Emergency planning after Fukushima: nuclear accidents during extreme regional emergencies

Jim Thomson outlines the challenges for emergency planning in the light of Fukushima

The Fukushima accident, following the earthquake that took place at 14:46 on 11 March 2011 and the subsequent tsunami, has brought into focus a difficult issue; namely, that nuclear power stations can become more vulnerable coincident with ongoing regional emergencies. This statement may with hindsight seem obvious, but nuclear civil emergency planning is generally based around an assumption that regional infrastructure and support arrangements remain more-or-less intact.

Fukushima has demonstrated clearly that regional emergencies and nuclear emergencies can have a common cause.

The Fukushima nuclear plants suffered from loss-of-grid and loss of diesel supplies, leading to core melts. However, many of the difficulties faced by Fukushima were compounded by poor off-site support and poor communications; this was of course due to the overwhelming nature of the damage in north-eastern Japan arising from the earthquake and tsunami, which was able to diminish – albeit temporarily and to a limited extent – the civil support arrangements even in such an advanced and highly organised country.

This article reviews the Fukushima experience, which has been the first major nuclear emergency to occur during a major regional emergency. There have also been much lesser incidents elsewhere, which perhaps show the challenges of dealing with nuclear emergencies during regional emergencies, and from which lessons might be learned. These include, for example, Hunterston B (severe storm, 1998), Blayais (flood and storm, 1999) and Fort Calhoun (flood, 2011). These will each be reviewed briefly.

This article follows on from the feature about the Fukushima accident and its consequences (see page 21).

Regional emergencies that might cause nuclear emergencies

What sort of regional emergencies might lead to (or occur coincident with) nuclear emergencies? If one 'thinks the unthinkable', a list of regional disasters with potential nuclear co-consequences could be as follows:

- war or terrorist attack
- earthquakes and tsunamis
- extreme weather and/or climate change: for example, extreme storms, flooding, blizzards, ice storms and prolonged drought (leading to wildfire and low river levels).

This list may not be exhaustive, and some items will be less relevant in certain countries.

Each of the above could, in extremis, lead to a situation where off-site support to a nuclear emergency was diminished, and could simultaneously be the cause of a nuclear emergency.

War or terrorist attack

Operating nuclear power plants have, at the time of writing, neither been involved in wars nor subject to any successful terrorist attack. All significant wars in the 'nuclear era' post-1945 have been in non-nuclear-power countries, and no terrorist threats affecting nuclear plants have yet been realised. This excludes the two attacks by Israeli forces on partially completed reactors in Iraq and Syria, which took place in 1981 and 2007 respectively; these apparently had no significant radiological impact.

'Total war' on the model of the world wars of the early 20th century has not thankfully been repeated; however, the prospect of a new total war, where nuclear power plants are regarded as legitimate targets, could lead to serious additional radiological impact (in addition to that arising from the presumed use of nuclear weapons).

It is possible to imagine terrorist attacks on nuclear plants as part of a coordinated programme of attacks, say in a similar fashion to those of 11 September 2001. A civil nuclear emergency, occurring at a time when government was incapacitated or regional communications were impaired, might lead to impoverished off-site support to the nuclear emergency.

(It is entirely likely that security services will already have thought through military scenarios as above but, as always, their deliberations will be secret unless or until their response is needed.)

Figure 1: *Fukushima Daiichi during the tsunami (TEPCO)*

Major earthquake and tsunami

Major earthquake/tsunami was of course the Fukushima scenario and is discussed further later.

Extreme weather

Extreme weather events, where the weather itself generates a regional emergency and simultaneously threatens the safety of a nuclear plant, are conceivable but seldom seem to be the subject of emergency planning. Some conceivable situations are as given below.

- Extreme storms can affect wide areas, causing infrastructure damage, housing damage, and loss of power and communications.
- Prolonged drought may cause a reduction in river levels to the point where reactor cooling is impaired. (This would obviously not affect plants using sea-water cooling.) Drought might coincide with wildfires that could threaten infrastructure in a wider area.
- River floods may affect wide areas, and damage infrastructure, communications and housing, and also threaten nuclear plant safety.
- Extreme blizzards or ice storms can also affect wide areas, and cause damage to infrastructure (including the electricity grid), damage communications and housing, and also potentially threaten nuclear plant safety.

