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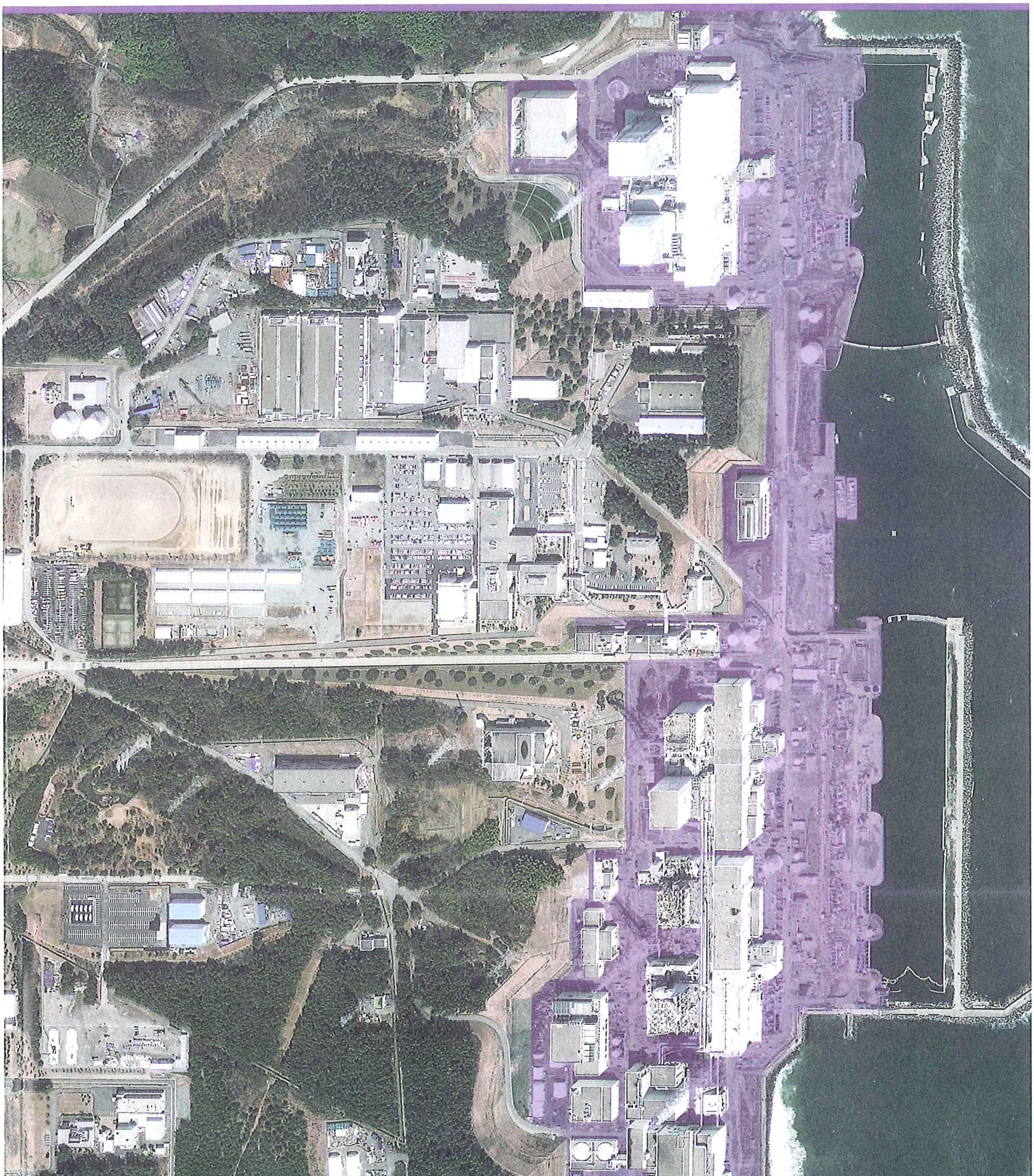
May 2011

Fukushima Daiichi disaster

Power plant performance

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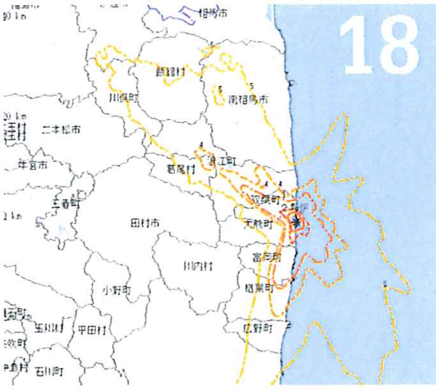
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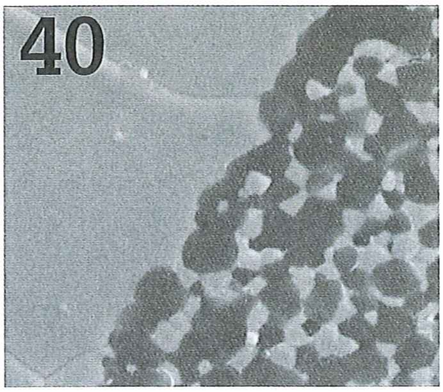
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The urgent need for facts

In the news this week was Fukushima prefecture's plans to conduct a large-scale, four-day sampling campaign for radioactive contamination at 2757 sites in the area. Such an intense campaign of monitoring—at 1 cm and 1 m above the ground, and soil sampling—requires visiting an average of 700 sites a day, so will require a team of perhaps 25 to 50 surveyors, each with their own equipment, and the training necessary to use it properly. They will join the other teams of monitors in the area, from electrical utility TEPCO, the International Atomic Energy Agency, and environmental campaigner Greenpeace.

The prefecture appears to be carrying out the tests to reassure local people that their environment is safe. This seems to me a perfectly good reason to do so. If consumers around the world are worried—Chinese consumers panic-buying iodized salt in a misguided attempt to inoculate themselves against I-131, American businesses demanding proof that shipments from Japan are radiation-free—then surely local residents have the strongest claim on concern. It is up to the government to protect them as best as it can, for which it needs good information.

As do local businesses. Data help counter people's fears. Ibaraki prefecture south of Fukushima has reportedly ordered sampling of local fish populations, because nobody is willing to buy fish from near the plant out of fears that it is contaminated. In mid-April, Japan's prime minister Naoto Kan asked the people of Japan to support people in the affected area, which is heavily agricultural, by buying their produce. "Consuming products from the regions that have been affected is also our way to support the area," he said.

