Fallout from Fukushima: the impacts so far

18 months have passed since the massive earthquake and tsunami off the east coast of Japan triggered the Fukushima nuclear accident. Ian Fairlie and Stuart Parkinson give an overview of why the nuclear disaster happened, why it is still occurring, and its implications to date.

New information about the Fukushima nuclear accident is still emerging on a frequent basis, and so this article will necessarily only give a snapshot of the evidence to date. Nevertheless, there is much about the disaster and its effects that has become clearer in recent months, so this is a good time to take stock.

The nuclear accident[1]

Following the earthquake on 11 March 2011, the three operating reactors at the Fukushima Dai-ichi nuclear plant[2] automatically shut down because of huge lateral vibrations caused by the quake. But the quake also disconnected the reactors from the national grid, meaning power to the cooling pumps was lost. Emergency diesel-powered pumps kicked in but these were unwisely located in reactor basements, which were flooded by the tsunami arriving 20 minutes later. The result was inexorable rises in nuclear fuel temperatures until the fuels melted.

Because of the paramount need to remove the large amounts of 'decay heat' from nuclear fuels, both in the reactors and in the ponds containing the spent fuel, cooling failures resulted in a compound, cascading series of explosions and other events, which are still being unravelled. The major events were as follows:

- core meltdowns occurred in the reactors of Units 1, 2, and 3;
- explosions destroyed the reactor buildings of Units 1, 3, and 4;
- an 'explosive event' damaged the containment structure inside reactor 2;
- several fires broke out at Unit 4 (luckily, reactor 4 was offline at the time of the earthquake);
- spent fuel stored in the pools of Units 1–4 overheated as their water levels dropped;
- many workers suffered high radiation exposures and often had to be evacuated;
- machinery for reactors 1–4 damaged by floods, fires and explosions remained inoperable.

On 12 March 2011, a probable hydrogen explosion at Unit 1 exposed its spent fuel pool to the open air, released radioactive matter into the environment and caused delays in cooling Unit 3. The ensuing huge explosion at Unit 3 a day later damaged seawater injection lines and vent lines for Unit 2, producing delays in its cooling. It is likely this caused the 'explosive event' on March 15 inside the reactor at Unit 2. A few minutes later, a fourth explosion badly damaged the rooftop area at Unit 4 that contained the spent fuel pond. In other words, explosions at one unit hampered responses to the damage at others, leading to a chain-reaction of explosions and radiation releases. No wonder staff members at the plant were often terrified and TEPCO (the electricity utility) wanted to withdraw all personnel from the plant at one stage.

Within about six hours of the Japanese earthquake, it appears that full or partial nuclear fuel meltdowns had occurred within Units 1, 2 and 3 at Fukushima due to the inexorable heat from radioactive decay inside the fuel. This was quickly followed by the molten fuel (at ~2,000 °C) melting its way through the steel pressure vessels into secondary concrete containment vessels. It is now thought these containment vessels have cracked and much fuel is now in the basement areas of the reactors. At the same time, the water in the spent fuel ponds above the reactors also began to boil, causing their water levels to drop and thus exposing spent fuel to the atmosphere.

So within a few days of the earthquake and tsunami, four major explosions had occurred: one at each of the relevant Fukushima Dai-ichi Units. These explosions caused massive damage, with the result that the reactor building at Unit 1 and the spent fuel pond at Unit 4, in particular, may collapse. It is important to note that the reactor malfunctions, resulting core meltdowns and explosions were due to the earthquake as well as the tsunami, contrary to the explanations given by TEPCO and the Japanese regulators, which only mentioned the tsunami.[3] The point is that the many Japanese nuclear reactors near fault lines are considerably more vulnerable to earthquakes than to tsunami.

The continuing disaster

18 months later, the accident is still continuing in slow motion and will do so for years. Major efforts are still being made to keep the reactor fuel cool to stop it from melting through the bottoms of the reactor buildings into the soil below (although the concrete bases are about 10 m thick). If this were to occur, Japan would be deep in uncharted areas: further explosions would likely occur. Water is also still being pumped into the storage pools to keep the spent fuel covered.