Some of these situations have occurred to a degree already; a brief description of some incidents is given later.

A final section of this article will outline some potential effects of climate change that may, during the lifetimes of nuclear plants currently being planned, yield much greater likelihood of extreme weather events in some parts of the world.

Off-site emergency response at Fukushima Daiichi

The Japanese government's preliminary report on Fukushima [1] has provided an insight into the immense difficulties faced by the Japanese government in dealing with this natural catastrophe: there was a magnitude 9 earthquake, followed by a tsunami which inundated an area of 561km^2 (the worst tsunami since the Jogan tsunami of 869 AD), and numerous aftershocks of which five exceeded magnitude 7, all of which led to 475,000 damaged residential buildings, and a death toll approaching 30,000 – at the same time as dealing with the emerging nuclear accidents at Fukushima.

After the tsunami inundated the site, station staff faced a failure in power supplies, impassable roads, blackouts and poor communications, not to mention the problems caused by aftershocks, concern about their families and homes, and a keen awareness of the need to restore post-trip cooling as soon as possible (see [1] for further details).

Given the sheer scale of this catastrophe, it is perhaps not surprising that off-site support to the stricken Fukushima plant was less than perfect. What is more surprising, though, is how effective and successful the off-site response effort actually was. Both on- and off-site, people at all levels will have been in a state of shock; a disaster of immense proportions had struck their country.

The following paragraphs are extracts from [1] which illustrate the challenges that faced the off-site emergency response support team, and the successes they achieved despite the circumstances. As the report notes:

> *"Emergency response activities had to be performed in a situation where the earthquake and tsunami destroyed the social infrastructure such as electricity supply, communication and transportation systems across a wide area in the vicinity. The occurrence of aftershocks frequently impeded various accident response activities."*

A Nuclear Emergency Preparedness Centre was set up at 15:42 on 11 March, and at 19:03 the Prime Minister declared the nuclear emergency, and established the Nuclear Emergency Response Headquarters and also the Local Nuclear Emergency Response Headquarters (which was at the off-site centre some 5km west of the Fukushima Daiichi plants).

However, in addition to blackout due to the earthquake, all power sources were lost due to malfunctions of emergency power source and no communication tools were available at the off-site centre. Therefore, the head and other staff had to move temporarily to the neighbouring Environmental Radioactivity Monitoring Centre of Fukushima, where they used the satellite phone installed in the centre to secure

Thus, although some of the external communications via the world media may have been confusing, it does indeed appear that appropriate decisions regarding evacuation were taken promptly and implemented as effectively as reasonably possible. The Japanese external communication. (Power was restored to the off-site centre on 12 March.)

The Emergency Response Support System (ERSS), which monitors status of reactors and forecasts progress of the accident in a nuclear emergency, got errors in the data transmission function of the system right after the occurrence of the accident. Therefore, necessary information from the plant could not be obtained and the intended functions of the system could not be utilised.

The System for Prediction of Environmental Emergency Dose Information (SPEEDI), which quickly predicts atmospheric concentration of radioactive materials and radiation dose in the surrounding area in an emergency situation... could not at first conduct its primary functions to quantitatively forecast atmospheric concentration of radioactive materials and air dose rate because source term information through ERSS could not be obtained in this accident.

Meanwhile the head of the Local Headquarters directed the heads of relevant local governments to confirm the evacuation status, give publicity to local residents, prepare for potassium iodide and conduct emergency monitoring, screening and decontamination etc. as the activities at the off-site centre.

Plant information, ERSS, SPEEDI and others were still unavailable at the off-site centre for some period of time. Subsequently, with high radiation dose due to the progress of nuclear emergency and lack of fuel, food and other necessities due to congested transportation around the site, it became difficult for the Local Headquarters to continue effective operation at the off-site centre.

Alternative facilities are required to be prepared for such a case pursuant to the provisions of the Act on Special Measures Concerning Nuclear Emergency Preparedness. Minami-soma City Hall originally selected as an alternative location for the off-site centre was already used as a place for responding to the earthquake and tsunami disaster.

