

FUKUSHIMA'S LEGACY OF FEAR

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Japan's worst-ever nuclear accident displaced more than 100,000 people. Many could now safely return home. Yet mistrust of the government prolongs their exile.

Yoichi Tao is busily shovelling dirt in Iitate, a small village about 40 kilometres from the ruined Fukushima Daiichi nuclear plant.

It is certainly different from his day job. Tao has a background in high-energy physics, and teaches students about information-security systems at Kogakuin University in Tokyo. But on this sunny February morning, he and a dozen volunteers have joined local farmers in removing the top few centimetres of radioactive soil from rice fields. "When the soil is frozen, we can remove it easily, like a board," Tao says. In a corner of the field, they dump the soil in a hole lined with absorbent sheets. "When spring comes, the ice melts but the [radioactive] caesium will be absorbed, so we can protect it from leaking out," he explains.

The volunteers, mostly researchers, informally call themselves *Fukushima Saisei-no Kai* (roughly translated as the Fukushima revitalization association), and come armed with car-mounted sodium iodide scintillators and Geiger counters linked to the Global Positioning System. Only in one of the world's most technically advanced societies could an ad hoc group have the means to cope with radioactive decontamination.

But there is a dark side to Tao's efforts: he is there because he and many others have lost faith in their government. "Since 11 March, people haven't trusted scientists who receive

funding from the government," Tao says. "They trust people who act without government funding and who work together with them."

One year after Japan's nuclear crisis began, researchers contacted by *Nature* say that a strong, evidence-based understanding of the accident, and the risks the reactors continue to pose, is within reach. The findings could inform decisions on public health, environmental clean-up and economic recovery (see 'The fallout'). But outside observers, and even some critics in Japan, are increasingly worried that the loss of public trust, together with politicians' desperation to regain it, could undermine rational decision-making about clean-up and resettlement. At stake are the futures of more than 100,000 residents who have been displaced from the area around the plant, and billions of dollars in economic activity across the region.

MELTDOWN

The crisis began on 11 March 2011, when a magnitude-9.0 earthquake on the Pacific floor sent a massive wall of water rolling towards the Japanese coastline (see page 141). The three operating reactors at Fukushima Daiichi automatically shut down in the moments after the

quake, but 41 minutes later the tsunami burst through the plant's defences and inundated the reactor buildings. Water flooded emergency generators, leaving the plant without power for cooling systems, while radioactive decay continued to heat the cores. In the control room, workers struggled to run crucial instruments, using torches and car batteries scavenged from nearby vehicles. Over the following days, the last line of emergency systems failed and the three reactors melted down. The process released hydrogen gas, which eventually triggered explosions in the reactor buildings. Volatile radioactive chemicals, notably iodine-131 and caesium-137, began to stream into the air and sea.

When unit 4 of the Chernobyl nuclear power plant exploded in 1986, the Soviet government imposed a strict information blackout. The situation could hardly have been more different at Fukushima: within the first 24 hours, the government began reporting radiation readings. In the following days and weeks, the deluge of information became swollen with data from university researchers, the military, international monitors, representatives of the US government and concerned citizens such as Tao.

"We've almost got too much," says Malcolm Crick, secretary of the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) in Vienna. At the UN's request, the committee has spent the past six months



A YEAR AFTER THE TSUNAMI

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trying to unpick which data came from where, and how they were calibrated. The committee will deliver its preliminary findings in May, and Crick says they should be able to say a great deal about how much radioactivity was released, where it went, and how much workers and the general public received.

DOSE LEVELS

It is already evident that rapid evacuation and careful screening protected Fukushima's citizens from harm, says Wolfgang Weiss, a physicist at Germany's Federal Office for Radiation Protection in Munich and chair of UNSCEAR. Early and informal analyses by his colleagues suggest that no members of the public received a dangerous dose of radiation.

That finding is supported by a sweeping public-health study begun last summer at Fukushima Medical University. With a ¥78.2-billion (US\$958-million) budget, the survey is designed to monitor the health of some 2 million people from the region for 30 years. According to the latest estimates, released on 20 February, 99.3% of 9,747 people living in towns or villages close to the plant received less than 10 millisieverts (mSv) in accumulated effective dose in the first four months after the accident. The highest recorded dose was 23 mSv, well below the acute 100-mSv exposure levels linked to a slight increase in cancer risk.

Yet suspicion is hampering the ambitious health survey, which hopes to nail down the long-term impact of Fukushima on ordinary citizens. Despite efforts to promote the study among evacuees, participation stands at just 21%. "Most of the people I've met here refuse to fill in the questionnaires. They don't see credibility in what the government does, and they say, 'this is just a survey of guinea pigs,'" says Shizuko Otake of the non-profit organization Shalom, which supports refugees in neighbouring Minamisoma and Iitate.