As far as I am concerned, the more data the better—although I would qualify that statement twice. First, those taking measurements should quality assured, to make sure they are taking good data. Second, a central monitoring system should be established to collect and store all the data for analysis. The records will be particularly important for determining groups in the local population at risk. These recommendations are not mine, but come from publication 111 of the International Committee for Radiological Protection, an expert advisory group that sets many key radiological standards. That 2007 document, 'Application of the Commission's Recommendations to the Protection of People Living in Long-term Contaminated Areas after a Nuclear Accident or a Radiation Emergency,' for which the publisher charges $111, has now been released for free in dedication to the Japanese (available for download via www.neimagazine.com/icrp111).

The Fukushima prefecture's monitoring plans do not include sampling inside the area within a 20km radius around the Fukushima Daiichi nuclear power plant. I can understand that there are good short-term reasons not to sample there. First, there is no pressing need to do so, since the area has been evacuated. Second, survey staff would need to take care themselves to avoid exposure. Third, there would no doubt be some logistical difficulties in organising permits to be issued to enter the area.

And we should not forget that there are still perhaps 15,000 people missing from the tsunami, and no doubt many square kilometres of debris and rubble to clear. The Japanese authorities are still facing many pressing issues, and have had to make many difficult decisions about what to do first to bring back normality to the people of the region, and their businesses.

But I am not sure that it is a good long-term decision. At recent meeting in Japan, some US experts recommended sampling in the area to be able to understand trends in the spread of radiation. That is probably the most important reason. But there is another one: I fear that the decision implies a willingness to give up on that area completely, rendering it a permanent no-man's land, like the demilitarised zone separating North and South Korea. After the meeting, the government and TEPCO began monitoring about 30 sites inside the exclusion zone in early April. Their data will help establish some of the facts.

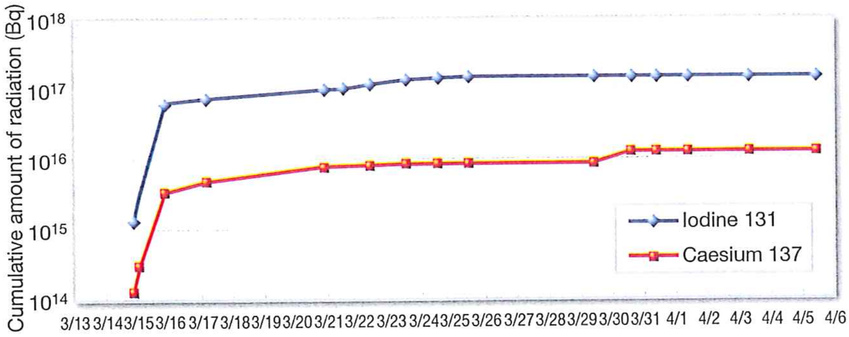
The first month

Efforts to stabilise units 1-4 of the Fukushima Daiichi nuclear power plant after the earthquake and tsunami on 11 March have now shifted to draining wastewater out of the site. New electrical cables were laid to the plant's distribution boards in mid-March, allowing lights to be turned on in control rooms (unit 3 on 22 March; unit 1 on 24 March; unit 2 on 26 march; unit 4 on 29 March), and to power up temporary pumps used to inject reactor cooling water (a job that had previously been performed by fire engines). Units 5 and 6 were reconnected to external power on 21 and 22 March, and the spent fuel pool received power on 24 March. But in units 1-4, much of the key equipment remains out of service, and restarting them requires access to the turbine hall basement.

On 24 March, three contractor workers laying cable on the first floor and basement level of one of the turbine halls splashed in water that had pooled there, and each received a dose of 170 mSv. The water pooling in the units 1, 2 and 3 turbine hall basements was found to be highly radioactive, and based on the fission products present, had probably leaked from the containment. The water's radioactivity prevents access to equipment necessary to stabilise the plant. Also, other pools of highly radioactive water were found in cable trenches outside units 1 and 2, and a tunnels outside unit 2.

Events took a turn for the worse on 2 April when one of these trenches, near the unit 2 water intake, was found to be leaking into the sea, which was eventually confirmed to be plugged on 6 April after injecting a

Early cumulative estimate of radiation released



Total amount of iodine-131 and caesium-137 emissions to the atmosphere (estimated from monitoring data) since the day after the accident, estimated by the Japan Nuclear Safety Council, in cooperation with the Japan Atomic Energy Agency. JNSC adds that it is difficult to gauge the accuracy of this early estimate. In addition to atmospheric release, there has also been radioactive deposition into the ocean, on the surface of the land and in site soil. The amount of radiation released prompted raising the INES rating of the incident in units 1, 2 and 3 from level 5 to level 7, the highest rating, in mid-April. Officials said that only about 10% of Chernobyl's radiation has been released.

