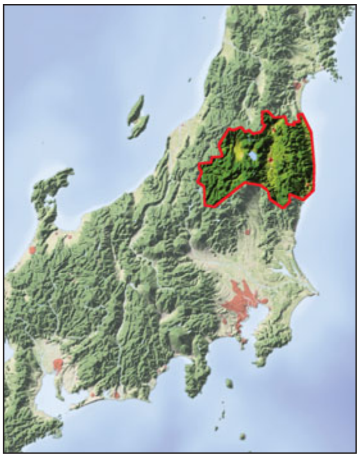

Cleanup technologies following Fukushima

By **Angela Saini**
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The accident at Fukushima Daiichi happened almost six years ago, but the after-effects will stretch on for many decades. Scientists and engineers remain in the early stages of the enormous task of cleaning the site and making it safe. Melted fuel debris must be cleared and stored, thousands of tons of contaminated water must be managed, and the reactors must be protected to stop any more radioactive material from escaping. Only then can engineers get to the heart of the problem—decommissioning.

To date, the job is far from complete. According to a spokesperson for the Tokyo Electric Power Company (TEPCO), which operates the plant, it will take another 30 to 40 years to complete all the processes toward decommissioning. So far, unbroken fuel rods have been removed from the cooling pool of one reactor unit, with work on another unit expected to begin in 2017, followed by another two in 2020.

The job demands many new technologies, including materials. "It is important to work on basic research in materials science and engineering, as well as research and development for practical use," in order to achieve all this, added the spokesperson for TEPCO.

On-site cleanup is being carried out by TEPCO, in conjunction with large corporations, including Toshiba, Hitachi, Kurion, Kajima, and Taisei, contracted to assist and supply technology. Solutions to problems are also being developed by Japan's International Research Institute for Nuclear Decommissioning (IRID), the Japan Atomic Energy Agency, the Central Research Institute of Electric Power Industry, and various universities around the world. To cope with the complexity of all the different research needs, the Japanese government created a Nuclear Damage Compensation and Decommissioning Facilitation Corporation in 2014 to manage the research activities on the road to decommissioning.

According to Hirofumi Kenda, president of IRID, "One of the most challenging issues for Fukushima Daiichi is the high radiation dose rate in the reactor buildings due to contamination by cesium-137, whose half-life is 30 years. Because of that environment, access by personnel is restricted, and remote operating and sensing technologies are required in all circumstances." Cesium-137 is both a strong gamma emitter and able to move in a soluble format, which makes it doubly dangerous.

Robot helpers

Although there are many thousands of workers at the site, it is unsafe for them to enter the plant itself because of the high radiation levels. The alternative has been to use robots. Swimming and crawling robots, for example, developed by Japanese multinational Hitachi, investigate leakages from the reactors. A robotic water boat meanwhile surveys leakages inside the reactor containment vessel. And one type of decontamination robot used on the upper floors deploys a high pressure water jet, while another type uses blasts of dry ice. An important materials challenge is to develop electronics, especially semiconductors, that can withstand high radiation fields.

Japanese firm Toshiba, which originally supplied reactors to the power plant, including the one that was the worst hit, has been heavily involved in the cleanup. Between 2012 and 2013, it used quadruped robots, fitted with cameras and able to walk up and down stairs, to investigate the vent pipe at Unit 2. It is now working on improving them so they can be deployed in further applications. In 2016, Toshiba also unveiled an amphibious remote-controlled robot designed to remove debris and nuclear fuel rods. This will be tested sometime in 2017.

Keeping water at bay

The spread of contaminated water is the greatest immediate concern. A 780-meter-long wall has been built on the sea side, made of 794 steel pipes of about a meter diameter each, around the bank where the reactor meets the ocean. This blocks groundwater from flowing into the sea and pumps it away. Water is also being treated directly, although as of July 2016, according to the latest status report to the United Nations International Atomic Energy Agency, 4400 tons remain in the tanks.

On the land side, the water problem is being dealt with by a frozen soil barrier, through which water and waterborne contamination cannot pass. This is a fairly straightforward technology that has been around for more than a century. "It is not difficult to build a frozen soil barrier on the scale of that needed at Fukushima Daiichi. And the materials required are not very exotic or difficult to obtain," explained Edward Yarmak, chief engineer at Arctic Foundations Inc., in the United States.

"A liquid at subfreezing temperatures is pumped down the center of a double-tubed freeze probe, and that liquid returns in the annulus between the two tubes. As the liquid returns, it absorbs heat from the ground, causing the ground to cool down. Remove enough heat from the ground, and the pore water freezes," Yarmak added.

