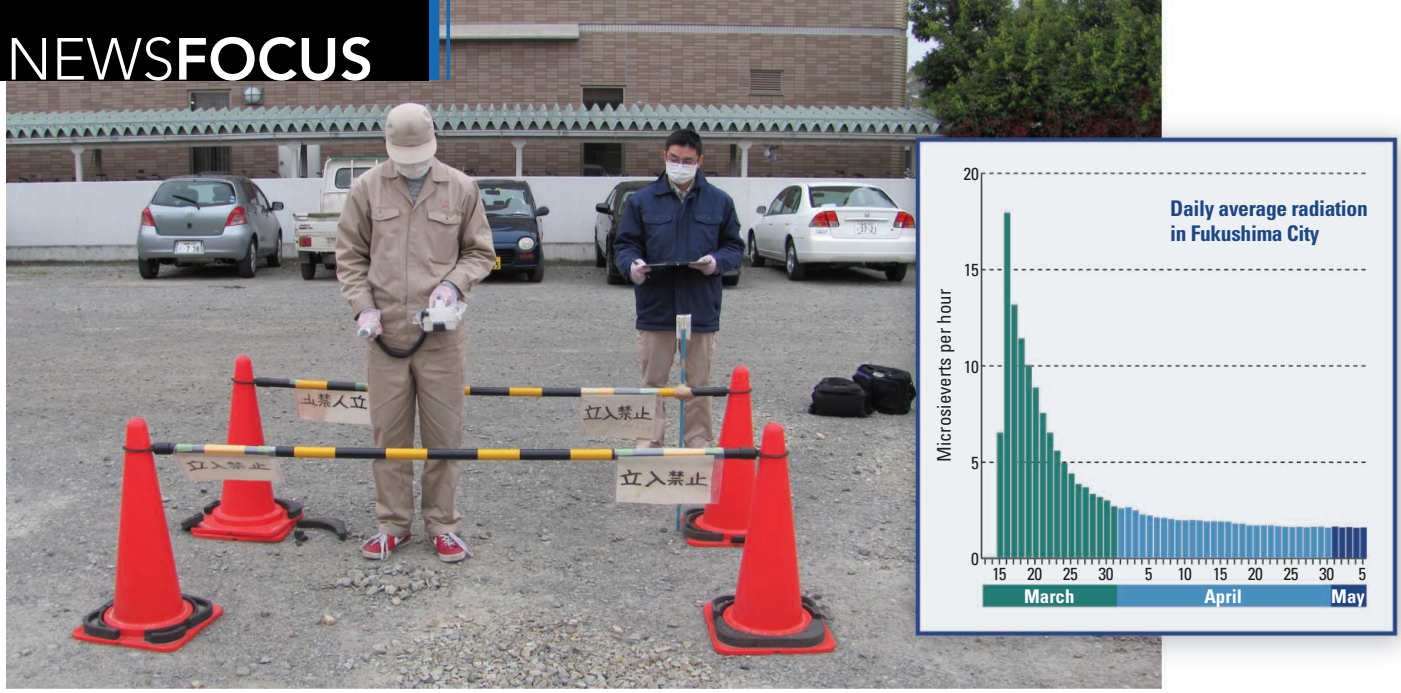

Fukushima Revives The Low-Dose Debate

The general public avoided exposure to high levels of radioactivity, but questions linger about the long-term effects of contamination

FUKUSHIMA, JAPAN—At 5 p.m. sharp, Mitsuru Itou watches as a technician steps inside a quartet of orange traffic cones and black-and-yellow traffic bars marking a "keep out" area in a gravel lot. Holding a radiation meter at his waist, the technician waits for the instrument to stabilize. Then every 30 seconds for the next 2½ minutes he recites the count. Itou, a supervisor with the Public Health and Welfare Office of Fukushima Prefecture, correctly predicts that the readings will average 1.6 microsieverts per hour. "That's what [the radiation] has come down to for some time now," he says. The results are phoned in to a disaster center, which posts them to its Web site. This ritual is repeated every hour at seven locations across the prefecture to track environmental radiation from the Fukushima Daiichi nuclear power plant, 63 kilometers southeast of Fukushima city. The measured levels range from two to 1000 times normal background radiation—and residents, officials, and scientists wonder what that may mean for public health.

