CABOT INSTITUTE
Living with global uncertainty

University of BRISTOL

Implications for the UK nuclear industry of the events at the Fukushima Dai-ichi nuclear power station, Japan: Major Issues

Initial Report produced by the Cabot Institute, Bristol University (www.bris.ac.uk/cabot)

P. Bates, W.P. Aspinall, K. Goda, T. Hincks, C.Peoples, D.J. Smith, R.S.J. Sparks, C. Taylor

Introduction

This note is a response to the request by Mike Weightman (HM Chief Inspector of Nuclear Installations, Head of ONR) for views of the implications for the UK of the events at the Fukushima Dai-ichi nuclear power station, Japan. The report draws on expertise in the Cabot Institute at the University of Bristol in the main pertinent topics and issues. This expertise includes seismic hazards assessment at nuclear facilities, seismology, earthquake engineering, geohazards, probabilistic hazards and risk assessment, extreme events and extensive experience of working in Japan on relevant issues. Following this initial interim report on major issues we will submit a main report, which explores some of the issues in more detail.

The events in Japan

A devastating earthquake with moment magnitude M_w9.0 struck the Tohoku and Kanto regions of Japan on 11th March 2011, causing tremendous casualties (estimated 25,000-30,000, including the missing), massive damage to structures and infrastructure, and huge economic losses. A consequent and on-going problem is the compromised safe operation of four reactors and other facilities at the Fukushima Daiichi Nuclear Power Plant (NPP), which has recently been declared a level 7 accident within the IAEA scheme. Releases of radiation into the atmosphere and ocean have caused major international concern. Also of relevance are the effects and damage that occurred at the Kashiwazaki-Kariwa nuclear power station in 2007 due to an earthquake where the ground acceleration at the plant exceeded the maximum expected value that informed the original design of the reactor by about a factor of 2, and reactors at that station remained closed for two years and more.

The latest earthquake was felt as a very intense tremor along coastal areas of the Tohoku and Kanto regions. In terms of peak ground acceleration (PGA) along the coast, measurements were in the range 500 cm/s^2 to 1000 cm/s^2, which might be close to or exceed typical seismic design load levels for many structures, although this does not mean that structures will necessarily fail. We have applied a ground motion prediction model that gives a preliminary estimate of 300 to 800 cm/s^2 as the range at the nuclear site (data from the site have not been made available or were lost). Disastrous damage was caused to many cities and towns by the ensuing giant tsunami. At several locations (e.g. Natori and Onagawa) tsunami heights exceeding 10 m were observed, overtopping engineered coastal defence measures. The tsunami overtopped tidal protection at the Fukushima Daiichi site, where the observed tsunami wave height was about 14 m, severing off-site electricity supplies and damaging on-site stand-by generation units. Consequently, power to the reactor buildings and crucial cooling systems was lost, triggering cascaded failures of the reactor control systems (both hard and soft).

General Implications

The Tohoku earthquake is the latest in a series of major disasters around the World. Other examples include the Banda Aceh earthquake and tsunami in 2004, Hurricane Katrina in 2005, the Iceland volcanic ash emergency in 2010 and Pakistan floods in 2010. They have in common the failure of appropriate analysis of known scientific knowledge to anticipate and prepare for extreme events, and also the failure to communicate this knowledge. Traditionally extreme natural events are classified as high magnitude or intensity events with low likelihood but high impact. The Japanese event was certainly an example of this. However, high impact events need not be very large or intense or indeed rare if they occur at the wrong place at the wrong time. "Extreme" is therefore used here not just to mean rare large magnitude or high intensity events but to also signify small events that have large impact. The Iceland ash emergency of April and May 2010 is an example of a modest sized and quite frequent kind of eruption on decadal timescales that took place when the wind was blowing in towards Europe producing circumstances that were exacerbated by the rapid very recent increase in air traffic. Climate change also may be changing the frequency of extreme hydrometeorological events while the World is becoming more vulnerable in all sorts of ways.

The recent events in Japan highlight the concern that extreme natural events are external hazards that could compromise the safety of nuclear facilities in the UK. While the UK is not located at a tectonic plate boundary where very large magnitude earthquakes occur, there are nonetheless intra-plate parts of the World where earthquakes exceed magnitude 6.5, and the possibility of such an event happening in the British Isles cannot be absolutely precluded. Several other natural hazards might affect nuclear facilities: these hazards include effects of volcanic eruptions, floods, storm surges, tsunamis, mass movements and electro-magnetic solar storms. For facilities with lifetimes typically of 50 years cognisance also needs to be taken of longer term effects that arise from global warming, coastal erosion and sea level rise, which might affect the frequency of extreme events and also affect the susceptibility of UK nuclear power facilities, which are mostly located at the coast.