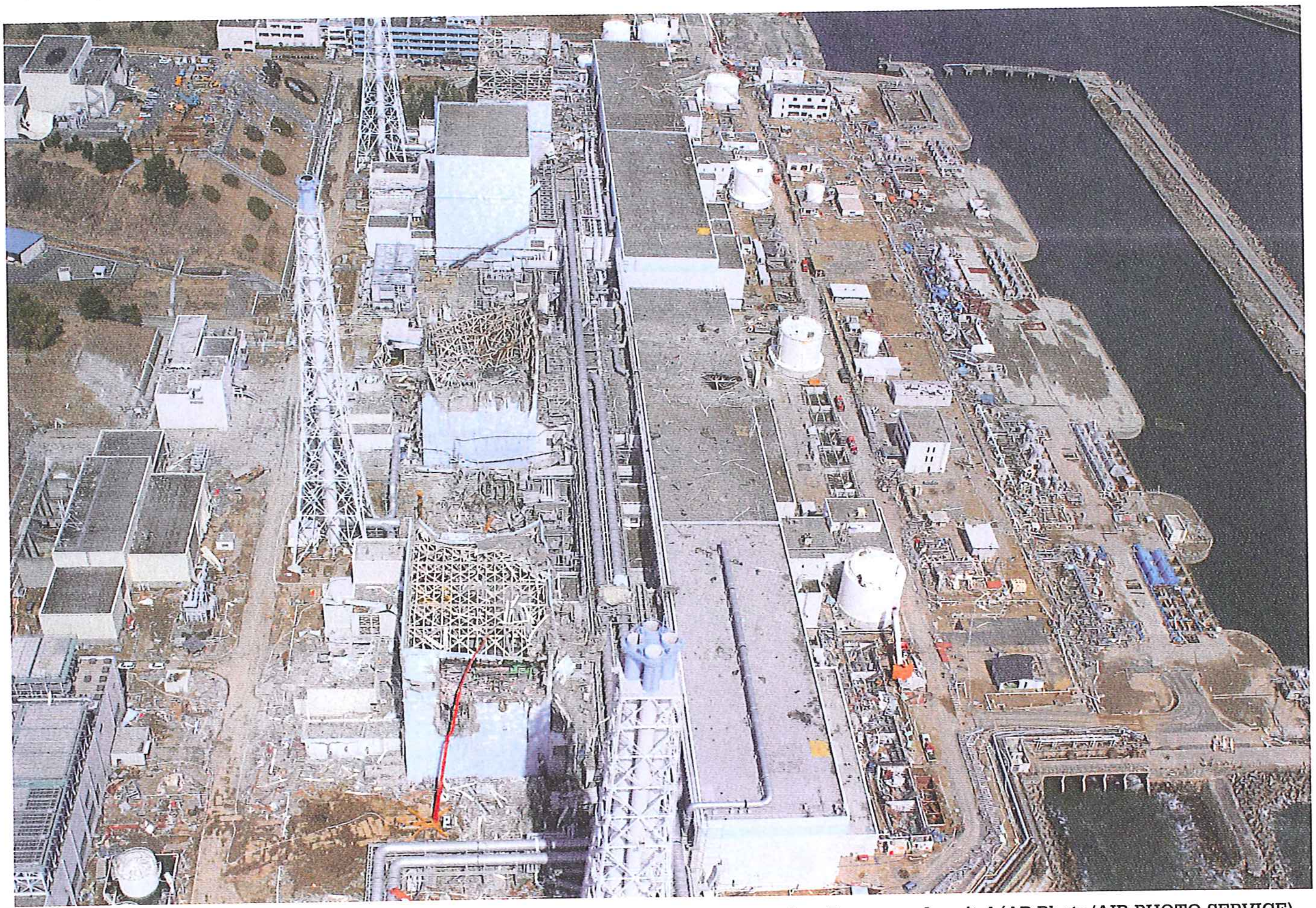
Fukushima Daiichi and Daiini deaths and injuries as of 11 April

	Caused by earthquake/tsunami			Caused by restoration work			
	Fukushima-Daiichi	Fukushima-Daiini	Elsewhere	Fukushima-Daiichi	Fukushima-Daiini	Elsewhere	Total
Deaths	2	1	4	0	0	0	7
Serious injuries	1	0	4	2	0	0	7
Minor injuries	6	1	5	16	1	0	29
Injuries (severity unknown)	0	0	0	2	0	0	2
Unaccounted for	0	0	0	0	0	0	0

No deaths and only two serious injuries are attributable to restoration work of the Fukushima Daiichi plant, according to data from utility TEPCO as of 11 April. The earthquake and tsunami claimed seven lives, including two workers who were found in the basement of the Fukushima Daiichi unit 4 turbine hall in early April. They were checking equipment at the basement of turbine building of Unit 4 when the tsunami hit, and had been missing since then. As of 11 April, no workers were unaccounted for. As of 13 April, a total of 22 workers had receive a dose of greater than 100 mSv, 19 employees of utility TEPCO and three of other contractors. None have received a dose greater than 250 mSv.

Flooded trench outside unit 2

Leak from trench wall flowing into breakwater lagoon



Images taken by a remote-controlled airplane on 24 March reveal the scale of devastation. Foreground: unit 4 (AP Photo/AIR PHOTO SERVICE)

hardener into holes drilled around the trench. At the time, a test using a tracking dye suggested that radioactive water leaked from a cracked pipe into gravel, which it seeped through to reach the concrete trench. Electrical utility TEPCO further isolated the plant from the sea by boarding up sections of an offshore dike that have been breached, and underwater silt barriers, including a dyke near the unit 2 water intake. But the water in the trench remains.

TEPCO's plan was to pump the 50,000 tons plus of trench water and the basement water into the units' turbine condenser hot wells, which have the advantage of being nearby. They had the disadvantage of being already full. Condenser water could be pumped into each unit's condensate storage tank, were they not full. Condensate storage tank water could be pumped into two shared suppression pool surge tanks, were they not also mostly filled. Operations began in units 1, 2 and 3 to shuffle water around between these vessels to free up space in the turbine condenser. Pumping out of the unit 2 trench water began 12 April. Pumping of the unit 2 turbine basement began on 19 April; pumping out less than half the 25,000 tons of water is expected to take almost a month.

Another potential facility that could receive some of this water is the on-site low-level waste treatment facility, but that too was full. TEPCO applied for, and received, government approval to flush out 10,000 tons of that water into the sea (which started on 4 April), to make way for more. Workers began inspecting the facility and rigging up hoses and knocking holes in the turbine buildings to allow for the water to be pumped to the waste treatment plant.

Even that facility may not have enough capacity; TEPCO has also borrowed a huge hollow barge, which had been used as a sport fishing park at nearby Shizuoka City, to store at least about 10,000 tons of water.

However, any further delay adds to the problem; every day an additional 500 tons of cooling water is injected into the reactors.

