Brief Note on

Possibility of Pre-Tsunami Seismic Damage at Fukushima Daiichi

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POSSIBILITY OF PRE-TSUNAMI SEISMIC DAMAGE AT FUKUSHIMA DAIICHI

Preliminary assessment reports on the ongoing incident at the Fukushima Daiichi nuclear power complex have now been published by the Japanese Government and the International Atomic Energy Agency (IAEA), and both reports have been discussed at the IAEA Ministerial Conference on Nuclear Safety Conference in Vienna on 20 June 2011.

IAEA MINISTERIAL DECLARATION

The outcome of the closed session conference is given in the 25-Point [§] Ministerial Declaration (INFCIRC/821) which, although acknowledging the *'serious consequences'* and calling for a strengthening of global nuclear safety standards, leaves the root causes of Fukushima incident very much unexplored. In their joint declaration Ministers accept that the investigation and reporting to date has been provisional and preliminary [§10], going on to stress the need for the IAEA and Japan to *'prepare a comprehensive and fully transparent assessment'* [§11], including the role of *multiple severe hazards* relevant the incident, with the Ministers also encouraging those States presently operating nuclear power plants (NPPs) to undertake *'comprehensive risk and safety assessments . . . in a transparent manner'* [§13] and, finally, the Declaration calls upon the IAEA Director General to prepare a Report and Action Plan [§23], and for this report to be presented *'covering all relevant aspects relating to nuclear safety'* [§23] to the IAEA Board of Governors during their meetings of 2011.

Even though the IAEA timescale of action within 2011 endorses the urgency that the Agency places on nuclear safety for NPPs worldwide, there are two nuclear safety issues that should be addressed immediately: These are i) the resilience of the present generation of NPPs worldwide to withstand the levels of seismic loading considered to be credible, and ii) the abnormal performance of the Zircaloy clad fuel system adopted almost universally by light water reactors (both pressurized water reactors PWR and boiling water reactors – BWR).

This brief review considers just i) the possibility of seismic damage to key nuclear safety systems and containments prior to the tsunami strike at Fukushima Daiichi, and how this might apply to nuclear safety of similar PWR and BWR NPPs worldwide.

i) SEISMIC PERFORMANCE OF THE FUKUSHIMA DAIICHI BWR NPPS

Worldwide, around 20% of all NPPs are sited in regions of significant seismic activity. The IAEA publishes several safety guides and technical documents on seismic design for NPPs, including NS-G-1.6 which requires the '. . . *seismic design of the plant shall provide for a sufficient safety margin to protect against seismic events* (para 5.22). The acceptable (ie credible) frequency of seismic events is usually defined on a probabilistic basis, such as that outlined by IAEA TECDOC-724 that recommends a Probabilistic Seismic Hazard Assessment (PSHA) to be undertaken when qualifying the NPP seismic design.

JAPANESE NPP REGULATORY COMPLIANCE FOR SEISMIC QUALIFICATION

Because of the frequency and magnitude of earthquakes in Japan, particular regard is given to seismic issues in the siting, design and construction of Japanese NPPs, with the plant structures and equipment (pipework, etc) required to tolerate specified earthquake intensities drawn from and evident in past ground motion experienced at the site or in the general geographical region.

Japan revised the regulatory guidance for qualifying the seismic design of existing NPPs, including the six NPPs at Fukushima Daiichi, in September 2006. For Fukushima Daiichi the seismic case upgrade (DBGM)[1] was completed in about March 2008 with the six reactor plants being, so claimed by the operator the Tokyo Electric Power Company (TEPCO), capable of tolerating earthquakes generating a horizontal force (Ss) ranging between 441 to 489 GAL (an acceleration in cm/sec^2 or ~0.5g).[2]