When in operation, steel pipes used in frozen barriers do not suffer corrosion

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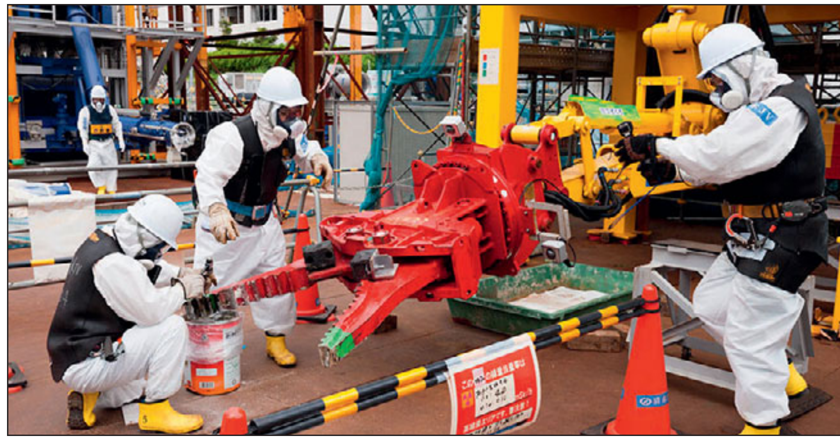

A device designed to grab up to seven tons of rubble to help clear debris from the Fukushima Daiichi site. It is in operation at Unit 1. Credit: Tokyo Electric Power Company Holdings, Inc.

because they are encased in ice. On the inside, corrosion inhibitors are added. In some cases on other projects, steel pipes have been replaced by plastic to ensure longer operation. Newer, more efficient, and lower cost refrigeration technologies may further improve frozen soil barriers in the future.

Freezing began at Fukushima Daiichi in March 2016. As a result, the groundwater levels have declined to below the level they were at before the freezing started, reducing the risk of radioactive contaminants spreading beyond the site. "There's no reason to think that the frozen barrier installed at Fukushima won't last 30 to 40 years, provided equipment is regularly maintained and replaced at intervals," Yarmak said.

Elizabeth Phillips, vice president of the East Tennessee Geological Society, who has worked on frozen soil barriers in the United States, added, "Since the ice wall is self-healing, and this is an earthquake prone area, it is a superior choice over a conventional concrete barrier." Even if the pipes break, the ice wall itself would take a long time to melt. There are also technologies available in which the pipes sit at the surface, which means they can be relatively easily repaired after the event.

Lowering the radiation threat

Kurion, a company founded in 2008 to clean up nuclear waste and recently acquired by French water and waste company Veolia, was chosen to help make safe 32 million gallons of contaminated water at the Fukushima Daiichi site. Starting in 2011, Kurion decided to use an enhanced zeolite that's particularly efficient when it comes to ion exchange. John Raymont, president of Kurion Veolia, explained, "This is a very high-end chabazite-based zeolite, which is well known for [its] robustness and natural affinity for cesium." After 2014, they also began the removal of strontium. According to Raymont, their system is able to remove both cesium and strontium to near non-detectable limits.

According to a status report supplied by TEPCO, by August 2016 approximately 277,000 cubic meters of water had been treated in this way. Kurion estimates that their system has so far removed almost 70% of all the cesium from the Fukushima water.

The firm is also developing a technology that stabilizes the waste through vitrification. "In vitrification, the waste is melted, and the volume reduced and converted into a highly robust glass waste form with extremely low leachability. This would ensure that, rather than bulking up the waste via cementation or other low-tech encapsulation approaches, that the Fukushima site would have the lowest volume of material to store," Raymont said.

Toshiba has also developed and installed a Multi-Radionuclide Removal System, designed to reduce the concentration of 62 types of radioactive nuclides. According to the company, it has already cleaned up more than 500 thousand tons of polluted water.

At universities around the world, researchers are working on other solutions that might also help in the future. Barry Goodell, professor of Sustainable Biomaterials at Virginia Tech in the United States and Yuichiro Otsuka at the Forestry and Forest Products Research Institute in Tsukuba, Japan, have jointly discovered a molecule known as PDC, which is derived from lignin, a common waste product of paper production. PDC turns out to be effective at binding to cesium, so it can be pulled out of a solution.

"The PDC works as a chelator—a compound that specifically binds metals," Goodell explained. "The PDC is a very unique chelator that selectively binds cesium even in the presence of other metals. So, for example, sodium in sea water is not readily bound by the PDC." He and Otsuka have already been in touch with TEPCO, but their compound cannot yet be used because there's no way to safely remove the precipitate it produces. Otsuka's team in Japan is working on solutions to this problem, including a resin that might allow larger precipitates to form, making them easier to dispose of.

One of the other challenges is measuring the levels of hardly separable radioactive isotopes. Yoshitaka Takagai, at the Institute of Environmental Radioactivity at Fukushima University, has developed a way of more quickly detecting strontium-90, which has a half-life of 29 years. His method is based on inductively coupled plasma mass spectrometry. "The traditional analytical way needs two weeks or more time to measure the concentration of strontium-90. However, my system can measure the actual environmental concentration level within 15 minutes," Takagai explained.

In the future, the most pressing need is for materials that can withstand high radiation levels. "Lightweight and highly effective radiation shielding materials and a highly efficient decontamination agent would be appreciated in Fukushima Daiichi," Kenda explained.

"The reactor buildings are widely and heavily contaminated. Consequently, for example, when we try to investigate inside of the containment vessel, personnel cannot get close to the access point," he added. Anything that might make it safer for workers to do their job in such a dangerous environment would make cleaning up faster and easier. □

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