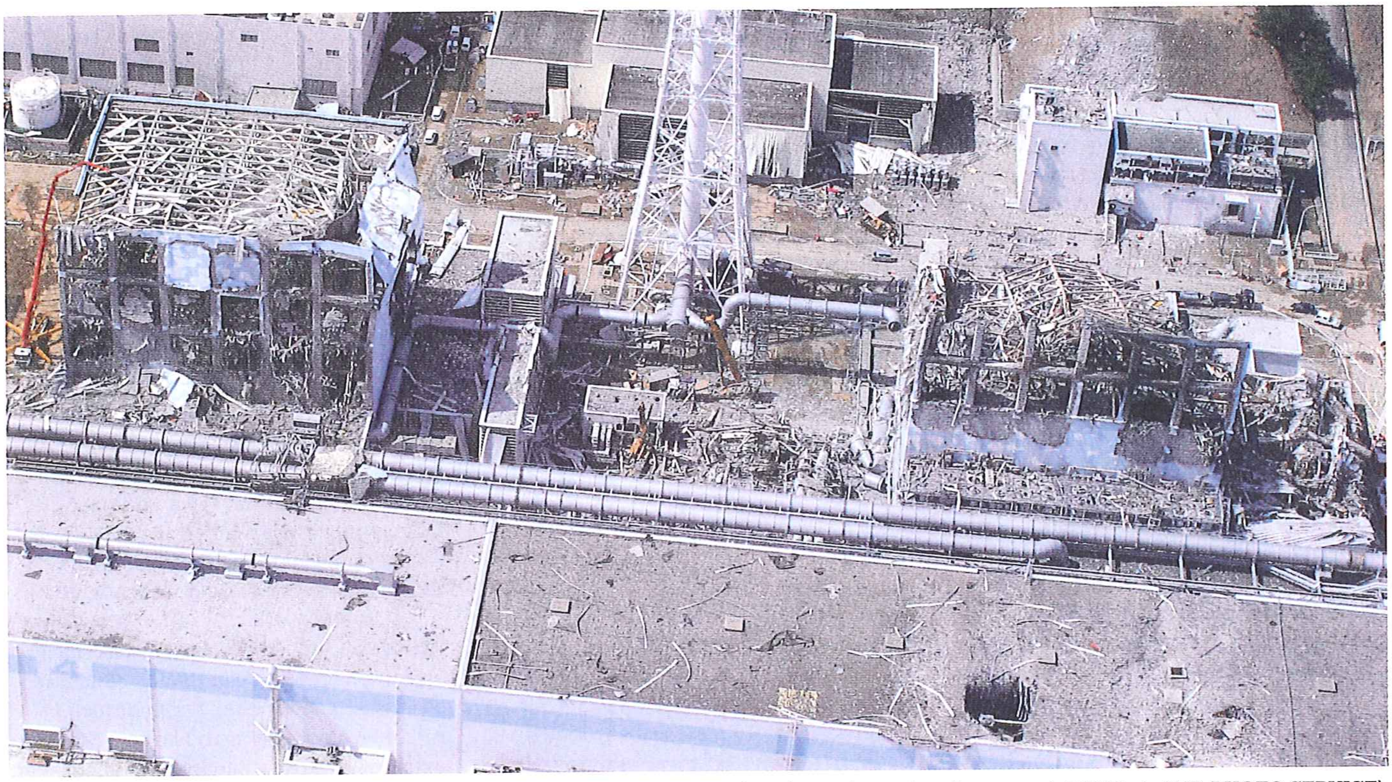
Recovery plans

In mid-April, electrical utility TEPCO outlined its plans for restoring units 1, 2 and 3 of the plant. It estimates that only by July 2011 will it be able to put radiation doses in steady decline, and by between October and December 2011 will it have the release of radioactive materials under control, and be able to significantly hold down radiation dose.

The three-month target of reaching declining radiation doses, called step 1, relies on two current activities: the prevention of hydrogen explosions, and prevention of release of contaminated water. The risk of hydrogen explosions increases because of steam condensation caused by injecting fresh water into the reactor, TEPCO said. It will continue to inject nitrogen gas into containment to reduce the concentrations of hydrogen and oxygen below the limit of inflammability. As of 14 April, it had injected 5500 m3 of nitrogen into the unit 1 containment vessel. To deal with contaminated water, TEPCO is working to acquire more storage and also processing facilities. As of 15 April, TEPCO reported that the central waste treatment facility, capacity 25,000 tons, had finished its examination and was prepared to receive contaminated water from turbine buildings and the trench.

Less immediate targets, called step 2, will take from six to nine months to achieve, TEPCO said. They include installing temporary covers for the buildings, and a seismic support structure for the unit 4 spent fuel pool in particular, whose walls have been damaged. In this stage, it will also aim to repair the damaged unit 2 suppression tank, and achieve cold shutdown for the units.

As part of the recovery analysis, TEPCO summarised the current state of the plant,



Unit 4 (left), with concrete pump cooling spent fuel pond, and damaged unit 3, from viewpoint above coast (AP Photo/AIR PHOTO SERVICE)

system by system, and summarised the countermeasures it was currently performing, and planning. It divided the reports into different categories.

Reactor cooling:

- (Units 1 to 3) Cooling achieved by water injection; partial damage to fuel pellets
- (Units 1 to 3) High likelihood of small leakage of steam containing radioactive materials through the gap of PCV [primary containment vessel] caused by high temperatures
- (Unit 2) Large amount of water leakage, indicating high likelihood of PCV damage
- Secured multiple off-site power (1 system each from TEPCO and Tohoku EPCO) and deployed backup power (generator cars /emergency generators).

Spent fuel pond cooling:

- Fresh water is injected from outside for Units 1, 3, 4 and through normal cooling line for Unit 2
- Confirmation of release of radioactive materials from the pool
- Walls of the building supporting the pool have been damaged (particularly unit 4).

Mitigation of contaminated water:

- Leakage of highly radioactive water assumed to have come from unit 2 into sea, but was subsequently stopped
- Leakage and accumulation of high radiation level contaminated water at unit 2's turbine building, vertical shafts and trenches
- Increase of storage volume of water with low radiation levels
- High likelihood of underground water around the building (sub-drainage water) being contaminated.

Mitigation of other contamination: debris is scattered outside the buildings and radioactive materials are being scattered.

Monitoring and decontamination: monitoring of radiation dose is being carried out inside and out of the power station. Seawater, soil and air sampling at 25 sites inside the boundary and 12 locations outside.

Scenes of the tsunami: Pictures from the neighbouring Fukushima Daiini plant 10km south showing (a) plant just before tsunami (b) inundated by tsunami. Inundated ground level was 12m above sea level.