A major headache is the structural instability of the wrecked reactor buildings, which may still collapse due to the massive weight of the storage ponds situated, again unwisely, on top of the reactors. This would spill thousands of tonnes of dangerous spent fuel and radioactive water over the site. Indeed, there have been warnings that the pond at Unit 4 – which contains over 1300 spent fuel assemblies – is especially vulnerable.[4]

When we look further afield, the situation is no better, as very large amounts of radioactivity were emitted to the atmosphere and released into the sea. The former resulted in much land being contaminated with fallout, and large amounts of agricultural produce also being contaminated. In addition, it is known that many nuclear fuel fragments were blasted throughout the plant and even as far as the large town of Iitate over 30 km away. About 100,000 people have had to be evacuated from their homes, most possibly for decades. These effects are on top of the estimated 20,000 people killed by the earthquake and tsunami themselves. The situation is truly numbing and our hearts go out to the Japanese people struggling with the horrible consequences of the earthquake and tsunami and of the Fukushima disaster.

How long will this dire situation continue? It is hard to say, but officials from the International Atomic Energy Agency privately talk of years: other scientists say decades.

Health and ecological effects[1]

Death and serious injuries so far due to the Fukushima accident are certainly small in comparison to the thousands caused by the earthquake and tsunami. About seven deaths to military personnel and plant operators were apparently caused by the site explosions. Nearly 600 deaths have been certified as "disaster-related" – mainly due to ill-effects caused by the evacuation.[5] None of these deaths was due to radiation exposure. But fears remain about longer-term effects, as radiation has decades-long latency periods before most solid cancers appear. Increased incidences of thyroid cancers – a prominent effect after Chernobyl – are unlikely to appear for another three years.

The first main projection of radiation-related deaths was by Professor Frank von Hippel at Princeton University in September 2011.[6] Hippel estimated an


Digital Globe

Satellite image of the damaged Fukushima Dai-ichi reactor buildings, 16 March 2011

additional 1,000 fatal cancers would arise from Fukushima. A more detailed study by Mark Jacobson and John Ten Hoeve, researchers at Stanford University, was published in July 2012.[5] They used an atmospheric model to estimate the dispersion of the main radioactive materials released by the accident, together with the 'linear no-threshold' model for radiation effects. Estimates for internal radiation from contaminated food were added. Their best estimate was 130 additional cancer-related deaths, and 180 non-fatal cancers to the year 2061. The uncertainty in the number of deaths ranged from 15 to 1,300. The researchers pointed out that two key factors meant that the exposure of the population to the release of radioactivity – and therefore the estimated death rate – was much lower than it could have been. Firstly, over 80% of the radioactive material was deposited over the Pacific Ocean and, secondly, the Japanese authorities did take major preventative actions – including large-scale evacuations and bans on contaminated food.

Studies of the ecological impacts have also started to be carried out. For example, data on the contamination of fish in coastal waters (within 20 km of the site) has been published by TEPCO.[7] Of 50 samples, over half were contaminated above the levels allowed for human consumption, and one was 50 times above this level. Another study, this time on butterflies, has highlighted both physical and genetic damage resulting from the radioactivity, and pointed out that the damage has increased in later generations.[8]

Further assessments

Fukushima is clearly a major disaster but not as serious as Chernobyl. Radioactive air emissions are much more important than radioactive sea discharges in terms of their resulting radiation doses to people, and the dispersed radioactivity to air from Fukushima has been estimated to be about 10% to 40% of the amount dispersed from Chernobyl. About 1,000 square kilometres near the Fukushima plant were seriously contaminated, but at Chernobyl the corresponding area was over 200,000 square kilometres throughout Europe, according to the European Commission.

The Japan Centre for Economic Research has estimated the full cost of the nuclear disaster, including compensation and decommissioning all six of the Dai-ichi plant's reactors, at 5.7 to 20 trillion yen or $70-$250bn.[9] This is a enormous amount, and is surely having a huge impact on Japan's already weakened economy.

A Japanese parliamentary panel – the Nuclear Accident Independent Investigation Commission – published a report in July 2012 that was very outspoken in its criticism of the government, the nuclear regulators and TEPCO.[10] It commented that Fukushima "was a profoundly manmade disaster – that could and should have been foreseen and prevented." It highlighted many institutional failures, both in advance of the accident and during it, cataloguing "a multitude of errors and wilful negligence." The lack of preparedness shown by the organisations involved was caused by the myth that the risk of major nuclear accidents is vanishingly small, which nuclear power proponents had nurtured over decades.