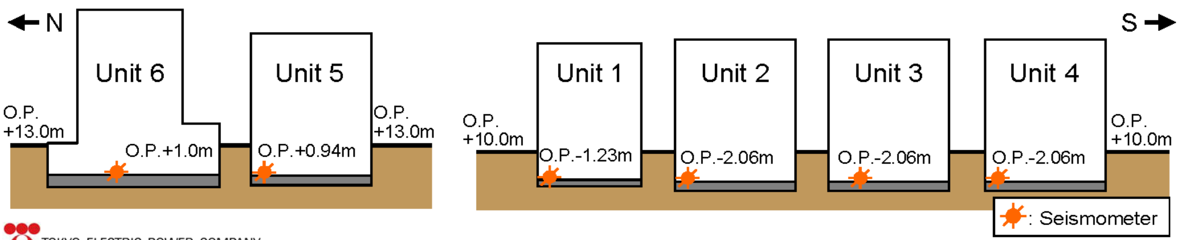
SEISMIC DATA AT FUKUSHIMA DAIICHI FOR THE EARTHQUAKE OF 11 MARCH 2011

In fact, as part of the automatic shutdown or SCRAM system, each Fukushima Daiichi NPP was fitted with accelerometer (seismometer) transducers to measure and record the seismic acceleration magnitude. For the magnitude (M_w) 9.0 earthquake of 11 March 2011, the seismic loadings recorded were as follows:

Records of Observations at Base-mat Slab of Reactor Building at Fukushima Daiichi NPS

	Maximum acceleration value from observation records (Gal)			Maximum response acceleration value (Gal): New design-basis seismic ground motion Ss			Maximum response acceleration value (Gal): Original design-basis seismic ground motion		Static horizontal acceleration (Gal)
	NS	EW	UD	NS	EW	UD	NS	EW	
Unit 1	460	447	258	487	489	412	245		470
Unit 2	348	[550]	302	441	438	420	250		
Unit 3	322	[507]	231	449	441	429	291	275	
Unit 4	281	319	200	447	445	422	291	283	
Unit 5	311	[548]	256	452	452	427	294	255	
Unit 6	298	444	244	445	448	415	495	500	

* ☐ indicates the observed value was beyond the response of Ss, the others were under the response of Ss.

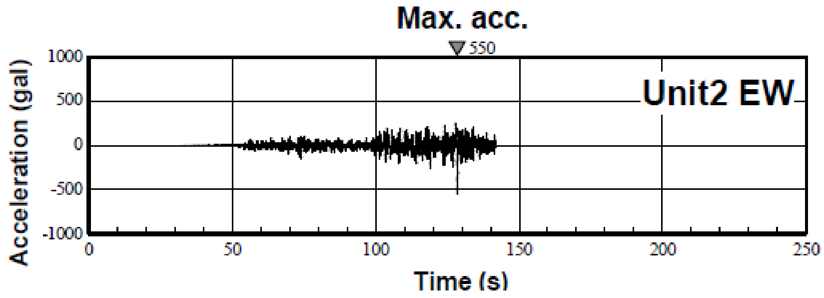


TOKYO ELECTRIC POWER COMPANY

 1

1 DBGM – *Design Basis Earthquake Ground Motion* or *Ss* – this 2008 revision of the Japanese regulatory guide uses the actual maximum ground motion anticipated for the NPP site (Ss) and classifies the NPP component parts in terms of safety function of the most important 'S Class' which includes RPV coolant boundary, spent fuel storage, emergency coolant make-up, with less critical systems or secondary safety component parts relegated to class 'B', including radioactive waste facilities, and class 'C' which, surprisingly includes diesel generators, etc.. This compares with the previous seismic code where each NPP site was defined in terms of two separate seismic intensities S1 and S2, with S2 being the 'maximum design earthquake' and S2 being the 'extreme design earthquake' deriving from knowledge of the local-regional seismo-tectonic faults.