After rearranging an alternative facility for the off-site centre, the Local Headquarters was moved to Fukushima Prefectural Building on 15 March.

In Fukushima Prefecture, the prefectural government personnel got together during this accident and started conducting emergency monitoring activities together with relevant authorities. However, it was quite difficult for Fukushima Prefecture to implement sufficient environment monitoring activities because unexpected events occurred. For example, equipment and facilities of Fukushima Prefecture were damaged by the earthquake and tsunami and affected by blackout; the local government itself had to take disaster response to widely-spread damage by the earthquake and tsunami; and the Local Nuclear Emergency Response Headquarters was relocated from the off-site centre to Fukushima Prefectural office, as mentioned before.

The initial response to environment monitoring on the requests just after the earthquake was limited because relevant ministries and agencies which are responsible for implementing and supporting monitoring upon request as provided in the Basic Disaster Prevention Plan, were engaged in other disaster response measures such as searching for missing many people in the wide disaster area.

Notwithstanding the above difficulties, the authorities proceeded with some rapid and key decisions:

At 20:50 on 11 March, the Governor of Fukushima Prefecture instructed Okuma Town and Futaba Town to evacuate their residents and others within 2km radius from Fukushima Daiichi NPS.

At 21:23 on the same day the Director-General of the Nuclear Emergency Response Headquarters (Prime Minister) issued instruction to... evacuate the residents and others within 3km radius from Fukushima Daiichi NPS and order the residents and others within 10km radius from the NPS stay in-house...

At 05:44 on 12 March, the Director-General of the Nuclear Emergency Response Headquarters instructed residents within 10km from the NPS who were originally instructed to stay in-house to evacuate to outside of the evacuation area...

At 18:25 on the same day, responding to an explosion at Unit 1 of Fukushima Daiichi NPS and the related emergency measures etc., the Director-General of the Nuclear Emergency Response Headquarters issued a new instruction to the heads of relevant municipalities... This instruction is to evacuate the residents within 20km radius...

From 12 March onward, various incidents at multiple units occurred including explosions which appeared to have been caused by hydrogen at Units 1 and 3 on 12 and 14 March respectively, an explosion incident and smoke at Unit 2 and an explosion and a fire at Unit 4 on 15 March. At 11:00 on 15 March, the Director-General of the Nuclear Emergency Response Headquarters issued a new instruction to the heads of relevant local governments... The instruction is to order residents within radius between 20km and 30km from Fukushima Daiichi NPS to "stay in-house."

...the Nuclear Emergency Response Headquarters directly called... local governments. However, because communication services including telephone lines were heavily damaged by the great earthquake, not all the direct calls reached the relevant local governments. On the other hand, the police communicated the evacuation instruction to the local governments using police radio. Furthermore... they used police vehicles such as patrol cars to inform the public and guided the residents in the evacuation process. In order to promptly communicate the evacuation instructions, the Chief Cabinet Secretary held press conferences to announce the instructions immediately after they were issued and mass media such as television and radio were fully utilised.

authorities deserve praise for this.

Relevant lessons learned for emergency response are suggested in [1], while acknowledging their preliminary nature. The primary recommendations are (i) to strengthen earthquake and tsunami resistance and (ii) to make emergency electrical supplies more robust. In particular, the report notes that:

"Japan will secure a power supply at sites... through the diversification of power supply sources by preparing various emergency power supply sources such as air-cooled diesel

Table 1: *Fukushima – lessons learned relating to emergency response and safety infrastructure*