The magnitude-9.0 earthquake and tsunami on 11 March knocked out nuclear fuel cooling systems at the power plant. In the days that followed, overheating triggered hydrogen explosions that spewed radioisotopes into the air. Radiation spiked 4 days after the first explosion, according to measurements here and at other ground-monitoring sites hastily set up after the earthquake. Since then, radiation levels have ebbed as short-lived radionuclides, such as iodine-131 with a half-life of 8 days, decay into stable isotopes.

Across Fukushima and neighboring prefectures, small amounts of cesium-134 and cesium-137, isotopes with half-lives of 2 and 30 years respectively, lie on the ground. Cleanup workers have stripped contaminated topsoil from some schoolyards, and remediation or permanent evacuation is likely for the worst areas. But for much of the prefecture, "we're stuck, there are no practical countermeasures," says Hisashi Katayose, a Fukushima official in charge of radiation monitoring.

As a result, several thousand of Fukushima's 2 million residents have been thrust into the middle of a vigorous scientific debate about the health effects of long-term exposure to low levels of radiation. "We're all guinea pigs," says Akira Watanabe, a meteorologist who is vice president of Fukushima University here. A central question is whether there's a threshold below which radiation has no ill effect. "Dose threshold is a very contentious issue in the radiation community," says radiation epidemiologist Roy Shore, research head at the Radiation Effects Research Foundation in Hiroshima. Some researchers believe even unavoidable background radiation can be a factor in causing cancer. Others argue that tiny doses of radiation are not harmful. Some scientists even claim that low doses, by stimulating DNA repair, make you healthier—an effect known as hormesis.

Studies in Fukushima could help clarify the picture. But getting answers will not be easy. Radiation exposure levels for most people were elevated so minutely above background that it may be impossible to tease out carcinogenic effects from other risk factors, such as smoking or diet. "In order to detect an elevation in risk, one needs to study much larger numbers of people," Shore says, especially given that 40% of all Japanese develop cancer.

That has experts wondering whether and how to carry out such studies. "It is difficult to say at this point, especially since the crisis is not over," says Shunichi Yamashita, a radiation health expert at Nagasaki University who is advising the Fukushima prefectural government. Forging ahead with a population study, as daunting as it may be, could nevertheless have a scientific payoff. "If you do the study and don't find anything, that should be an important message," says Dale Preston, a biostatistician specializing in radiation health effects at Hirosoft International in Eureka, California.

Where to draw the line?

Perhaps the sole point on which scientists agree is that radiation damages DNA in ways that can cause cancer many years after exposure. When radioisotopes lodge in cer-

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Hot job. Technicians check radiation hourly in a gravel lot in Fukushima City. Exposure has dropped but remains 35 times above background.

tain organs—such as iodine-131 in the thyroid gland—the constant bombardment of surrounding tissue can overwhelm repair mechanisms and trigger cancer.

The clearest insights come from decades of follow up on survivors of the atomic bombings of Hiroshima and Nagasaki. These studies have linked an acute dose of 100 millisieverts (mSv) of radiation—16 times the amount that an individual receives on average from all sources over the course of a year—to a 1.05 times increase in the chance of developing some form of cancer. Children with similar exposures appeared to have a higher risk of developing cancer later. These risks scaled linearly as exposures increased.

But the health effects of chronic low-level radiation exposure over years or decades are far from clear. Several large cohort studies of medical x-ray technicians and nuclear industry workers suggest a slight increase in cancer risk at exposures below 100 mSv, Shore says. To err on the safe side, most radiation protection agencies follow the linear no-threshold model, which posits that risk diminishes with decreasing exposure but that any increase above background poses a cancer risk. Extrapolating from this model to estimate health effects in a population "is not wise because of the uncertainties," Shore says.

Opportunities to narrow uncertainties have been missed. In the aftermath of the Soviet Union's April 1986 Chernobyl nuclear accident, which spewed radionuclides over a swath of Europe, "there was no continuity, no overarching panel looking at how science should be done," says Ronald Chesser, a radiation biologist at Texas Tech University in Lubbock. The subsequent Soviet collapse, scarce funding, imprecise dosimetry, and difficulties tracking people over the years have limited the number of studies and their reliability, he says. The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) concluded in a 2008 report that over 6000 cases of thyroid cancer in young people could be linked to Chernobyl but that evidence for other cancers was inconclusive. To resolve outstanding questions, on 26 April the World Health Organization's International Agency for Research on Cancer in Lyon, France, asked the international community to support a Chernobyl Health Effects Research Foundation to conduct life-span studies, similar to those following A-bomb survivors in Japan.