Public exposure in Japan

The earthquake and tsunami that hit Japan on 11 March has affected the entire country. Multiple agencies have been monitoring radiation release from the six 1970s BWRs at the Fukushima Daiichi site since then, both at the site and beyond, although predicting the long-term effects of the radiation remains premature. By Penny Hitchin

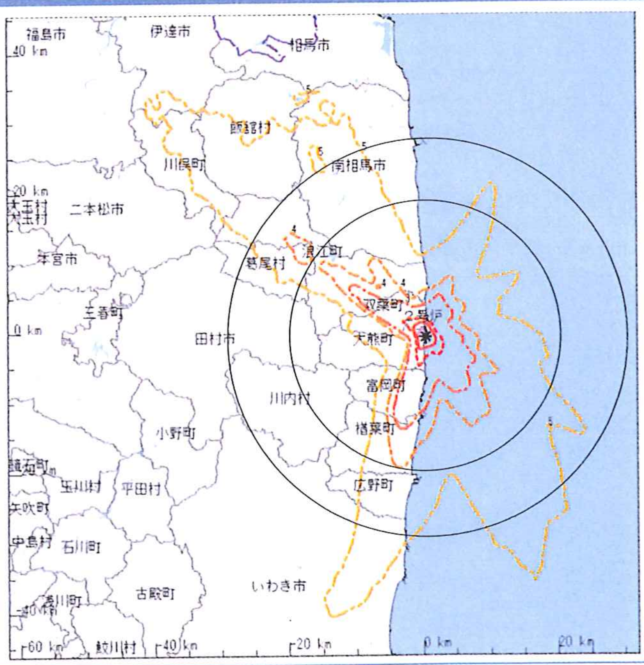
Units 4, 5 and 6 were undergoing planned maintenance outages when disaster struck. Units 1, 2, and 3 shut down automatically in response to the earthquake. The subsequent tsunami disabled the emergency diesel generators required to cool the reactors. A loss of cooling water to the reactors and to the spent fuel cooling ponds led to hydrogen explosions, fires, leaks and core meltdown. Over the following weeks the utility TEPCO (Tokyo Electric Power Company) battled to contain the damaged reactors, a situation, which a month later, continues to pose highly complex challenges.

The International Atomic Energy Association (IAEA)'s Convention on Early Notification of a Nuclear Accident requires civil nuclear nations to provide data about the accident's time, location and radiation releases when trans-boundary radiation release is feared. This treaty, introduced following the 1986 Chernobyl nuclear accident, requires countries to have specific reporting mechanisms, giving internationally recognized figures for releases of radiation.

The utility which owns and operates Fukushima Daiichi, TEPCO has been releasing daily bulletins about the state of the reactors at Fukushima Daiichi and the results of its own radiation monitoring. Radiation monitoring across the whole country has been carried out by Japanese authorities, which have been releasing data regularly, some available in English. Two IAEA monitoring teams were dispatched to Japan following the accident.

The US Department of Energy carried out aerial monitoring in Japan and a team from the US National Nuclear Security Administration (NNSA) collected and analyzed data gathered from more than 40 hours of flights and thousands of ground monitoring points. In addition IAEA has been giving daily press releases, interpreting and clarifying the news from Japan. Greenpeace started monitoring outside the evacuation zones at the end of March.

Fig. 1: SPEEDi simulation of radiation spread (yellow and orange) shown with 20km and 30km radius evacuation zones



As the stricken reactor sites continued to release radioactive liquid into the sea, TEPCO was authorised by the Japanese regulators to discharge 10,000 tons of low level contaminated water into the sea (to make capacity to store highly contaminated water), and monitoring of the marine environment was stepped up.

Dispersal projections

NHK, the Japanese Broadcasting Service reported April 4 that the Japanese government withheld the release of projections indicating high levels of radioactivity more than 30 km from FD1 following explosions at the plant. The estimates used the Education, Culture, Sports, Science and Technology Ministry (MEXT) System for Prediction of Environmental Emergency Dose Information (SPEEDi) for dispersal forecasts. The projections used available data and were based on the assumption that radioactive substances had been released for 24 hours from midnight on March 14th (Figure 1). The SPEEDi estimate showed that in some areas more than 30 km from FD1, radiation would exceed 100 milliSieverts (mSv) in people who remained outdoors for 24 hours between March 12th and 24th. This is 100 times higher than the 1 mSv-per-year reference level for humans recommended by the International Commission on Radiological Protection (ICRP). The figures, prepared on March 16 but not released until a week later, showed higher levels of radioactive substances to areas to the northwest and southwest of the plant. Japan's Nuclear Safety Commission says it did not release the projections because the location or the amount of radioactive leakage was not specified at the time.

Separately, on April 4 the government said it had ordered the Japan Meteorological Agency to promptly disclose its data on the projected spread of radioactive materials from Fukushima Daiichi. Chief Cabinet Secretary Yukio Edano said in a news conference on April 4 that he had told the agency "should have made the data public along with an adequate explanation." The projection formed part of reference materials compiled in response to a request from the International Atomic Energy Agency.

Graphs of radiation trends as of 4 April collected by local prefectures, and collected and plotted by the Japan Atomic Industrial Forum (Figures 2-5) show that radiation has generally fallen since mid-March, although there are large disparities between some sampling locations.

Food bans

Environmental scientist Steve Jones told *NEI* magazine (on April 1) that the releases at Fukushima Daiichi are significant. Over the area 50 to 60 km from the site, the contamination levels are greater than were found over the same distance from the source after the UK Windscale Pile fire in 1957 (rated INES 5). However it is too early to make an assessment of the long-term effects on the health of the population. He says that after Chernobyl (INES 7), it took 5-10 years before information about the extent of early effects (particularly thyroid cancers in children) started to emerge.

Jones said that the major concern in Japan is the food chain: "The critical factor is how successful Japan will be in keeping contaminated foodstuffs out of the human food chain." Terrestrial readings in Fukushima and neighbouring Prefectures are showing elevated levels of iodine-131 and caesium-137, with high localized contamination.

Jones says that the main area of potential concern is the terrestrial route. If radioactivity is released to the atmosphere it can be carried as vapour (iodine) or airborne particulate (iodine and caesium) before being deposited on the ground or on vegetation. Direct deposition onto foliage leads to high concentrations immediately after an accidental release, hence the prevalence of leafy vegetables in the lists of restricted foods. Grazing animals can consume the contamination. In the case of dairy cows grazing on contaminated vegetation, the effect will show up in the milk within a few days.