Finding	Text from report [1]
3-16	"...tremendous difficulty in communication and telecommunications..."
3-17	"...appropriate environmental monitoring was not possible immediately after the accident because the equipment and facilities for environmental monitoring owned by local governments were damaged by the earthquake and tsunami..."
3-18	"...responsibility and authority were not clearly defined in the relationship between the NERHQs Nuclear Emergency Response Headquarters and Local NERHQs Headquarters, between the government and TEPCO, between the Head Office of TEPCO and the NPS on site, or among the relevant organisations in the government."
3-19	"...information to residents in the surrounding area and local governments was not always provided in a timely manner."
3-20	"...no specific structure existed within the government to link such assistance offered by other countries to the domestic needs."
3-21	"...the System for Prediction of Environmental Emergency Dose Information (SPEEDI) could not make proper predictions on the effect of radioactive materials as originally designed, due to the lack of information on release sources."
3-22	"The size of the protected area defined after the accident was considerably larger than a 8 to 10 km radius from the NPS, which had been defined as the area where focused protection measures should be taken."
4-23	"...it was not clear where the primary responsibility lies in ensuring citizens' safety in an emergency."
4-24	"...various challenges have been identified regarding the establishment and reinforcement of legal structures on nuclear safety and nuclear emergency preparedness and response, and related criteria and guidelines. Also, based on the experiences of this nuclear accident, many issues will be identified as ones to be reflected in the standards and guidelines of the IAEA."
4-25	"...the Japanese government will enhance human resource development within the activities of nuclear operators and regulatory organisations along with focusing on nuclear safety education, nuclear emergency preparedness and response, crisis management and radiation medicine at educational organisations."
4-26	"Although multiplicity has been valued until now in order to ensure the reliability of safety systems, avoidance of common cause failures has not been carefully considered and independence and diversity have not been sufficiently secured."
4-27	"PSA has not always been effectively utilised in the overall reviewing processes or in risk reduction efforts at nuclear power plants. While a quantitative evaluation of risks of quite rare events such as a large-scale tsunami is difficult and may be associated with uncertainty even within PSA, Japan has not made sufficient efforts to improve the reliability of the assessments by explicitly identifying the uncertainty of these risks."

generators, gas turbine generators, etc., deploying power-supply vehicles and so on... as well as equipping switchboards, etc. with high environmental tolerance and generators for battery charging..."

This finding is key and applies to all situations where there may be coincident regional and nuclear emergencies; whatever the situation, if the nuclear site has secure electrical supplies, it is more likely to achieve safe removal of decay heat and minimise fault escalation.

Particular lessons learned relating to aspects of emergency response and safety infrastructure are summarised in Table 1.

Experiences from lesser incidents

A few nuclear incidents involving extreme weather have had the potential, if other things had gone wrong and/or the situation had escalated considerably, to pose a threat to core integrity.

Hunterston B, 1998, severe storm

Central Scotland was affected by a severe storm on 26–27 December 1998. Both reactors at Hunterston B power station were operating at full power when all off-site power connections were lost. The operators manually tripped both reactors at 00:22 on 27 December. Electrical power was supplied initially by auto-start of the emergency diesel generators. Off-site power connections were restored within a few hours, the reactor cooling functions were returned to normal power supplies, and the diesels generators were shut down.

The reactors remained shut down, but at 11:05 a second loss of off-site power supplies occurred. The diesel generators had been left on manual control, however, so there was a temporary station blackout (until the diesels were manually started), and cooling functions were lost for a short period.

Natural circulation was established on both reactors within about an hour, and forced circulation was returned in about 3 hours. Shortly after this the off-site power connections were restored and reactor cooling functions were again returned to normal.

The event was declared to be INES 2 on the International Nuclear Event Scale [2].

Of interest in the current context are the wider effects of the storm. As well as leading to loss of grid on two occasions (possibly due to salt spray on the HV conductors), the storm also affected communications. Many non-essential staff were on holiday; the mobile phone network was out of service for several hours during the event (which meant that phone calls to staff on holiday were difficult or impossible); some roads were blocked by fallen trees; and the houses of some station staff suffered damage [3].

Hence, although the storm damage did not create a regional emergency and the nuclear incident was relatively minor, the potential for escalation existed.

Blayais, 1999, flood and storm

Several buildings at the Blayais nuclear power plant, located north of Bordeaux on the Gironde estuary, were flooded on 27 December 1999, and an internal emergency was declared early on 28 December. Two units were down for inspection and repair of safety systems and concrete structures.

A combination of tide, storm surge and storm waves overtopped the coastal dyke around the plant causing flooding on site.