Animal studies have yielded conflicting data. Laboratory experiments on animals indicate that as doses decrease, less and less damage escapes DNA-repair mechanisms, says Yoshihisa Matsumoto, a radiation biologist at the Tokyo Institute of Technology. "There must be some threshold below which the damage is completely repaired," he says. Chesser says some of his group's studies of mice exposed to radioactivity around Chernobyl hint at hormesis: Small exposures over 10 to 45 days, they found, appeared to temper damage from an acute radiation dose delivered in the lab later. He thinks the reaction to low doses could be quite complex. "There's not going to be a uniform response of all biological functions to low levels of radiation," Chesser predicts.

Patchy contamination

Japan's experience tracking A-bomb survivors, an early start gathering data on environmental exposures in Fukushima, and a family registry system that tracks virtually all individuals all offer "great advantages" in devising more definitive low-dose studies, says Preston, who believes such a study would be well worth the cost. "I think we will learn something important," he says.

The 800 or so workers who have helped bring the Fukushima reactors under control will be included in an ongoing study of nuclear industry workers by the Tokyo-based Radiation Effects Association. Many workers are getting higher doses in weeks than they would have received on the job over a year. Fukushima residents facing higher than background exposure can blame an unfortu-

Schoolyard Radiation Policy Brings a Backlash

TOKYO—The Japanese government has made a number of missteps during the 2-month-long Fukushima nuclear power plant crisis. But the most controversial may have been the release of guidelines from the education ministry on allowable radiological contamination in schoolyards. They seem to allow children to accumulate radiation exposures of 20 millisieverts (mSv) over the course of a year. By comparison, nuclear industry workers in Japan can absorb no more than 100 mSv per year; the limit for U.S. nuclear personnel is 50 mSv per year.

The 19 April announcement unleashed a torrent of criticism from civic groups and experts. "Setting [such radiation limits] for elementary schools is inexcusable," Toshiso Kosako, a radiation health expert at the University of Tokyo, said on 30 April, when he resigned as an adviser to Prime Minister Naoto Kan on the nuclear crisis. Because children are known to be more susceptible than adults to risks of cancer from radiation, Physicians for Social Responsibility, a U.S. antinuclear proliferation group, condemned the exposure limit as "unconscionable."

Dirty dirt. Fukushima schools are stripping contaminated topsoil from playgrounds.

The ministry has backpedaled—but not fully retreated. On 11 May, it released suggestions for removing contaminated topsoil from schoolyards to reduce radiation exposures. But it did not change or retract the exposure guidelines.

In its "provisional idea" for acceptable levels of radiation in schoolyards, the education ministry cited a 2009 recommendation from the International Commission on Radiological Protection (ICRP), an Ottawa-based nongovernmental organization. During emergencies, ICRP Publication 109 states, populations can be exposed to 20 to 100 mSv per year. The education ministry calculated that children could spend 8 hours a day in a schoolyard exposed to as much as 3.8 microsieverts per hour, and 16 hours a day indoors exposed to 1.52 microsieverts per hour, and not exceed the 20-mSv limit. Civic groups contend that the education ministry should follow another ICRP recommendation, which states that exposure limits for long-term residence in contaminated areas after an accident should be kept "in the lower part of the 1-20 mSv/year" range.

In the past few weeks, several schools took matters into their own hands and stripped topsoil from their grounds. On 11 May, the ministry jumped on that bandwagon, announcing test results showing that swapping the top 10 centimeters of topsoil with dirt from deeper down cut surface radiation 90%. Stripping and burying the topsoil in a deep hole reduces surface radiation 99%. The ministry is leaving final decisions on what to do in the hands of local officials. **–D.N.**

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nate shift in the prevailing winds. Just after the 11 March disaster, much of the radioactive contamination from the reactor complex was swept out to sea. But on 15 March, a counterclockwise wind carried contamination back over the prefecture, Watanabe says. "And then it rained."

Authorities are keeping a close vigil on the patchy contamination. In addition to the sampling by Fukushima Prefecture, the education ministry is monitoring radiation levels nationwide, including at 100 locations in the prefecture. A team from Fukushima University recently mapped radiation levels at 370 spots in the prefecture and, using weather balloons, confirmed that atmospheric radiation levels have dropped to near background levels.

That broad-brush impression of radioactive contamination of the landscape isn't sufficient for population studies. Shore says it will be important to reconstruct exposures to identify a cohort with the highest exposures. Researchers also need to ascertain where people were during the peak exposure period and where they obtained food and drinking water. Any robust study would also include detailed medical histories and information on smoking habits, diet, and possible exposure to other toxicants, as well as matched controls with little or no exposure. That information "would make possible an informed long-term cohort study," Shore says.