Perhaps the simplest of the lessons to be learned from Fukushima is that nuclear power is a supremely unforgiving technology. When things go wrong, they can go very wrong with consequences that are extremely difficult to remedy, even in advanced industrial nations. But nuclear power is merely a complicated way of boiling water and, after Fukushima, many countries have begun to examine safer energy policies, especially Japan itself which appears to be moving to phase out its nuclear industry by 2030.[11]

Ongoing political fallout in Europe

The political response to the Fukushima disaster in the months immediately following the disaster was discussed in *SGR Newsletter no.40*.[12] While many countries – including Germany, Switzerland and Italy – opted to phase out nuclear power or cancel proposed programmes, some – notably the UK – vowed to continue with their plans. This stark divide was perhaps best illustrated by two parliamentary votes taken within weeks of each other in summer 2011. In the UK, only 14 out of 650 MPs voted against the government's Nuclear Policy Statements, which proposed new development, while the German parliament voted by 513 to 79 to phase out all nuclear power by 2022.

In the months since then, historically pro-nuclear France has elected a new President, Francois Hollande, who has pledged to reduce the share of French electricity derived from nuclear power from its current 75% to 50% by 2025.[13] Government support for renewable energy will also be increased.

With Austria, Denmark, Greece, Ireland, Norway and Portugal all non-nuclear, and phase-out programmes also in Belgium and Spain, European support for nuclear power is on a clear downward path. Add to this the major problems in the construction of new reactors in France and Finland,[14] and it is little surprise that French nuclear companies are looking to the UK as a safe haven for new nuclear projects – with the Coalition government offering enthusiastic support. Yet, even here, plans for new nuclear are looking decidedly shaky. German companies have pulled out of the Horizon consortium, which had been proposing nuclear plant for two sites, while the government seems in disarray over its Draft Energy Bill which proposes major new financial support being provided to nuclear developers.[14]

It is a sobering thought that on the nuclear power issue after Fukushima, the UK appears to be increasingly out on a limb in comparison with most other European countries.

Dr Ian Fairlie is an independent consultant on radioactivity in the environment. He holds an MSc in radiobiology and a PhD in radioactive waste studies. Website: http://www.ianfairlie.org/

Dr Stuart Parkinson is Executive Director of SGR. He has written widely on energy issues.

This article is an updated version of one published on the SGR website on 7 March 2012.

Notes and references

1. Among the better websites on Fukushima, Wikipedia has a number of pages including:
   http://en.wikipedia.org/wiki/Fukushima_Daiichi_nuclear_disaster
   http://en.wikipedia.org/wiki/Radiation_effects_from_Fukushima_Daiichi_nuclear_disaster
   http://en.wikipedia.org/wiki/Japanese_reaction_to_Fukushima_Daiichi_nuclear_disaster
   These sites are kept up-to-date, are well-informed, and with good sources. Collectively they cite around 1000 references. Most important, they are pretty even-handed. These sites represent a vast amount of work: it seems they are maintained by a team or teams of Japanese academics.
2. The Fukushima Dai-ichi plant had six reactors. Units 1-3 were operational at the time of the accident, Unit 4 was de-fuelled, and Units 5 and 6 were in cold shutdown for maintenance.
3. Adelstein J, McNeill D (2011). Meltdown: What Really Happened at Fukushima? http://www.theatlanticwire.com/global/2011/07/meltdown-what-really-happened-fukushima/39541/
4. Burnie S et al (2012). The Highest Risk: Problems of Radiation at Reactor Unit 4, Fukushima Daiichi. Japan Focus. March. http://www.japanfocus.org/-Murata-Mitsuhei/3742
5. Ten Hoeve J, Jacobsen M (2012). Worldwide health effects of the Fukushima Daiichi nuclear accident. Energy and Environmental Science. doi:10.1039/c2ee22019a. http://www.stanford.edu/group/efmh/jacobson/TenHoeveEES12.pdf
6. Hippel F (2011). The radiological and psychological consequences of the Fukushima Daiichi accident. Bulletin of the Atomic Scientists, vol.67, no.5, p.27. http://bos.sagepub.com/content/67/5/27
7. World Nuclear News (2012). Fishy figures at Fukushima. 22 August. http://www.world-nuclear-news.org/RS_Fishy_figures_at_Fukushima_2208122.html
8. Hiyama A et al (2012). The biological impacts of the Fukushima nuclear accident on the pale grass blue butterfly. Nature Scientific Reports, 2, no.570. doi:10.1038/srep00570. http://www.nature.com/srep/2012/120809/srep00570/full/srep00570.html
9. Japan Center for Economic Research (2011). Redesigning of the Japanese Economy: Beyond the Earthquake Disaster. http://www.jcer.or.jp/eng/research/pdf/pe(iwata20110425)e.pdf
10. BBC News online (2012). Fukushima report: Key points in nuclear disaster report. 5 July. http://www.bbc.co.uk/news/world-asia-18718486
11. Reuters (2012). Japan leans toward zero nuclear stance, caution remains. 29 August. http://www.reuters.com/article/2012/08/29/japan-nuclear-idUSL4E8JT2LJ20120829
12. Elliott D (2011). The race for the nuclear exit. SGR Newsletter, no.40, p.1&20-21. http://www.sgr.org.uk/publications/sgr-newsletter-40
13. Renewable Energy World (2012). Hollande Victory Signals Shift in France's Renewable Energy Policy. 8 May. http://www.renewableenergyworld.com/rea/news/article/2012/05/hollande-victory-signals-shift-in-frances-renewable-energy-policy
14. NuClear News (2012). No.43. August/September. http://www.no2nuclearpower.org.uk/nuclearnews/NuClearNewsNo43.pdf