The waters of the Gironde were pushed by the winds over the protective dyke around Blayais, which houses four reactors. Units 2 and 4 were stopped in the evening of 27 December; unit 1 around 12:00 on 28 December; unit 3 was already shut for maintenance. Invading the site through underground service tunnels, the waters flooded the pumps of unit 1's Essential Service Water System (ESWS). This disabled the residual heat removal system. Shortly afterwards, the flood waters reached

Figure 2: *Fukushima Daiichi during the tsunami, taken from the radwaste building looking north. The car gives the scale of the inundation – at its highest level, the two storage tanks next to the car were completely submerged (TEPCO).*

Figure 3: *Fort Calhoun NPP, Nebraska, during the flood of June 2011.*

the spent fuel buildings for units 1 and 2, knocking out their safety inspection system and containment spray system. After the internal emergency was declared, fire-fighters from the nearby town of Blaye assisted Blayais' own flood-fighting team. On 30 December, the ESWS resumed operation and Blayais-4 was restarted.

The flooding event was originally rated at INES level 1, but on 29 December, it was uprated to level 2.

Northwestern Europe was battered by two large extra-tropical cyclones after Christmas 1999. With hurricane force wind speeds, 'Lothar' and 'Martin' tore through southern England, France, southern Germany, Switzerland, Austria, northern Italy and northern Spain. The storms caused over 140 casualties, 88 of whom were in France which bore the brunt of the two storms, and economic damage is estimated at €10 billion [4].

The Blayais event has some similarities to the Hunterston event (which occurred exactly one year previously). The scale of storm damage across France did create a regional emergency. Although the nuclear incident was relatively minor, there was the potential for escalation.

Fort Calhoun, 2011, flood

Fort Calhoun NPP in Nebraska, a 500MWe pressurised water reactor (PWR) operational since 1973, suffered severe flooding because of high levels in the Missouri river during the spring snow melt of 2011 (Figure 3). It appears that the river level rose in a manageable way, and there was time for appropriate precautions. These included reactor shutdown, and contingency actions including [5]:

- provision of back-up diesel generator;
- additional diesel fuel oil storage;
- additional make-up water storage;
- pumping facilities to remove barrier seepage; and
- elevated walkways, bridges and boats.

The flooding was triggered by record snowfall in the Rocky Mountains of Montana and Wyoming along with near-record spring rainfall in central and eastern Montana. All six major dams along the Missouri river released record amounts of water to prevent overflow, which led to flooding threatening several towns and cities along the river from Montana to Missouri – in particular Bismarck, North Dakota; Pierre, South Dakota; Dakota Dunes, South Dakota; South Sioux City, Nebraska; Sioux City, Iowa; Omaha, Nebraska; Kansas City, Missouri; and Jefferson City, Missouri – as well as putting countless smaller towns at risk. According to the US National Weather Service, in the second half of the month of May 2011, almost a year's worth of rain fell over the upper Missouri river basin. Extremely heavy rainfall in conjunction with an estimated 212 per cent of normal snowpack in the Rocky Mountains contributed to this flooding event [6].

The flood was not a short-term event; it lasted for three months from June through August as a result of regulation of the release of water through 850 miles (1,370km) of open river from Garrison Dam in North Dakota to the confluence with the Mississippi river at St Louis.

The difficulties at Fort Calhoun generated some adverse local media coverage, particularly as this happened during the ongoing recovery work at Fukushima.

Drought affecting nuclear plants

There have been instances of drought threatening the operation of nuclear plants due to restrictions on the availability of river cooling water. This has occurred in France and the USA, and probably elsewhere.

This is a situation that by definition will always develop slowly, and there should always be time to take the necessary action to shut down the plant and minimise cooling water needs.

Drought of course could also lead to wildfire in the land surrounding nuclear plants. Where such a risk exists, good management should ensure that a clear fire-break exists between the nuclear plant and any woodland or other vegetation.

(On a personal note, I have carried out project work at an oil refinery in a country with hot dry summers where such precautions were not taken; there were trees and long grass growing immediately next to a hazardous plant. Staff seemed unaware of any possible hazard.)

Hence, good management should always ensure that drought

– even if combined with wildfire – should not represent a nuclear safety threat.