Aloft. Fukushima University's Akira Watanabe is leading an effort to map radiation in the air and on the ground.

Estimating individual doses from environmental data is neither easy nor precise. An alternative technique was developed by a team led by David Brenner, a radiation biophysicist at Columbia University Medical Center in New York City, to plan a response to a radiation release by terrorists. The method rapidly screens blood samples for fragments of DNA and DNA-repair complexes; exposures are calculated based on the number of fragments.

Scientists hope a respected entity will organize a high-quality research plan involving all levels of government. Fukushima Medical University is bidding for that role. A spokesperson has confirmed that the university will establish a research initiative with support from radiation health experts at Nagasaki and Hiroshima universities. Details may be released next month.

Some researchers doubt that any study in Fukushima, no matter how well devised, will reveal much. The radiation exposure of the general population "is too small to give a statistically significant increase in stochastic effects such as cancer," argues Ohtsura Niwa, professor emeritus of radiation biology at Kyoto University. But even negative data would complement UNSCEAR's conclusions on Chernobyl, Niwa says, "and, in this sense, have global implications." As for the linear no-threshold model, Preston says, "I don't think anything [done in Fukushima] is going to resolve that debate."

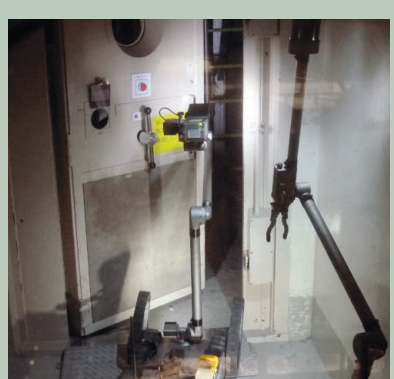
One real effect of the radioactive contamination is the gnawing fear—groundless or not—that low levels of radiation could harm their children. For that reason alone, Yamashita says, "a center or some sort of system to support long-term health follow-ups is definitely necessary." **–DENNIS NORMILE**

Crippled Reactors to Get Cooled and Wrapped

TOKYO—The crisis at the stricken Fukushima Daiichi nuclear power plant may have faded from the headlines, but it's far from over. To cope with the loss of reactor cooling systems knocked out by the 11 March earthquake and tsunami, the plant's owner, Tokyo Electric Power Co., has installed jury-rigged cooling setups that have cut radiation emissions dramatically. But some 100,000 residents who were evacuated will not return home until the reactors are firmly under control. Last month, Tokyo Electric unveiled a two-stage plan to build more robust cooling systems and reduce radiation leaks within 3 months, then, 3 to 6 months later, achieve a cold shutdown in which fuel is cooled by water below the boiling point at atmospheric pressure.

Nuclear fuel in four of the plant's six reactors overheated, with extensive core damage in three units. Last week, a robotic inspection increased suspicions that the fuel in unit 1 may have melted through the bottom of the pressure vessel and pooled at the base of the containment structure. Hydrogen explosions completely blew the upper walls and roofs off two units and severely damaged a third; vessels and piping are leaking contaminated water. "There are many challenging tasks ahead," says Tony Irwin, a nuclear technology expert at Australian National University and the University of Sydney. Workers must reduce radiation levels, plug leaks, and decontaminate water—all while the threat of aftershocks persists.

In the early days, Tokyo Electric hoped to restart Fukushima's original cooling systems. But the company was forced to explore alternatives, says Hidehiko Nishiyama, deputy director of Japan's Nuclear and Industrial Safety Agency. The utility is now planning to build heat exchangers that will circulate fresh water through the reactors to cool the fuel. To seal off reactor buildings, engineers are planning to wrap them in polyester sheets stretched over steel frames.



Off limits. Robots are finding radiation too high for humans.

The biggest challenge, Nishiyama says, is protecting workers. Some have been entering the unit 1 building to prepare for construction. But so far, only robots have entered the unit 2 and 3 reactor buildings, where radiation levels top 50 millisieverts per hour. Tokyo Electric may expand the use of robots, which so far have been limited to taking radiation measurements and videos. Because integrated circuits can be affected by radiation, these probes must be primarily mechanical or have hardened electronics. Once new cooling systems and enclosures are in place, work could start on the semipermanent buildings needed for recovering nuclear fuel and decommissioning the reactors, a process that could take a decade or longer. **–D.N.**

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