Much of the initial deposit will be removed from vegetation by weathering within a few weeks, with the radioactivity being transferred to the soil. Radioactive material in the soil can be taken up by plant roots and transferred back into the plant, although this will result in lower concentrations than were caused by the initial deposit onto vegetation.

Radioecologist Nick Beresford of the Centre for Ecology and Hydrology, Lancaster Environment Centre, has been looking at the implications of the release of radioactive material for the food chain. He told *NEI* that the farm animal management system in the affected prefectures involves keeping animals indoors most of the year. "A lot of the animal feed is imported, which will minimize the transfer through the food chain."

Radioactive caesium will remain in the soil for a long time, but the rate at which it will transfer back to the plant depends on the soil type. Jones says, "The experience from Chernobyl is that caesium uptake by plants is highest when soil has low mineral content. Lowland pasture soils with higher mineral content bind the caesium and reduce the transfer back to plants."

How long will food restrictions be necessary? Jones says that deposition levels to the northwest of the plant are very high and that while I-131 will disappear within a few months, caesium deposition will mean that areas with peaty or sandy soils may be under restriction for a long time. Restrictions were imposed on sale or movement of sheep from upland farms in the UK which received fallout from Chernobyl in 1986 and some are still in place 25 years later. Beresford says, "It looks as though restrictions and counter-measures will be in place for some time. From the current data it is difficult to tell the extent of the area which will be affected."

The marine food chain is complicated: fish can take up of contamination through their gills as they respire, while filter feeders can pick up sediment. Contamination can be transferred up the food chain from phytoplankton through grazing and predatory organisms. Very high levels of contamination have been reported in seawater close to the Fukushima Daiichi site. As a fraction of the caesium becomes bound to sediment and can stay in place, Jones believes there are likely to be long term problems within a few kilometres of the site even if the leaks are stopped quickly.

By March 21 the Ministry of Health, Labour and Welfare had bans in place on distribution and consumption of fresh foods, including raw milk and leafy vegetables such as broccoli, cabbage, cauliflower, kakina, komatsuna and spinach, and turnips from Fukushima. The adjoining prefectures of Ibaraki (8), Gunma (10) and Tochigi (9) also had restrictions placed on spinach and kakina. But the next day Prime Minister Naoto Kan placed an indefinite ban on spinach and another local vegetable produced by Fukushima and neighbouring prefectures after samples were found to be abnormally radioactive. He also suspended Fukushima milk.

Standards hastily drafted by Japan's Health, Labour and Welfare Ministry (HLWM) state milk or other dairy products containing more than 300 becquerels of radioactive iodine or 200 becquerels of

Fig. 2: 13 March-4 April sampling data

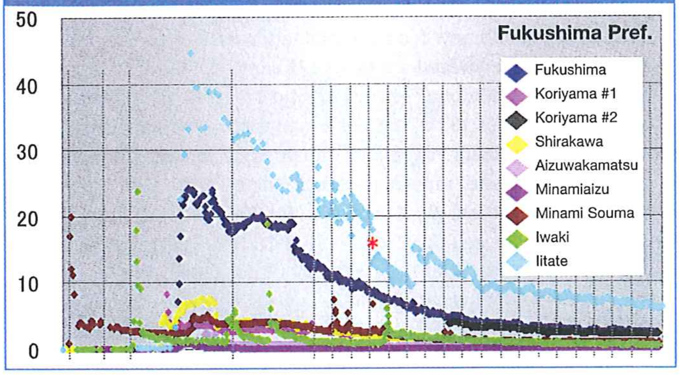


Fig. 3: 18 March-4 April sampling data

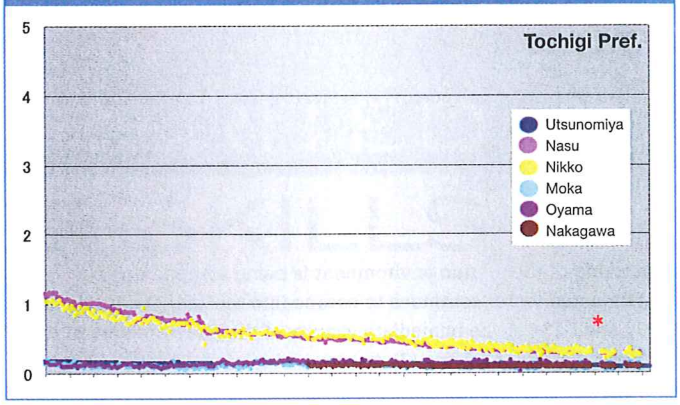


Fig. 4: 18 March-4 April sampling data

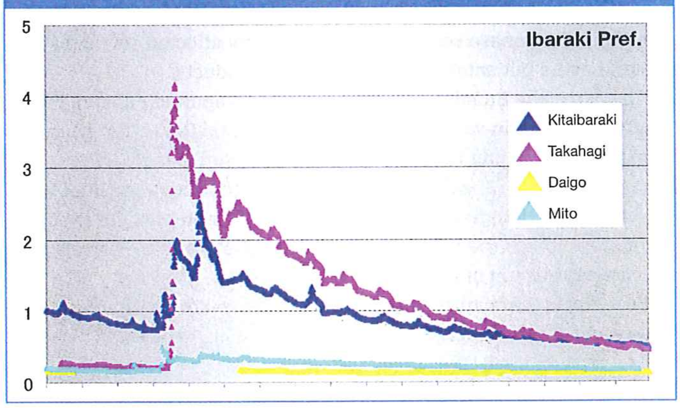
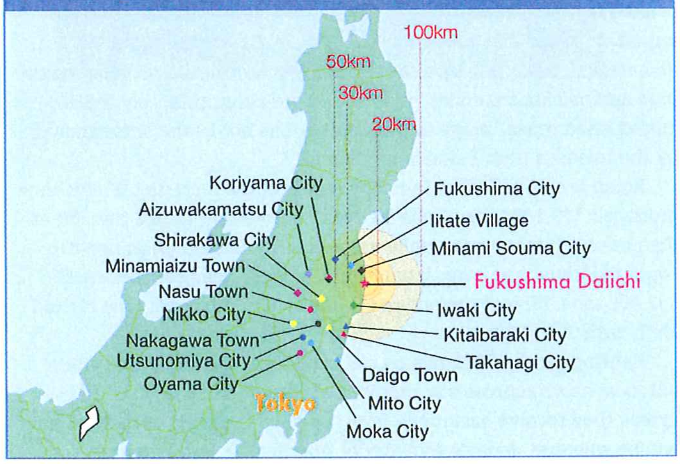


Fig. 5: Map of surveyed towns and evacuation zone



radioactive caesium per kg cannot be shipped. The figure for vegetables is 2000 becquerels and 500 becquerels respectively.