Ice storms affecting nuclear plants

Ice storms can occur suddenly, and can bring down power lines and hence lead to loss of grid. In parts of the world these are quite common. The direct consequences for the nuclear plant should be no worse than a loss of grid, although they can cause regional failures in road, rail, air and telephone communications. Hence, again, these could lead to coincident nuclear and regional emergencies if there are any problems with post-trip cooling. In particular, ice storms can cause such extensive damage to power cables that nuclear power stations could conceivably be isolated from the grid for prolonged periods.

Canada is one country where ice storms are experienced on a regular basis. Bruce Power in Ontario has recently indicated that it will be enhancing its emergency exercises to ensure they are adequately prepared against ice storms [7].

Tsunami risk in the UK

Tsunami risk in the UK was reviewed in a DEFRA report of 2005 [8]. Tsunamis have occurred in the UK in the fairly recent past, in particular:

- The Storegga Slide event (a submarine landslide off the coast of Norway at about 64 degrees north) caused a tsunami in Britain about 7,250 years ago. This led to an 8m tsunami in Shetland, where the run-up was some 20m. Further south, the run-up was less: some 3–4m in northeast Scotland and about 1m in northeast England. The DEFRA report classifies such events as "probably the most significant tsunami threats for the UK".
- The most probable source of future tsunamis in the UK is an earthquake at the plate boundary off the southwest coast of Portugal. The great Lisbon earthquake of 1755 was probably about magnitude 8.5, and Lisbon itself was hit by a major tsunami where the wave heights were between 5m and 13m. The tsunami had significant effects in the Scilly Isles, Cornwall, Plymouth and South Wales. Its effects were also observed in the Caribbean and in Newfoundland.

Concern has been expressed about possible 'mega-tsunami' arising from landslides in the Canary Isles, and affecting the entire North Atlantic. The DEFRA report concludes that such events would be "likely to create tsunamis of only local concern".

> "If the nuclear site has secure electrical supplies, it is more likely to achieve safe removal of decay heat and minimise fault escalation."

Possible effects of climate change

The Stern review of the economics of climate change [9], among many findings, concluded that the most likely effect of climate change in the 21st century was that global temperatures are likely to rise by an average of about 4°C by 2099. This outcome included assumptions regarding ameliorating measures taken to limit greenhouse gas emissions, for which governments need to act soon.

It has been noted by many experts in this field that the precise implications of such a rise in global mean temperature are difficult to assess for any particular geographic region. The UK Meteorological Office and DECC [10,11] have nevertheless published forecasts showing local effects of climate change which suggest that southern and eastern Asia (in particular) may become unable to support their current large populations, due to extreme weather and reduced crop yields. In particular, a

reduction in rice yields of 30% in China, India, Bangladesh and Indonesia has been mooted.

Climate change of significant magnitude is therefore entirely credible – indeed, it is likely – within the 60 years or more lifetimes of nuclear plants that are currently in planning or construction. Hence, new nuclear plants will probably face significant changes in their ambient conditions during their operational lives; this will include the major nuclear programmes proposed by countries such as China, India and Russia in particular. (For example, China currently plans to have 100 nuclear plants in operation or in construction by 2030.) Temperature increases of around 5°C are indicated for China and India by 2099. Russia may see its mean temperature rise by 7 to 11°C.

There is a risk of sounding too 'apocalyptic' here. However, there are at least two big reasons why nuclear safety may be affected by these changes. First, the extreme weather arising from climate change could lead to food shortages and political instabilities, and even to war. Secondly, the changes may affect the safety of particular nuclear plants, for example by increasing flood or drought risk.

Conclusions

Fukushima has highlighted that nuclear emergencies may occur coincident with regional emergencies, and emergency planning needs to take this into account. Although tsunami risk may be lower in those parts of the world away from the Pacific basin, there have nevertheless been instances elsewhere of nuclear plants having safety incidents during other types of regional emergencies; the industry should learn from these experiences.

One clear priority from Fukushima seems to be that portable sources of power and fresh water should be readily available at regional (national or international) level to provide support for nuclear accidents in which post-trip cooling is threatened.

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