Feature Article for EoS

Active Faults and Nuclear Power Plants

Following the Fukushima disaster, most of Japan's 50 nuclear power plants (NPPs) are closed down. After routine closures for planned maintenance outages, the government restricted the restart of plants until they could successfully pass "stress tests", which were subsequently replaced by new safety criteria, issued this July by the new Nuclear Regulatory Authority (NRA). Some restarts are blocked because the NRA is concerned about the proximity of NPPs to active faults. The NRA's definition of what constitutes an active fault and how it intends to apply new draft regulations on ground stability is critical here. Also at issue is the best way to deal with the hazards of low likelihood events in a society that, in the wake of the March 2011 Tohoku earthquake and tsunami, had a rude awakening with respect to its assessment of, and preparedness for, natural hazards. In this article, we explore the nature of this problem and how geoscientists and engineers are responding to what seems likely to be a ballooning problem in Japan, affecting the future of its major energy infrastructure. We look specifically at the case of the Tsuruga NPP on the eastern, Japan Sea coast of central Honshu.

Tsuruga is an historic port lying at the head of the large, sheltered anchorage of Tsuruga Bay. Two major nuclear complexes are located on the mountainous peninsula that forms the western side of the Bay. One of these, the Tsuruga NPP, has two reactor units, including the oldest functional nuclear power station in the country. They lie in a deep valley that extends southeastwards to form an embayment on the peninsula – Urasoko Bay (Figure 1). The eastern side of the valley and Urasoko Bay are the scarp slope of a major active fault – the Urasoko Fault, with a mapped length of about 10 km, but possibly extending further, south across Tsuruga Bay and northwards into the Japan Sea. The evidence suggests that this fault has moved repeatedly in the late Pleistocene, with a recurrence interval of about 4000 years. The foundations of both NPP reactors lie only about 200 m to the west of the fault. The Urasoko Fault was not considered to be active when the NPP was sited in the 1970s, but it has appeared on sequential updates of Japan's active fault map since 1991, as either 'active' or 'possibly active'. The impact on plant safety of the Urasoko fault was evaluated during the seismic re-evaluation (back check exercise) mandated by the then regulator, NISA, in the period from 2007-2010.

However, it is not the Urasoko Fault that has been causing problems over the last year for Japan Atomic Power Company (JAPC), the operators of Tsuruga NPP. An inspection by experts commissioned by the NRA concluded that a bedrock fault (the 'D-1 fault') that was already known to lie in the granitic rocks that lay directly beneath the base mat of the Unit 2 reactor might be connected to the Urasoko fault and might move in sympathy with it – and should consequently be defined as 'active'. According to NRA's regulations, an active fault beneath critical facilities means that they should not be operated. In fact, this type of criterion is intended to avoid such a situation arising when a new NPP is sited. Here, NRA was considering 'back-fitting' the regulation to an old facility, with Tsuruga now being only one of several NPPs and other nuclear facilities in Japan that are threatened with closure as a consequence: the Ohi, Higashidori, Mihama and Shika NPPs, together with the prototype Fast Breeder Reactor, Monju.

The definition of what is meant by 'active' thus becomes critical. The question also arises of what the appropriate response should be to ensure plant safety in the situation where nearby active faulting is found to occur – is it to close and vacate a site, or is it to assess the risk and consider how it could be mitigated, before taking a decision? JAPC and other NPP operators are currently struggling to avoid closure, with the decision hanging on the simple black and white criterion of whether an 'active' fault is present below their facility or not.

Many countries have definitions of 'active fault' that have been established for various civil engineering purposes and which vary significantly. Japan's NRA uses a definition based on palaeoseismological evidence of movement during the late Pleistocene – approximately the last 120,000-130,000 years. Where there is no evidence to determine whether movement has occurred or not over this period, investigators should look for evidence over the last 400,000 years. The meaning and application of the latter requirement with respect to the period judged to indicate activity has not yet been clarified.