HLWM published new food contamination data at the beginning of April. The analysis covered a total of 134 samples taken on 15 March (2 samples), 29-31 March (77 samples) and 1-2 April (55 samples). Analytical results for 133 of the 134 samples cover various vegetables, spinach and other leafy vegetables, mushrooms, strawberries, beef and pork, seafood and unprocessed raw milk in Chiba (12), Fukushima (7), Gunma (10), Ibaraki (8), Kanagawa (14), Kyoto (26), Niigata (15), Saitama (11), Shizuoka (22), Tochigi (9) and Tokyo (13). IAEA says that the analysis indicated that I-131, Cs-134 and/or Cs-137 were either not detected or were below the regulation values set by the Japanese authorities. Only one sample of shiitake mushrooms taken on 1 April in Fukushima prefecture was above the regulation values set by the Japanese authorities for I-131, Cs-134 and Cs-137.

On 4 April HLWM reported analytical results for a total of 24 samples taken on 31 March (4 samples) and 1st, 3rd and 4th April (20 samples). Analytical results for all of the 24 samples for various vegetables, strawberry and seafood in Gunma (10), Ibaraki (8), Niigata (15), Saitama (11) and Tochigi (9) indicated that I-131, Cs-134 and/or Cs-137 were either not detected or were below the regulation values set by the Japanese authorities. In neither report were the actual readings made available.

Sea

Monitoring of the marine environment is being stepped up as contaminated water continues to escape into the sea. The levels of Cs-37 and I-131 in the immediate vicinity of the plant are very high. On the coast of Fukushima (7), fishing and related activities have been halted. Japan's Fisheries Agency believes that if radioactive materials are released into the sea, the concentration level will remain low, due to the huge volume of the seawater and the current of the sea. However, according to various east Asian news reports, exports and sales of Japanese seafood have been badly affected, as many foreign buyers put safety first and shun the products.

The Japanese Broadcasting Company NHK reported on April 5 that small fish caught in waters off the coast of Ibaraki Prefecture have been found to contain radioactive caesium above the legal limit. Ibaraki Prefecture (8) says 526 becquerels of radioactive caesium was detected in one kilogram of sand lances. The acceptable limit is 500 becquerels. It was the first time that higher-than-permitted levels of radioactive caesium in fish have been reported.

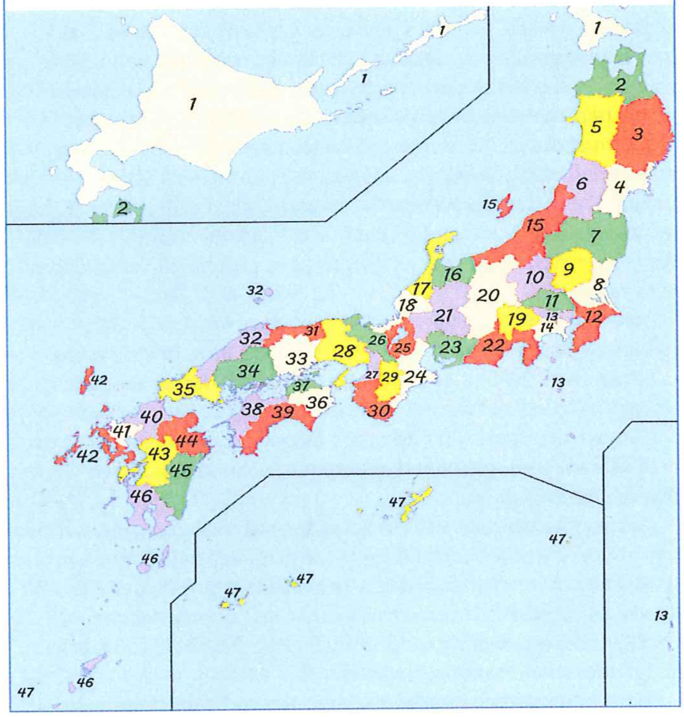
Fukushima Prefecture (7) relies on large-scale agricultural and fishery industries, supplying food to the 30 million people of Tokyo as well as further afield. The annual catch, of shore and ocean fish, is about 235,000 tons. The prefecture is Japan's fourth largest farmland area; the Fukushima Basin is noted for its rice fields and orchards, while further inland the Aizu Basin produces high-quality rice, which is used by the local sake-brewing industry. Livestock is also important, although the Ministry of Agriculture, Forestry and Fisheries of Japan say that, because of winter conditions, most cattle, pigs and chickens are still indoors, and are being primarily fed on stored dried grass, silage and grain that has not been contaminated by the releases from Fukushima Daiichi.

Japan is self-sufficient in rice, a staple of the local diet. Fukushima produced 439,100 tons of rice last year, accounting for 5.3 percent of the nation's total output, while neighbouring Ibaraki (8) prefecture, south of Fukushima, was Japan's fifth-biggest rice producer with 392,800 tons. Miyagi prefecture (4), north of Fukushima, was ranked sixth with 391,300 tons.

Planting for the 2011 rice crop should have started in mid-April, but local news sources say that farmers are unlikely to go ahead unless they receive assurance from the government that their crops will be saleable. Japan's Ministry of Agriculture, Forestry and Fisheries (MAFF) is reported to have started collecting data for each crop on acceptable levels of radioactivity in the soil. MAFF says it hopes to complete testing of 150 samples by mid-April.

Japan's prefectures

Japan consists of 47 administrative areas - prefectures – which are often referred to by number or name, (see map and key). Fukushima is Prefecture number 7, situated in the north east of Japan on the Pacific Ocean around 200km from Tokyo. The coastal town of Futaba is home to two nuclear stations – Fukushima Daiichi (six reactors) and Fukushima Daini (four reactors).