2 The force deriving from the induced acceleration follows the relationship $F=Ma$ where the mass of the structure or equipment is M and a the induced acceleration – suspended and elastically supported masses (for example pipework) might be expected to respond more in more complex ways, particularly if the duration of the earthquake is prolonged (as for 11 March 2011).



UNIT 2 ACCELEROMETER RECORD OF THE 11 MARCH 2011 EARTHQUAKE - TEPCO

Of interest in the above tabulation are comparisons between the actual horizontal accelerations (NS and EW - 1st group in RED) recorded on 11 March 2011 to, first, the revised seismic qualification of 2008 (Ss mid columns) and, second, the original seismic design basis (right-hand columns). On 11 March, NPP Units 2, 3 and 5 were each subject to maximum accelerations that exceeded the 2008 seismic qualification (Ss) by about 20%,[3] although the exceedance is much greater (up to x2.2) the original design basis for horizontal ground motion.

So, obviously, the 11 March earthquake local effects at Fukushima Daiichi were greater than the 2008 seismic assessment of the Fukushima Daiichi site, meaning that the TEPCO 2008 requalification grossly underestimated to the potential seismic forces nominated for the Fukushima Daiichi site (the Ss value). In fact, it is not at all clear as to the extent and nature of physical work and plant modification that was actually undertaken by TEPCO for the 2008 seismic qualification upgrade – the IAEA fact finding mission of May-June 2011 clearly states that *'only some upgrading on piping supports was performed'* and that *'no detailed information was provided [by TEPCO or NISA] regarding the physical upgrades [that were] effectively executed'* (IAEA – p 70).

It is also interesting to note that the post-incident assessment of the remaining (post 11 March) seismic capability[4] of the Fukushima Daiichi NPPs and associated buildings and plant submitted by TEPCO to the nuclear safety regulator NISA,[5] only related to the building structures and not the nuclear plant and equipment housed within. That said, in a later press release (17 June) TEPCO referred to the seismic analysis of *'reactor building, facilities and pipes important to earthquake safety'* for all six NPP Units, although this claimed to be of much greater detail of analysis and assessment it has not been made publicly available. In fact, NISA considered that it is

> "... *extremely important to evaluate the impacts from the earthquake on reactor buildings, turbine buildings, and major facilities and pipes from earthquake resistance perspective in Fukushima Daiichi and Daini nuclear power station in order to confirm the status of safety function of those facilities at the time of earthquake and following period. . . ."*

3 NISA report a greater exceedance, *'being evaluation of basic earthquake ground motion Ss in most periods, however, spectra collected in Unit 2, 3, and 5 exceeded spectra for evaluation by 30% at maximum during 0.2 to 0.3 seconds'* .

4 Summary *'Reports About the Study Regarding Current Seismic Safety and Reinforcement of Reactor Buildings at Fukushima Daiichi'*. TEPCO, 28 may 2011.

5 NISA – Nuclear and Industrial Safety Agency – effectively the Japanese nuclear safety regulator.

SUGGESTIONS OF SEISMIC DAMAGE AT FUKUSHIMA DAIICHI

The 'official' line seems to be that there was no apparent seismic damage sustained as a direct result of the seismic activity (that is set apart from damage from the following tsunami strike).

The IAEA fact finding team report does not, albeit noting some caution about the information provided by TEPCO/NISA, depart from this, in that (pp 71-72)

"...

1. *Although it appears that the Great East Japan earthquake exceeded the licensing based design basis ground motion . . . in all units, . . . the operating plants were automatically shutdown and all plants behaved in a safe manner, during and immediately after the earthquake. . . . in some cases the observed values even exceeded the recently determined maximum response acceleration values showing apparently an underestimation of the new DBGM Ss.*
2. *It was also reported that the three fundamental safety functions of (a) reactivity control, (b) removal of heat from the core and (c) confinement of radioactive materials were available until the tsunami reached the sites.*
3. *Based on the reports from Japanese experts and plant personnel, safety related structures, systems and components of the plant seemed to have behaved well for such a strong extreme earthquake, possibly due to conservatisms introduced at different stages of the design process. . . ."*

my truncation . . . throughout

Concluding on the seismic damage (again excluding the tsunami-invoked damage), the IAEA notes

"...

