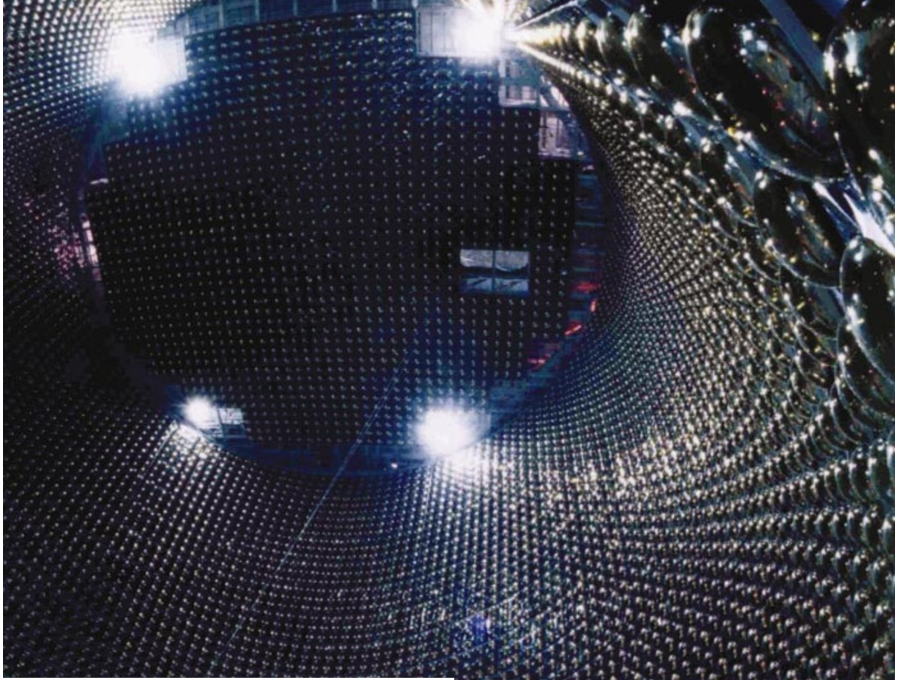
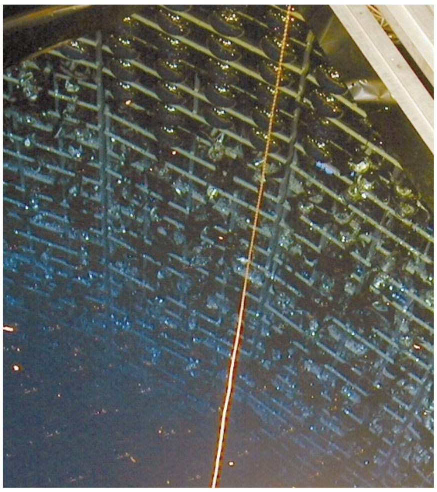
news feature

Picking up the pieces

Last November, a shock wave crippled Japan's Super-Kamiokande neutrino detector. David Cyranoski and Geoff Brumfiel find out how physicists plan to resurrect the device.





ICRR/UNIV. TOKYO

Before and after: more than half of Super-K's sensors were destroyed in the accident (inset).

Noboru Furuta was standing outside a room above the giant Super-Kamiokande detector when he felt a gust of wind. The vinyl flaps covering the doorway behind him blew apart in the breeze. Gurgling and clanging noises filled the air. "All these sounds were mixed together," says Furuta, a technician at Super-K, as the detector is known. "I'd never heard anything like it." The furore picked up pace, like popcorn popping, before coming to an abrupt halt.

Furuta didn't know it, but a shock wave had just ripped through the detector — a huge cylindrical tank filled with 50 million litres of ultra-pure water and lined by some 11,000 light-sensitive sensors. More than half of the sensors had been smashed. In less than 10 seconds, one of the past decade's most significant physics experiments had been reduced to tatters.

Situated in a disused mine below Mount Ikena, 240 kilometres northwest of Tokyo, Super-K was designed to look for elusive subatomic particles called neutrinos. Collisions between neutrinos and water molecules in the detector's tank produce characteristic flashes of light that are captured by sensitive photomultiplier tubes. The layers of rock above the detector serve to screen out other particles that could produce similar flashes.