A few examples illustrate that there are reasons not be complacent, partly in the light of new knowledge of natural hazards. The UK has experienced earthquakes up to nearly magnitude 6, including the Dover Straits Earthquake of 1580 and the 1931 Dogger Bank earthquake. As vividly illustrated by the New Zealand earthquake at Christchurch in February 2011, a quite modest earthquake directly under a site can cause great damage. For example an earthquake of magnitude 5.5 could cause similar peak ground accelerations in the UK as those experienced by the Fukushima plant, albeit of shorter duration. The UK can be affected by tsunamis although they are likely to be very low frequency. It is known that the huge Storegga submarine landslide in Norway at about 7000 years ago formed a major tsunami that inundated the east coast of the UK with estimated wave heights of up to 4 metres. One increasing concern is that warming of the Arctic might lead to increasing risk from large sub-marine landslides due to destabilisation of clathrates on continetal margins. If this is correct then tsunami risk could be on the increase. As an example we highlight here information on flood risk in the Bristol Channel area where there are two power plants and two new ones are being contemplated. In 1607 a devastating and sudden coastal flood, thought to be related to a storm surge, inundated over 500 km^2 of land around the Bristol Channel with an estimated 3000 deaths. Modelling by one of us (Bates) in the Cabot Institute on flood susceptibility of the Bristol Channel shows a marked increase in flood risk over the next few decades as a consequence of anticipated rising sea level. There is also the possibility of an increase in an extreme storms and precipitation in a warmer world, although no compelling evidence for this happening has yet emerged in the UK. Another issue is the resilience to electrical systems to an extreme magnetic storm like in this region such as the 1859 Carrington solar storm that likely represents a 1 in 100 year event.

A key issue to tackle is "chained" or "cascaded" hazards/risks, which, as very low probability events, have traditionally been treated as independent random events and hence have too low likelihood of coinciding together (e.g. simultaneous storm surge and a tsunami coinciding with high spring tide). There may be hidden dependencies, which are not always either obvious or intuitive, requiring careful analysis to tease out or recognise. Although these remarks are preliminary the evidence is emerging that the huge size of the giant tsunami in Japan may have resulted from two separate fault ruptures and massive earthquakes within a few tens of seconds. The uplift of the east coast of Tohoku by over a metre due to plate rebound was also not considered in the design of the Fukushima Power Plant.

Lessons with respect the safety of nuclear facilities in the UK

Here we list some key lessons.

1. The need for comprehensive analysis of the vulnerability of complex infrastructure systems that identify weaknesses. The events in Japan have significant implications for many complex infrastructure systems (anywhere in the world). The cascading effects and hidden dependencies must be taken into account in hazard and risk assessments.

2. It is no longer adequate to rely on deterministic assessments of hazards and risks from natural hazards. It has become clear that deterministic approaches informed the design of Japanese power stations and it appears that TEPCO (Tokyo Electric Power Company) were reluctant to apply probabilistic methods. Probabilistic approaches should now be regarded as mandatory, and application of rigorous, structured approaches to assessing risk are needed. Such assessments must include evaluation of all credible alternative models for natural processes rather than just adopting particular models that happens to be inherited views. In the UK context probabilistic approaches are widely accepted already in certain domains but there is some lack of consistency in applications. Also, our experience is that commonly far too few resources are put into carrying out thorough national risk assessments of all types and that, in nuclear matters, regulatory inertia has stood in the way of incorporating some well-based scientific advances into hazard and risk assessment approaches (e.g. in seismic hazard, sticking with a peak acceleration-anchored piece-wise linear spectrum representation of loading when less over-conservative but more rational uniform hazard spectra can be derived instead).

3. Imagine "unimaginable situations" and “expect the unexpected” are two very useful aphorisms to apply. The "coupled events" off Japan, producing a composite M9.0 earthquake rather than multiple M7.0-M8.0 events, were not considered as possible scenarios by TEPCO. In hindsight it is quite clear that the historical record of earthquakes in Tohoku is far too short to capture the magnitude-frequency relationship of a region where return periods of extreme events on active faults may be hundreds or even thousands of years, and that conventional

models do not capture the potential for non–Poissonian behaviour. In addition the very large section of the Pacific Plate, subducting at 10 cm/year, which had not had any major historic earthquake should have been obvious. The reality is more complex and uncertain that expected. This poses challenges to prepare scenarios that are within the bounds of existing scientific imagination but somehow beyond our current knowledge parameters, normal expectations and experience. To some extent, all infrastructure systems are subjected to this kind of uncertainty.

4. A rational deliberation of the potential consequences of really extreme scenarios should be "risk-informed", more than hazard estimate-based. Put another way: if the outcome of a particular event or cascade of events is so cataclysmic that it ought to be avoided whatever the cost then that risk consideration should trump arguments of diminishingly small or infinitesimal probabilities of occurrence.