Although the need to consider prehistorical and historical data is well established in the international safety requirements for assessing the natural hazards at nuclear installations, this has not been followed especially in older nuclear power plants. . . . There is a need for Member States regulations to reflect these considerations both for the new build as well as for re-evaluation of existing NPPs. . . ."

and, with this, the IAEA thereby acknowledges that the seismic qualification of existing NPPs worldwide requires to be reassessed.

Possible damage directly attributable to the seismic loading has to be deduced by inference from the TEPCO/NISA press releases, for example:

1) **Intake Channel of Unit 3 Outflow**

The high levels of radioactivity in water flowing from the fracturing of the Unit 3 condenser outflow channel required in situ and somewhat expedient repairs to the reinforced concrete outflow pit which was badly fractured – this fracturing damage (possibly also extant in other sections of the outflow tunnels and subterranean drains and services ducts to all Units) most likely arose from seismic loading.

2) **Off- and On-Site Electricity Distribution and Switchgear Damage**

Multiple failures occurred to electricity power and distribution systems both on- and off-site prior to the tsunami strike - certain of the seismic physically damaged and failed on-site equipment was DGBM highest safety Class S. The key element is the loss of off-site electricity supplies was the toppling of several electricity line pylons nearby the Fukushima Daiichi site prior to the arrival of the tsunami.

3) **RPV Water Levels and Core Cooling Water Injection**

Cooling water injection was underway on 11 March but the RPV water levels in Units 1 and 2 but by 23:00 hours the radiation levels in the associated turbine buildings were rising rapidly, suggesting a serious breach of the reactor coolant circuit pipework located within each turbine building. Other than basement flooding because of the tsunami swamping, the higher level reactor connected circuit should not have been affected by the tsunami so, possibly, the reactor pipework breach was caused by seismic loading.

Since the reactor building explosion did not occur until 15:36 JST on the following day (12 March) hydrogen deflagration could not have contributed to the coolant leak into the turbine building.

4) **Main Steam Isolation Valve (MSIV)**

The MSIV serves to isolate the main steam pipework connection between the reactor and the high pressure steam turbine chest, being located beyond the reactor primary containment in the turbine hall.

Immediately following the earthquake shock waves (14:40 JST), at 14:47 JST a failsafe signal was generated to close the MSIV which was actioned on standby battery power.[6, 7] Closure of the MSIV is outside the normal SCRAM sequence and, arguably, the downstream pipework could have been damaged and steam leaking thereby prompting the steam line closure signal.[8]

5) **Injection Water Losses**

Again for Unit 1, although possibly applicable to the Units 2 and 3, the thermodynamic balance suggests that not the entire amount of injection water was generated into steam by dissipation of the decaying fuel core heat.

6 *'Analysis and Evaluation of the Operation Record and Accident Record of Fukushima Daiichi Nuclear Power Station at the time of the Tohoku-Chihou-Taiheiyou-Oki-Earthquake (Summary)'*, TEPCO, 23 May 2011

7 This potential fault was also noted for Units 2 and 3 - since there was no noted increase in steam flow TEPCO assumed that it was a common instrument malfunction across all three Units.