Letters

Tidal reef

In response to the letter in *SGR Newsletter 40* by Andrew Ferguson, and the editorial reply, we at the Green World Trust are wholeheartedly in favour of optimising all of our renewable resources including those of sun and wind. However there is another source which can provide energy which is predictable, constant, reliable and would operate for at least 20 hours in every 24. I refer to the tidal energy available in the Severn Estuary, in particular to the harnessing of this energy by means of a 'reef' which would be sited between Minehead in Somerset and Lavernock Point in South Wales.

There is more information regarding this project on the Green World Trust website, see
http://www.greenworldtrust.org.uk/Energy/Tidal/ReefCompared.htm

William Acland, Chair, Green World Trust

Peak oil or climate change?

Mandy Meikle's article 'Why we must prepare for a low energy society' (*SGR Newsletter 40*) addresses the concerns of people who foresee the end of cheap fossil fuels and she rightly describes the ways in which we could manage with much lower energy consumption. However, the *BP Statistical Review of World Energy* published in June 2011 claims that proven reserves at the end of 2010 would be enough oil to last the next 46 years, if global production remain at the current rate. Long before the end of this time frame, all fossil fuel emissions of carbon will need to have been drastically reduced to prevent escalating climate change.

So the vital question is not how long fossil fuels will last but how soon will we begin to treat them as dangerous pollutants?

Dr Morris Bradley, Edinburgh

Technology and control

Bronislaw Szerszynski's article 'Emerging technologies and risk' (*SGR Newsletter 40*) reminded me of three propositions I advanced some time ago, while teaching Environmental Impact Assessment:

- The benefits and dis-benefits of any technology are symmetrical but they may manifest themselves at different levels of organisation and have to be managed so that the consequences do not fall disproportionately on one sector of society, economy or culture;
- Technology cannot negotiate absolute physical thresholds, and as these thresholds are approached the solutions have to be 'ethical' rather than technological;
- Technology may accelerate the rate at which we approach an 'absolute threshold' rather than ameliorate the basic problem.

They are essentially restatements of the Laws of Thermodynamics but as I listen to politicians and economists it seems that they are being encouraged in the belief that there will always be a timely technology to save them in the face of serious long term hazards. Over the years I have tried to refine the model to take account of accessibility, intensity and frequency and the distinctions between electronic technology and all preceding technologies, but the stark truth is that globalism is the creation of a technology that confuses information with knowledge and both with wisdom, which is a function of human control. The admission that actually this technology imposes an inhuman logic remains the issue, and makes us victims of an exogenous authority which we hardly understand let alone control and it makes the very term 'technology' a dubious and a dangerous term.

Bénédict Cowell, Builth Wells, Powys