The roots of mistrust can be traced to the confusing days immediately after the explosions, when authorities made a series of inconsistent statements, issuing radiation readings that often turned out to be incorrect. As radioisotopes spread from the plant, the government was repeatedly forced to raise its recommended safety limits for radiation exposure to citizens and workers — otherwise, it would have been legally required to evacuate the site immediately. As a result, some Japanese people believe that the government is corrupt; others think it is incompetent. The prevailing feeling is that "what the government says always changes", Otake says.

Abel González, a radiation-protection expert with Argentina's nuclear regulatory authority in Buenos Aires, says that the government was forced to raise the safe limits because it started with an international standard that made no provision for accident scenarios or for emergency workers likely to receive higher



Citizen clean-up crews carry out rudimentary decontamination in villages such as Minamisoma.

doses. Without clear guidelines, the Japanese government simply had to increase the safe limits to enable people to keep working to bring the nuclear plant under control, he says. The downside is that "when you relax the regime in the middle of an accident, you lose credibility immediately".

In an effort to win back the trust of its citizens, the government is planning one of the most extensive and costly clean-up operations ever — an effort some experts view as unrealistic. Last autumn, it announced plans to bring

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radiation doses from the accident to below 1 mSv per year in as much of the evacuation zone as possible. But the goal is based on an international standard for doses received during the normal operation of a nuclear plant, not following an accident.

It is also seen by veterans of nuclear accidents as highly ambitious, especially given the mountainous and heavily wooded terrain around Fukushima. "The best thing to do, according to Chernobyl, is to really turn the first metre of soil upside down," says Weiss. "But if you do that, you would kill the whole ecosystem."

The Japanese authorities acknowledge the problem, and have started trialling a variety of clean-up methods in Fukushima. The most

prominent pilot project began last November under the Japan Atomic Energy Agency (JAEA), with an estimated budget of ¥10.9 billion. The JAEA contracted the project to joint ventures led by three major construction companies — Taisei, Obayashi and Kajima — which are testing various technologies to clean up radioactive materials in 11 cities, towns and villages whose citizens mostly remain evacuated.

"I am impressed how companies have come up with novel ideas to remove decontaminated caesium based on existing technologies," says Shinichi Nakayama, deputy director of the JAEA's Fukushima Environmental Safety Center. For example, scouring caesium from roads with a high-pressure water jet was thought to be insufficient because contaminated water would simply spread out across the pavement. But engineers have modified the system to recover the contaminated water, purifying and recycling it, he says.

Many communities are taking matters into their own hands. With the help of independent researchers like Tao, they are removing contaminated soil and conducting other clean-up operations. But without a central disposal location, Weiss says, these clean-up operations are just creating a different waste problem. "People are not allowed to transport the waste, so they put everything in holes on their property."

The government's ambitious goals for decontamination could harm evacuees by inciting needless fears, says Oleg Nasvit, a radioecologist at the National Institute for Strategic Studies in Kiev, Ukraine, who has studied the impact of the Chernobyl nuclear accident. In 1986, the Soviet authorities demanded

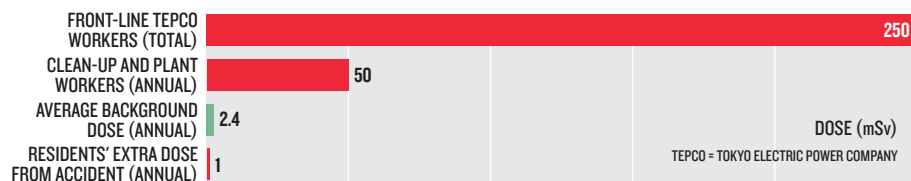
“obligatory evacuation” of residents living in regions where the additional radiation exposure from the accident was greater than 5 mSv per year, he says. Evacuees struggled to cope with their dislocation, and many were stigmatized because they had come from a contaminated region. “Frankly, this brought to people more harm than good,” he says.

Setting low radiation-dose limits is already damaging the economy around Fukushima. Later this year, the health ministry is planning to lower the safe level for caesium in vegetables, grain and other foods from 500 becquerels per kilogram (Bq kg^{-1}) to 100 Bq kg^{-1} (see ‘The limits’). Tomoko Nakanishi, a researcher specializing in plant radiophysiology at the University of Tokyo, says that food with radioactivity lower than 500 Bq kg^{-1} is not harmful to human health, and that areas not heavily affected by Fukushima’s radioisotopes may already exceed the proposed lower limits because of older nuclear fallout. Some mushrooms from Chiba prefecture, more than 200 kilometres south of Fukushima, exceed 100 Bq kg^{-1} , for example, but the relative amounts of radioisotopes are characteristic of residual contamination from nuclear weapons tests in the 1950s and 1960s or the Chernobyl accident, not Fukushima.