5. Multi-hazards: in this specific case, damage due to ground shaking was manageable (or just about within expectations) but the tsunami was not. The framework of multi-hazards is necessary. It is also important to achieve comparable levels of accuracy in hazard/risk assessment across the range of phenomena. If uncertainty on one component dominates others, then the entire hazard/risk assessment becomes obscured. Understanding the cascading effects of natural events on human systems and infrastructure require both more rigorous and more imaginative approaches.

6. Assessments of risk should not just be about the physical effects but should explore all aspects of the possible impacts. Issues include how to anticipate human responses to low probability, high consequence and unprecedented events. For nuclear facilities accidents can be exacerbated by human factors and the effective response to accidents is influenced by how well prepared the emergency services are and the circumstances under which they operate. This is a complex area but evacuations, contamination of agricultural land and access of emergency services to make repairs and combat leaks are examples. It is easy to imagine that circumstances might have been even worse at Fukushima, for example if the wind carrying radiation had been onshore more of the time or the emergency services had been prevented from getting to the plant due to coincidence of extreme weather. The issue of how group-think develops in big organizations (like TEPCO or indeed banks) and how to improve decision-making to be better prepared is another example of a highly pertinent issue to address.

7. All of the above major issues are very challenging and in our view require radical changes in the way risks are assessed, how these risks are communicated, and how risk-informed decisions are made. In addition to lessons that need to be learned with regard to risk assessment, there are also clear challenges to reflect on in terms how these assessments of risk can be factored into decision making processes and governance structures, and communicated at a broader public level. We propose to outline the suggested way forward in our full report.

Biographies:

Professor Paul Bates is Director of the Cabot Institute at the University of Bristol. Since commencing his PhD in 1989 his primary research focus has been to improve the prediction of flood inundation. This has been achieved through the active development of new numerical models and better techniques for model calibration, validation and uncertainty analysis, with particular emphasis on the use of remotely sensed data. He has held Visiting Scientist positions at Princeton University, Dept. of Civil Engineering, Laboratoire National d'Hydraulique, Paris and the EU Joint Research Centre, Ispra, Italy. He also undertakes significant International collaboration, including work with the French National Space Agency (CNES), NASA Jet Propulsion Laboratory, Instituto Nacional de Pesquisas da Amazônia in Brazil, as well as numerous universities in the US and Europe

Professor Willy Aspinall is a consulting Chartered Scientist and Chartered Geologist, and Cabot Professor in Natural Hazards and Risk Science at Bristol University, with interests in probabilistic assessments of earthquake and volcanic hazards and risks, and the formalised use of expert judgement in decision-making in circumstances of scientific uncertainty. Aspinall is a Member of the Scientific Committee of the IAEA International Safety Centre, and participated in IAEA Missions to Japan following the 2007 Kashiwazaki-Kariwa NPP earthquake incident, and to the Metsamor NPP, Armenia. He is a member of the British Government Scientific Advisory Committees on Montserrat Volcanic Activity and on the Icelandic volcanic ash emergency, and sits on the Chief Scientific Adviser's Blackett Group concerned with low probability-high consequence national risks.

Dr Katsu Goda is a lecturer in Civil Engineering and a member of the Dynamics Research Group at the University of Bristol. He specialises in seismic risk assessment, infrastructure design and impact reduction.

Dr Thea Hincks is a research associate in the School of Earth Sciences, whose research interests focus predominantly on the numerical and statistical modelling of hazards, vulnerability and impact. She also works with Professor Aspinall in the use of expert systems for hazard evaluation and forecasting.

Dr Colomba Peoples is a lecturer in International Relations at the School of Sociology, Politics and International Studies, University of Bristol. He specialises in critical security and theory, and in particular how narratives of technological development are employed within nuclear security.

Professor David Smith is a Professor of Engineering Materials in the Department of Mechanical Engineering at the University of Bristol, a recipient of a Royal Society Wolfson Research Merit Award (2007-2012) and the founding Director of the Systems Performance Centre, which is a research alliance with EDF-Energy (was British Energy).

Professor Steve Sparks FRS is the Director of the Bristol Environmental Risk Research Centre (BRISK). He is a geologist with major interests in geohazards, volcanology and risk assessment methodologies. He has advised governments on volcanic emergencies, including the eruption on Montserrat and the Iceland ash. He is a member of the international tectonics advisory panel of the Nuclear Waste Management Organisation of Japan with regard to radioactive waste disposal sites. He sits on the advisory Panel for Research and Development for the Nuclear Decommissioning Agency.

Professor Colin Taylor is director of the Earthquake Engineering Research Centre and head of the Department of Civil Engineering at the University of Bristol. He specialises in the performance of complex infrastructure systems, with particular emphasis on managing natural hazard impacts. Professor Taylor is the Immediate past Chairman of the Institute of Civil Engineering South West and is a Member of the British Nuclear Energy Society.