Iodine tablet recommended for evacuees

On March 16 the Japanese Nuclear Safety Commission recommended that evacuees leaving the 20-kilometre area around Fukushima Daiichi should take a single dose of stable iodine, from 12.5mg-76mg, depending on age. Iodine is a trace mineral required by the body for the synthesis of the thyroid hormones which are essential for metabolism. Under normal circumstances people have approximately 20 to 30 mg of iodine in their bodies, most of which is stored in the thyroid gland. Ingesting stable iodine (usually in the form of potassium iodide, KI) is a precaution against the uptake of radioactive I-131 which can cause cancer by damaging cell DNA. This is especially serious if the cells are multiplying quickly – hence the importance of iodine tablets for infants, children and pregnant women. Further afield, notably in the USA, sales of potassium iodide tablets are reported to be soaring, despite the fact that local levels of I-131 detected are tiny.

Cs-137 has a half life of 30 years, but its biological half-life in humans is between one and four months. It behaves like potassium in the environment and in the body and can cause different kinds of cancer. If ingested, the half-life can be shortened by ingesting Prussian Blue, which acts as a solid ion exchanger absorbing the caesium while releasing potassium ions.

Undoubtedly there will be long term effects, political, operational and radiological, from the disastrous sequence of events at Fukushima Daiichi, but at this stage, with the site yet to stabilised, it is too early to predict how serious they will be, and how far they will extend.

The problems of stabilising a melted core

As this magazine issue went to press, electrical utility TEPCO announced its plan to stabilize Fukushima Daiichi units 1, 2 and 3. Those plans do not account for the possibility that core material has leaked out of the lower head of the reactor pressure vessel, says Theo Theofanous

I believe that given the extent and timing of the core damage (as manifest by the hydrogen explosions and sudden pressurization events) that some fraction of the core debris is already found on the drywell floor, especially for the higher-power units 2 and 3.

Unfortunately no-one knows the answer to this critical question with any significant degree of certainty. The main reason is lack of information about the status and activation of various systems in the reactor coolant system (RCS) and thereby the timing of events that lead to core uncovery.

It should also be noted that BWRs have their lower head full of penetrations for the control rods and the instrument tubes. The instrument tubes are not supported on the outside and they are susceptible to failure by melting of the welds that seal them in place, and there is no significant cooling from the outside to prevent such failures.

The presence of core material on the drywall floor has major significance on the long-term stabilisation of the reactor. The significance depends on how much debris is on the floor. Let's suppose at one extreme there is a major fraction on the floor, and it is inside the pedestal area, where the walls of the reactor vessel are supported, where the debris bed would be quite deep actually, and then it is very likely it would not be covered by water. If the debris is not coolable, then it will attack the concrete, and depending on the kind of concrete, it would generate gases, and if there are unoxidised materials in the debris, hydrogen, which would vent to the outside along with radioactive aerosols found in the containment. I don't know how much of a basemat the unit has, but am concerned about the long-term possibility of the debris melting through the bottom, and also melting through the pedestal walls that hold the reactor vessel.

If, on the other hand, all or the vast majority of core material is in the lower head of the reactor pressure vessel, then the question is, how can you cool it there, since you can't fill up the drywell all the way to submerge the reactor vessel, since the suppression chamber, which drains the wetwell, is damaged at least in unit 2. In BWRs, even if the lower head could be submerged, there are some very big questions about whether outside cooling is sufficient to stabilise it. This method of cooling would be effective in keeping debris inside the lower head of PWRs, based on my experience with a concept of severe accident management we established for PWRs of this power [750 MWe]. However, this is not the case for BWRs. In addition to all of the lower head penetrations, which PWRs do not have, their flatter lower head shape and the metal skirt underneath the lower head near its attachment to the reactor vessel, both tend to prevent vapour from escaping. In such a case, there would be vapour blanketing the lower head from underneath, making it very difficult to cool.

Given the amount of radiation and hydrogen that the reactors have been putting out, I would expect core melt and degradation to a significant extent. Given this, and the fact that the TEPCO has put a lot of salt in it [by injecting seawater], I am puzzled about why the Japanese are saying that there is going to be a major fraction of the core still inside the core region and the reactor pressure vessel. I hope that would be the case, but even if it were, it would be hard to stabilise the melt inside the lower head now.

The presence of salt could complicate the process of stabilising of the reactors, but it could also be helpful. We cannot know the extent of each until we have more information about where the core debris is. Obviously, salt water injected into the core, combined with core water boiling, tends to increase core salt concentration. Accumulated salt can plug up coolant passages. But at high temperatures, the salt would melt, and circulate through the debris by natural convection. In that way, it would function as a coolant.

The principal issue is finding out where the core materials are. Only then can we reach the next step. I know it is extremely difficult to do so, but I don't know if it is impossible. For the time being we need to be concerned about the open-ended water flow through the system, and the associated releases of radioactivity to the environment. ■

The optimistic point of view

Richard Lahey, the Edward E. Hood professor of engineering at the USA's Rensselaer Polytechnnic Institute, was head of R&D for GE BWR thermal-hydraulic and safety technology. He spoke briefly to Will Dalrymple:

"I worked for GE in R&D on BWRs, including the Fukushima design type, and worked on the Fukushima plant in particular. Then in 1975 when I came to Rensselaer, we developed the APRIL simulation code to look at this kind of core melt and how it propagates in BWRs. What we found, which was since verified by experiment, is that the core preferentially melts through the control rod guide tube bottom, and comes out there rather than through the bulk head. That can be good news.

"The bad news is that it comes out early. At Three Mile Island 2 [during the famous March 1979 accident at the Pennsylvania, USA-based PWR], they were able to quench it before it came out. Although a core melt and relocation happens earlier in a BWR, it emerges from the lower head in a distributed way; the bottom head is perforated like a colander.

If corium is distributed on the floor evenly, that is not bad news, because it is easier to cool than a lump. Because they have been spraying water into the reactors, water should pool there to a depth of 500mm, and the water will sparge out any radioactive aerosols from the corium-concrete interaction.

But we do not know for sure that this is happening; there is no real instrumentation or visualisation. If core melt and relocation is happening, you really need to know, so you do not do something crazy like cut off the water or entomb the reactor with concrete.

If I were there, I would try to get a nuclear-hardened camera into the drywall and see the state of the lower header.

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