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Schools such as this one in Fukushima City are a high priority for clean-up efforts.

NUCLEAR POWER

Fukushima impact is still hazy

Chaos and bureaucracy hamper assessment of nuclear crisis.

BY DAVID CYRANOSKI IN TOKYO
AND GEOFF BRUMFIEL IN LONDON

Tatsuhiko Kodama began his 27 July testimony to Japan's parliament with what he knew. In a firm, clear voice, he said that the Radioisotope Center of the University of Tokyo, which he heads, had detected elevated radiation levels in the days following the meltdown of three reactors at the Fukushima Daiichi nuclear power station. But when it came to what wasn't known, he became angry. "There is no definite report from the Tokyo Electric Power Company or the government as to exactly how much radioactive material has been released from Fukushima!" he shouted.

Kodama's impassioned speech was posted

on YouTube in late July and has received nearly 600,000 views, transforming him into one of Japan's most visible critics of the government. But he is not alone. Almost six months after an earthquake and tsunami triggered the meltdowns, other researchers say that crucial data for understanding the crisis are still missing, and funding snags and bureaucracy are hampering efforts to collect more. Some researchers warn that, without better coordination, clean-up efforts will be delayed, and the opportunity to measure the effects of the worst nuclear accident in decades could be lost. Kodama and a handful of Japanese scientists have become so frustrated that they are beginning grassroots campaigns to collect information and speed the clean-up.

Since the crisis began, the Tokyo Electric Power Company and the Japanese government have churned out reams of radiation measurements, but only recently has a full picture of Fukushima's fallout begun to emerge. On 30 August, the science ministry released a map showing contamination over a 100-kilometre radius around the plant. The survey of 2,200 locations shows a roughly 35-kilometre-long strip northwest of the plant where levels of caesium-137 contamination seem to exceed 1,000 kilobecquerels per square metre. (After the 1986 Chernobyl disaster in Ukraine, areas with more than 1,480 kilobecquerels per square metre were permanently evacuated by the Soviet authorities. In Japan, the high-radiation strip extends beyond the original forced evacuation zone, but falls within a larger 'planned evacuation zone' that has not yet been completely cleared.)

EXPOSURE ESTIMATES

Japan's Nuclear and Industrial Safety Agency has also published new estimates of the total radiation released in the accident, based on models that combine measurements with what is known about the damage to the reactors. The latest figures, reported to the International Atomic Energy Agency in June, suggest that the total airborne release of caesium-137 amounts to 17% of the release from Chernobyl (see map). The government estimates that the total radiation released is 7.7×10^{17} becquerels, 5–6% of the total from Chernobyl.

Yet "there are still more questions than definite answers," says Gerald Kirchner, a physicist at Germany's Federal Office for Radiation Protection in Berlin. High radiation levels make it impossible to directly measure damage to the melted reactor cores. Perhaps the greatest uncertainty is exactly how much radiation was released in the first ten days after the accident, when power outages hampered measurements. Those data, combined with meteorological information, would allow scientists to model the plume and make better predictions about human exposure, Kirchner says.

Several measurements suggest that some evacuees received an unusually high dose.

Five days after the crisis began, Shinji Tokonami, a radiation health expert at Hirosaki University, and his colleagues drove several hundred

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For a video on the crisis and a briefing on the reactors, see: go.nature.com/ulsz2n

FALLOUT COMPARISONS

New data from Fukushima show caesium-137 levels approaching those of Chernobyl — but over a much smaller area.

► kilometres from Hirosaki to Fukushima City, taking radiation measurements along the way. The results indicate that evacuees from Namie, a town some 9 kilometres north of the plant, received at least 68 millisieverts of radiation as they fled, more than three times the government's annual limit (<http://dx.doi.org/10.1038/srep00087>).