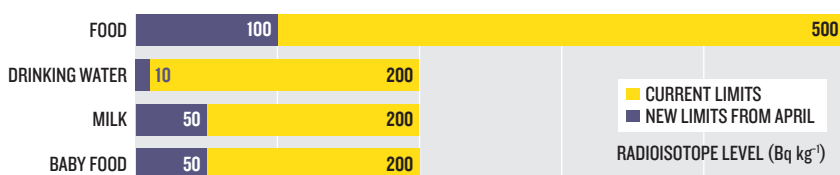
Fukushima prefecture is among the largest rice producers in Japan, but last year the agriculture ministry considered completely prohibiting cultivation where crops contained more than 100 Bq kg^{-1} of caesium. Nakanishi and her colleagues at the University of Tokyo were concerned that the excessively stringent safety measures could hinder not only the recovery of the region’s agriculture, but also the collection of scientific data. “Continuous cultivation is very important to predict what will happen in the future. We don’t know if rice paddies that produced high-level caesium will do the same this year,” she says. Backed by strong demand from farmers, the ministry recently decided to allow cultivation in most areas of Fukushima as long as cities, villages and towns can prevent the distribution of rice containing more than 100 Bq kg^{-1} of caesium.

THE LIMITS

The Japanese government wants citizens’ exposure to Fukushima’s radiation to be less than half their annual dose from natural sources.



To meet this goal, Japan plans to enforce stricter contamination limits for food and drink.



THE FALLOUT

Risks linger in reactors and the environment

The reactors In the immediate aftermath of the accident, operators could do little other than flush the overheated reactors with sea water using a fire engine as an improvised pump. Today, the situation at the plant has improved dramatically. Corrosive salt water has been replaced with fresh water that is passed through a filtration system to remove radioactive caesium before being recycled back into the cores.

The system seems to be working reasonably well. Late last year, temperatures at all three reactors dropped below 100°C , leading officials to announce that the plants had achieved ‘cold shutdown’. But dangers remain. The plant continues

to leak water, and an analysis by Japanese researchers warns that recent seismic activity could hint at a looming earthquake that might threaten the plant.

Meanwhile, Japan has developed a ‘stress test’ to assess the safety of its other nuclear plants. But for now, just two of the country’s 54 reactors are running.

The environment Fukushima has stopped releasing radioisotopes into the air, and radioactivity in the sea seems to have dispersed with little effect. But some organisms may still be accumulating nuclear material from the plant.

Researchers at the Forestry and Forest

Products Research Institute in Tsukuba have found earthworms containing nearly 20,000 becquerels per kilogram of radioactive caesium in Kawauchi, 26 kilometres from the plant. And local bird populations seem to have declined by about a third, according to Tim Mousseau, a radioecologist at the University of South Carolina in Columbia (A. P. Møller *et al.* *Environ. Pollut.* **164**, 36–39; 2012). In the ocean, says Ken Buesseler, a marine chemist at Woods Hole Oceanographic Institution in Massachusetts, radioactive plutonium and strontium seem to be finding their way into fish and bottom-feeders living near the reactor. **G.B. & I.F.**

But the ministry will allow only experimental cultivation in areas that produced rice containing more than 500 Bq kg^{-1} last year.

In April, the environment ministry will begin the nation’s full-scale decontamination programme, the core part of a ¥990-billion recovery roadmap. The ministry says that it wants science to underpin its programme. “We would like to make detailed plans based on feedbacks from government-led pilot projects as well as other scientific data,” says Kuniaki Makiya, an official in charge of the decontamination roadmap. Already, the ministry has decided to prioritize areas of mid-level contamination above those with very high or very

low levels, a move that Nasvit says makes the plan more credible because the areas that will benefit the most from decontamination will be dealt with first.

At the moment, there is no clear plan for allowing displaced residents to go home. Although the government’s goal is to ensure that people should not receive a dose in excess of 1 mSv per year if they return, it is not a firm rule. Indeed, locals can already go home to villages outside the 20-kilometre restricted zone around the plant if they choose, but many public facilities, such as schools, have not yet reopened. Nasvit believes that citizens should move back, even to zones where they might receive up to 20 mSv per year. González agrees, noting that in some parts of the world, natural annual levels of radiation are in the range of 10–100 mSv.

But Tatsuhiko Kodama, director of the Radioisotope Center of the University of Tokyo, thinks the safety margin is not so clear cut. “There are various interpretations about what to do in the area of 1–20 mSv per year,” he says. He agrees, though, that ultimately the public must choose the course of action. “The most important thing is to respect what the residents think. We have to proceed with plans based on their decisions.”

Fred Mettler, a radiologist serving on the UNSCEAR panel, agrees. Rather than setting a strict number or limit, he says, the discussion should be more open ended. “We tell the people what’s there, we tell people what the consequences are, and they decide whether to accept the risk.” ■ **SEE EDITORIAL P.123**