Super-K hit the headlines in 1998, when studies there cast doubt on the long-held assumption that neutrinos have zero mass (Y. Fukuda *et al. Phys. Rev. Lett.* **81,** 1562–1567; 1998). The researchers had studied neutrinos produced when cosmic rays collide with the Earth's atmosphere, but in 1999 they sought to confirm their finding by focusing on another source — a beam of neutrinos sent through the Earth's crust from a particle accelerator at KEK, Japan's High Energy Accelerator Research Organization in Tsukuba, near Tokyo. This experiment was paused last summer, as researchers drained the tank to replace burnt-out photomultipliers. Disaster struck on 12 November, when the tank was being refilled.

Shattered dreams

The roar of the shock wave, which was picked up by seismometers eight kilometres away, threw those present into a state of panic. In a room close to Furuta, Masayuki Nakahata was monitoring neutrino detections. Nakahata, a physicist at the University of Tokyo, had worked on Super-K's predecessor, Kamiokande, and had been involved in Super-K long before data collection began in 1996. "It felt like it was right under me," he recalls. "Like it was sending spears up through me."

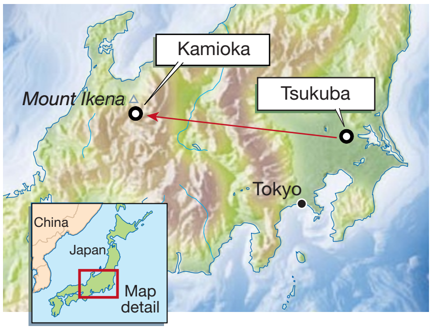
Nakahata's computer registered a dramatic leap in neutrino detections as almost all of the 11,146 detectors lit up before going dark. Thinking the water tank might have burst open, he sent a technician to investigate while he rushed to shut off the power at the four units that house the controls to the detector's high-voltage supply. "I think I probably went to each one three times," he says. "I didn't know what I was doing."

The technician found no evidence of leaking from the tank, so Nakahata lowered himself on a platform until he was suspended just above the water. The dim light revealed thousands of pieces of black plastic, which normally tethered the black sheeting behind the sensors, floating on the water. The bottom of the tank, usually visible, was obscured by a whitish haze. Twisted wires and the shattered remains of the photomultipliers dangled out of the support frames. Except for those near the surface and above the water, all appeared to be broken. "I knew I had to call and tell people," Nakahata says. "But I couldn't move."

D. CYRANOSKI

State of shock: Masayuki Nakahata.

Yoji Totsuka, director of the University of Tokyo's Kamioka Observatory, which runs Super-K, arrived back from a neutrino conference in Canada on the day of the accident.



Super-K should soon be able to continue analysis of high-energy neutrinos from KEK's accelerator.

D. CYRANOSKI

Phoning his wife from the airport, he was told staff at the detector had been trying to contact him. He phoned Nakahata, who gave him the details. "I never dreamt of this kind of destruction," says Totsuka, recalling his shock on learning the news. When researchers assessed the damage over the next few days, they found that 6,779 of the sensors had been destroyed.

Within a week of the accident, a committee of physicists began searching for the cause. The team did not have to look too far. The photomultipliers resemble giant light bulbs, roughly half a metre in diameter. Those at the bottom must each support a huge weight of water. If one was damaged, the committee theorized, the surrounding water could crush it. The resulting shock wave might then shatter neighbouring detectors, creating further shock waves.

Blow out!

Confirmation came when the team lowered nine photomultipliers, arranged in a grid, to the bottom of the tank. An explosive bolt was used to break the central detector, and the resulting shock wave swept through the array, shattering the sensors in a few milliseconds.

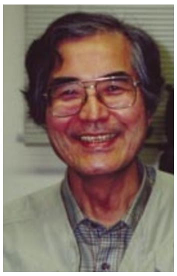
The team was also able to trace the course of the accident, as each imploding bulb marked its own destruction with a signal. Two tubes at the bottom of the tank — one of which had been replaced during the refurbishment — were identified as the starting point. The committee concluded that the neck of one of these tubes could have been weakened when technicians walked over them, despite the use of thick foam padding to protect the bulbs. The pressure on the tube would have increased as water filled the tank, eventually causing it to implode.