The dose is still safe, says Tokonami. Gerry Thomas, a radiation health expert at Imperial College London, adds that radiation exposures from Fukushima were far lower than those from Chernobyl. "Personally, I do not think that we will see any effects on health from the radiation, but do expect to see effects on the psychological well-being of the population," she says.

But Kodama says that residents of Namie and other towns inside the evacuation zone could have been better protected if the government had released its early models of the plume. Officials say they withheld the projections because the data on which they were based were sparse.

HOTSPOTS

Many questions also remain about the radiation now in the environment. The terrain around Fukushima is hilly, and rainwater has washed the fallout into hotspots, says Timothy Mousseau, an ecologist at the University of South Carolina in Columbia who recently travelled to the Fukushima region to conduct environmental surveys. The plant, located on the Pacific coast, continues to spew radio-nuclides into the water, adds Ken Buesseler, an oceanographer from Woods Hole Oceanographic Institution in Massachusetts. During a cruise in mid-July, his team picked up low-level radiation more than 600 kilometres away. Ocean currents can concentrate the fallout into hotspots something like those on land, making

the effect on marine life difficult to gauge.

Gathering more data is a struggle, say researchers. Tokonami says that overstretched local officials are reluctant to let his team into the region for fear that it will increase their workload. Buesseler and Mousseau add that Japan's famed bureaucracy has made it difficult for outside researchers to carry out studies. Funding has also been a problem. To complete his cruise, Buesseler turned to the Gordon and Betty Moore Foundation for a US\$3.5-million grant. Mousseau got a biotech company to sponsor his trip and has since found funding through the Samuel Freeman Charitable Trust.

Some Japanese scientists have grown so frustrated with the slow official response that they have teamed up with citizens to collect data and begin clean-up. Because radiation levels can vary widely

"There are still more questions than definite answers."

over small distances, the latest government maps are too coarse for practical use by local people, says Shin Aida, a computer scientist at Toyohashi University of Technology. Aida is proposing a more detailed map-making effort through 'participatory sensing'. Using the peer-to-peer support website 311Help (<http://311help.com>), Aida plans to have people gather samples from their homes or farms and send them to a radiation measuring centre, where the results would be plotted on a map.

Kodama, meanwhile, is advising residents in Minamisoma, a coastal city that straddles the mandatory evacuation zone. Minamisoma has set aside ¥960 million (\$12.5 million) for dealing with the nuclear fallout, and on 1 September it opened an office to coordinate the effort. "We needed to find out what's the most efficient and effective way to lower the risk," says one of the

leading officials, Yoshiaki Yokota, a member of the local school board. The first job is to collect and bury soil at schools. Residents have learned to first roll the soil in a vinyl sheet lined with zeolite that will bind caesium and prevent it from seeping into the groundwater.

Farther northwest, in the city of Date, decontamination efforts are moving from schools to nearby peach farms. On 31 August, some 15 specialists started removing the top centimetre of soil at the farms with a scoop or with suction machines, trying not to damage the peach trees' roots. They hope to lower the radiation enough to produce marketable fruit next year.

After a sluggish start, the central government is launching two pilot clean-up projects for the region. One will focus on areas like Minamisoma, where radiation is less than 20 millisieverts per year on average but includes some hotspots. The other will look at 12 sites of radiation of more than 20 millisieverts per year.

Researchers are hopeful that the chaos immediately after the crisis will soon give way to a sharper picture of the fallout and its toll. The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), which conducted many studies after the Chernobyl disaster, is working with Japanese officials to collate the stacks of data collected since the crisis began. UNSCEAR is also studying the environmental effects of the accident and the exposure of workers and evacuees, and aims to have an interim report ready by next summer.

Clean-up is the top priority, but Fukushima also offers a unique research opportunity, says Mousseau, who has worked extensively at Chernobyl. Because of Soviet secrecy, researchers missed a crucial window of opportunity in studying the Ukrainian crisis. "Japan offers us an opportunity to dig in right off the bat and really develop a profound understanding," he says. ■