8 Since the increase in the main steam flow volume that would be measured if the main steam piping was broken, was not confirmed in the *Past Event Records Device*, TEPCO judged that there were no breaks in the main steam. The shutoff of the MSIV increased the RPV pressure, and at 14:52 the isolation condenser (IC) automatically started up but then, at 15:03, the IC was manually shut down. This was, according to TEPCO, because RPV head temperature should be adjusted to not exceed 55°C/h. Moreover, the reactor pressure varied three times between 15:10 and 15:30, and TEPCO performed manual operations using only the A-system of the IC – throughout this period the fuel core was undergoing complete melt down

For example, TEPCO reports that by 31 May the Unit 1 RPV received 13,700 tonnes of injection water (fed directly into a closed RPV connected feedwater line) but that the total amount of steam generated was approximately 5,100 tonnes. This disparity, even in account of the RPV capacity of about 350 tonnes, suggests that not only leakage of generated steam but also liquid leakage occurred (and possibly continues to occur). A potential leakage path of the injected cooling water, in addition to any top and/or bottom failure of the RPV (from which steam leakage would be throttled), is the connecting reactor circuit pipework (feedwater and steam) routed through to the turbine hall – this might explain the high radiation levels in certain of the turbine hall spaces of Unit 1 (which spiked at around 23:00 JST 11 March before the Unit 1 explosion of 15:36 JST 12 March, which itself may have further damaged the reactor cooling circuit pipework).

OBSERVATIONS AND COMMENTS

From this brief review:

- Reporting of alleged earthquake damage has been largely by press and media[9] often relying upon unidentified and not infrequently somewhat anecdotal sources. Nevertheless, the allegations are that before the tsunami strike certain of the reactor boundary (ie pipework, etc) failed, that pressure and water level performance in the RPV were inconsistent with the close down situation for an intact RPV circuit, and that at least one radiation alarm sounded on the Fukushima Daiichi site.
- On its part TEPCO, often with the endorsement of NISA, has never acknowledged even the possibility that some pre-tsunami physical damage could have occurred. Where alarms and fault conditions have been triggered, TEPCO has perhaps all too readily dismissed these to be instrumentation malfunctions, and/or where questions have been raised by a number of authoritative individuals[10] TEPCO has neither participated nor responded.
- Overall, the management and presentation of seismic information by TEPCO, might be considered to over-managed if not be somewhat contrived.
- Certain circumstances and actions of TEPO strongly suggest that a degree of seismic load induced damaged occurred to critical nuclear safety systems prior to the arrival of the tsunami – an illustration of this might be the early intervention action taken by TEPCO on the isolation condenser cooling of Unit 1 reactor.
- In its final report the IAEA fact finding mission team seem to guardedly step around the issue of seismic damage, although it infers that the 2008 seismic requalification undertaken by TEPCO may have been little more than a paper exercise that *'underestimated'* the potential seismic forces for the Fukushima Daiichi site.
- Surprising, therefore, that the IAEA chose not to further investigate and report on the possibility of seismic damage in any detail although, that said, the IAEA team strongly concludes that existing NPPs worldwide should be seismically re-evaluated.

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9 Eg *Fukushima May Have Leaked Radiation Before Tsunami*, Bloomberg, 19 May 2011 – *Earthquake, not Tsunami, may have damaged N^o 3 Reactor*, Asahi. 26 May 2011 – *TEPCO concealed radiation data before explosion at No 3 reactor*, Asahi 14 May 2011.

10 Eg Keiji Miyazaki, professor emeritus of nuclear reactor engineering at Osaka University, who raised the issue the failure of the emergency core cooling system (ECCS) being in train before the tsunami strike.

- In light of the Fukushima Daiichi incident, the Ministers attending the IAEA June Nuclear Safety Conference urged individual nuclear power States to undertake *'comprehensive risk and safety assessments'* and that the IAEA Director General prepare a Report and Action Plan *'covering all relevant aspects relating to nuclear safety'* within the current year 2011.

Clearly, there is some doubt about the seismic performance of the Fukushima Daiichi NPPs. Unless this doubt is adequately addressed and dismissed, and TEPCO certainly has not done so, questions must remain about the reliability of DSGB methodology in determining and adopting specific maximum seismic loadings on a site by site basis. In effect, the IAEA recommendation for the *'need'* that all existing NPPs worldwide be *'re-evaluated'* clearly indicates that this doubt remains unresolved.

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