Faced with the assertion by NRA's expert geoscientists that the D-1 fault should be defined as active, JAPC embarked on a major programme of trenching around the Tsuruga site to gather palaeoseismological evidence and determine whether it really was 'active' or not. The evaluation work was completed in mid-2013. JAPC spent the equivalent of several millions of USD in excavating deep trenches (Figure 1), some of which required massive support as they encroached on the scarp slope of the Urasoko fault and eventually exposed both it and several outcrops of the D-1 fault in the granitic basement formations. Work focussed on identifying the stratigraphy and characterising the chronology of the overlying Quaternary sediment layers – a mixture of terrestrial and marine margin sediments draped over the basement rocks. A total of nine layers were discovered and it was possible to get clear evidence of the periodic movement history of the Urasoko fault itself. The critical dating evidence has proved to be the ability to correlate tephra layers and distributed tephra phenocryst fragments in these layers. Regional tephra correlations with sediments from distal terrestrial, lake and marine boreholes was essential to understanding the movement history of the faults that had been found. Consequently much of the detailed argument developed by JAPC's scientific team has been based on geochemical similarities of tephra phenocrysts, palynology and a limited amount of 14-C dating.

The trenching work exposed more fault structures than were known about from the original foundation works of the NPP. The NRA experts considered that one of these, the K-fault, was also active and could extend beneath reactor Unit 2. The key evidence for the age of last movement of both the D and the K faults came from several deep exposures in the trenches that allowed plotting of the extent of upward fault penetration into the sediment layers. By seeing which layers had been penetrated and the geometry of the penetrations it was possible to conclude when the latest movement had occurred. For both features, it was clear that there was no evidence for movement in the last 120 – 130,000 years. Indeed, the D-1 fault, which had been known about since Unit 2 was under construction, appeared to be considerably older than this, and the K-fault was seen to trend towards a termination well before it approached Unit 2.

At the end of the investigations, an independent team of geoscientists assessed the evidence and concluded (1) that JAPC was correct in saying that there was no evidence of active structures below the reactor units. A recommendation was made to both JAPC and the NRA to open a constructive dialogue to consider how to build on the evidence and decide how best to manage decisions on the future of the Tsuruga site.

The independent experts were also very clear that the issue should not be a simple black-and-white, guilty or not-guilty, matter of whether features close to a NPP are 'active' or not. Certainly, for situations like Tsuruga, proximity to a known major active fault means that seismic hazard has to be taken very seriously. Indeed, all NPPs, including Tsuruga, undergo routine seismic hazard analysis to evaluate the impact of ground motion on structures, systems, and components (fragility analysis), with peak ground acceleration being used as the measure for classic probabilistic seismic hazard analysis (PSHA). This had been re-evaluated recently for Tsuruga as part of the national 'back check' exercise on NPPs, taking account not only of the Urasoko fault, but also of several other major active faults in the region. It is interesting to note that the international standard approach of probabilistic risk analysis, used almost universally for NPPs worldwide, is one of the very few areas where Japan's science and engineering community use probabilistic techniques and PSHA is the only part of PRA that is recognised by Japan's nuclear regulators.

However, the assertions that JAPC has had to counter concerning the presence of smaller faults in the vicinity suggest that the classical PSHA needs to be extended in circumstances where a facility lies so close to known active features. Given that every case is unlikely to be as clear-cut as Tsuruga and that, even there, and despite the findings on the D-1 and K-faults, it is possible that there might be secondary fault displacement in the damage zone of the Urasko fault during some future movement episodes, seismic hazard analysis could usefully be extended to include an assessment of the possibility of and impacts of fault displacement beneath the facilities. Even though the features mapped beneath Tsuruga appear inactive using NRA's definition, a probabilistic fault displacement hazard analysis (PFDHA) has been suggested to explore 'what if' scenarios where features like the D-1 fault do move, incorporating expert, evidence-based judgements on the likelihood of movement and possible magnitudes of displacement. Using information from combined fragility analyses and PFDHA, it will be possible to make sensible, risk-informed decisions about how to manage those of Japan's nuclear power facilities that are currently under threat of permanent closure owing to supposed active fault issues.

Neil Chapman (MCM Switzerland), Kelvin Berryman (GNS Science, New Zealand), Woody Epstein (Lloyd's Register, Japan) and Hideki Kawamura (Obayashi Corporation, Japan).

Contact: neil.chapman@mcm-international.ch

Reference

(1) 'International Review of the 2nd JAPC Report (July 2013) on Fracturing at the Tsuruga Nuclear Power Plant': http://www.japc.co.jp/english/index.html

Figure 1: The Tsuruga NPP, looking to the north-west, with Urasoko Bay in the foreground and the Japan Sea in the background. The upthrown side of the active Urasoko Fault forms the prominent scarp to the right of the complex and the yellow-brown excavation to the top-right of the picture indicates the scale of one of the trenches used to expose the Urasoko fault and the 'D-1' and 'K' faults. The No. 2 reactor, under which the 'D-1' fault passes, is the large, octagonal building to the left-centre of the site.