Even before the investigation was concluded, Super-K researchers made it clear that no individual was at fault. More than 100 physicists worked on the design, but no one had spotted its fatal flaw. "This is one case where you are not going to be able to assign blame," says Francis Halzen, a physicist at the University of Wisconsin in Madison, who works on other neutrino-detector projects.

Totsuka feels differently. He has run Super-K since 1995, and takes very seriously the Japanese code of honour that requires those in authority to take personal responsibility when things go wrong. Totsuka is due to retire next year, but on 18 February, he offered his resignation as director of the Kamioka Observatory. "We couldn't determine who was at fault, so the person at the top must take responsibility," he says. "Someone must be punished for this huge loss of taxpayers' money."

On 20 March, senior researchers at the University of Tokyo's Institute for Cosmic Ray Research, of which Kamioka is part, will meet to consider Totsuka's resignation. But Motohiko Yoshimura, the institute's director, doubts whether the group will find Totsuka to be blameworthy and assumes that the question of resignation will be dropped.

While colleagues consider his future, Totsuka is focusing on getting Super-K working again. Within days of the accident, he made it clear that the detector should be rebuilt. But full recovery will not come cheap. Around ¥2.4 billion (US$18 million) is needed to pay for replacement sensors — a big investment at a time when many Japanese science projects are being cut back or streamlined. The education ministry will not comment on the matter before the University of Tokyo submits its budget request this summer. If the money is forthcoming, the new sensors could be ready in two years.



Yoji Totsuka is determined to restart research.

In the meantime, undamaged sensors and spares are being used to restore Super-K to half strength. Fears that outside workers could be injured if other tubes imploded, coupled with a lack of money, led researchers to do most of the work themselves. Some of Japan's top physicists spent most of February paddling around inside the giant tank removing intact detectors for damage testing. All the sensors will eventually be removed, and each will have a protective plastic case added around the bulb. The sensors will then be fitted back in the tank in a chequer-board pattern, covering alternate spots.

Business as usual

Totsuka hopes to restart the neutrino beam experiment in October, and is confident that the reduced number of detectors can still generate useful data. Other projects may not be so lucky. Super-K's ability to study neutrinos emitted by the Sun, for example, will be severely limited. Neutrinos with energies below a certain minimum level are invisible to the detector, and the initial repairs will leave this lower limit 50% higher than before the accident. High-energy neutrinos from the KEK particle accelerator will not be affected, but some lower-energy solar neutrinos will now be impossible to spot.

The damage will also be felt in other fields. Another of Super-K's aims is to watch for proton decays. Different theories predict different types of decays for protons, and detecting such a decay would help physicists choose between the competing models. But proton decays are thought to be very rare, and have never been observed.

If a proton inside Super-K's tank did decay, it would produce a characteristic flash of light that could be distinguished from those caused by neutrino collisions. But with the detector operating at half strength, researchers are unsure if they could spot such a rare occurrence. "Our analysis is like looking for needles in haystacks — now it's harder," says Ed Kearns, a proton-decay specialist at Boston University who has worked on Super-K.

Astronomers on the hunt for supernovae could also suffer. The wave of matter thrown out by supernovae slows down light from the exploding star, but does not hinder the burst of neutrinos emitted by the explosion. Super-K was part of an international collaboration, known as the Supernova Early Warning System, designed to alert astronomers to supernovae. But until it is restored to its full capacity, the detector will have to withdraw.

The coming six months will be a critical time for Super-K, as Totsuka awaits a decision on his future, and physicists hope the Japanese government backs full refurbishment. Whatever the outcome, those involved say that they have, in some sense, been fortunate. "We were lucky," says Totsuka. "Lucky that no one got hurt; lucky it didn't happen before we got some interesting data." ■

David Cyranoski is *Nature*'s Asian-Pacific correspondent; Geoff Brumfiel is *Nature*'s Washington physical sciences correspondent.

➧ **www-sk.icrr.u-tokyo.ac.jp/doc/sk**

ICRR/UNIV. TOKYO

Light work: engineers at Super-K replace a sensor during the pre-accident upgrade.