Greenpeace protest the arrival of AREVA plutonium MOX fuel at Fukushima-daiichi, Japan, September 1999 © Greenpeace / MacColl

UPDATE ON THE NUCLEAR AND RADIOLOGICAL SITUATION AT FUKUSHIMA DAI-ICHI

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UPDATE - NUCLEAR AND RADIOLOGICAL SITUATION AT FUKUSHIMA DAI-ICHI

SUMMARY

This brief review collates and updates the two previously issued Large & Associates reports R3196-A1 and R3197-A1. In particular, evaluation is made of the detail and extent of the information released by the plant operator, the Tokyo Electric Power Company (TEPCO), about the plant stability and condition from the onset of the incident to the most recent revelation of 15 May 2011 when, for the first time, TEPCO acknowledged that the Unit 1 reactor fuel core had completely melted.

The nuclear and radiological situations at the plant at Fukushima Dai-ichi continue to be severe. Subject to earthquake and struck by the following tsunami, successive explosions occurred at each of the three operational boiling water reactors and a fourth reactor block, although not in operation at the time, was severely damaged by hydrogen explosion. There have occurred significant radiological releases to atmospheric and marine environments, although the magnitudes of these respective releases has been poorly chronicled and, relating to the overhead plumes and ground deposition in the region of Fukushima Prefecture, the results of the comprehensive, real time radiation monitoring system SPEEDI have not been forthcoming. Realisation of a worsening situation eventually led to the Japanese Government revising its assessment of the incident severity from the International Nuclear Incident Scale (INES) of Level 4 to 5 and, eventually, the worse case Level 7 on 11 April 2011, that is one month following the *Tohoku-Taiheiyou-Oki* earthquake-tsunami that triggered the incident.

In the weeks following the start of the incident, it seems that TEPCO failed to move from the initial and very demanding *firefighting* role to that of wresting control of the situation by implementing and moving ahead with mitigation measures. In the ensuing weeks, it became apparent that TEPCO's assessment of the structural damage of the reactor buildings, including the spent fuel ponds, was unrealistically optimistic. This was particularly in respect to the damage to the drainage sumps, trenches and basement areas of the adjacent turbine buildings which continued to fill with and yield forth very substantial quantities of highly radioactive water, so much so that considerable resources have had to be deployed to adapt existing and provide for new contaminated water storage, even so, very large quantities (tens of thousands of tonnes) both leaked and had to be intentionally discharged directly into marine environment.

Even though the mounting evidence, much of it anecdotal, strongly suggested a direct pathway between the nuclear fuel of at least one reactor (Unit 2) and the contaminated water, TEPCO continued to claim that the all three reactor pressure vessels (RPVs) remained intact and that only the higher regions (~1.5m) of the nuclear fuel were exposed. The reasoning proffered was that the jury-rigged water injection into the RPVs was at sufficient rate to maintain the RPVs partially filled, thus capable of dissipating the decay fuel core heat and stabilising the situation from progressing to more fuel damage. Indeed, such was the confidence in this assessment of the situation that the nuclear safety regulator, NISA, continued to publish daily updates on the in-RPV conditions (temperature, pressure, etc) suggesting to greater extent that the partially fuel core situation had stabilised and was being maintained.

Moreover, such was TEPCO/NISA's confidence in what must have been their joint assessment of the situation that, predicated on this, TEPCO announced a scheme whereby the reactor primary containment (PC) of Unit 1 was to be flooded to a level coinciding with the top of the RPV fuel bundle. The flooded primary containment would, so claimed TEPCO, provide a greater thermal mass of cooling water and surface area through which to dissipate the fuel decay heat. This scheme introduced a number of new risks, although these were not identified or followed through in TEPCO's somewhat flimsy 4 page justification summary released into the public domain (5 May):

First, the proposal to continue water coolant injection into the RPV thence flowing into the PC wetwell via the RPV pressure relief line, effectively reduced the number of barriers between the damaged fuel and the environment (from two barriers of RPV+PC to PC alone). Second, up until that time, because of the high radiation environment (particularly in the ground and basement levels of the Turbine Hall) access to inspect the structure of the Unit 1 reactor block had been denied so, it was not possible to realistically assess the capability to structurally contain the 7,400 tonnes of water to be pumped into the

PC, a structural role for which the 40 year plus aged structure was never designed, particularly if it was at risk of future seismic events whilst continuing in this flooded role. Third and possibly the greatest risk, was if the damage severity of the fuel core was not as benign and stable as that assessed by TEPCO and reported by NISA, particularly if the fuel core had melted and slumped into the bottom of the RPV from which it could, quite possibly, violently eject from the RPV down into the progressively flooding PC water – a nightmare scenario capable of generating a molten metal-water explosion quite capable of utterly destroying the PC and the surrounding Unit 1 block.

However, upon gaining access to Unit 1 TEPCO reported much higher levels of radiation, particularly within the areas to which prolonged working was required to jury-rig the diversion flows into the PC and, interestingly, it reported that the structural damage to the building and reactor services pipe work was much more severe than previously estimated. Following this revelation, TEPCO abandoned the plan to flood the PC of Unit 1.

Interestingly, TEPCO gave no assessment publicly of whether the structural damage arose from the pre-tsunami earthquake and/or for the hydrogen explosion that was sourced in the upper charge hall of the reactor block of Unit 1. Similarly, the assessments of the structural surety of the built structures on the Fukushima Dai-ichi site, as earlier ordered by NISA, have not been to date released into the public domain.

The most recent development at Fukushima Dai-ichi relates to knowledge about the condition of the fuel core of Unit 1. For this TEPCO has made publicly available instrumentation records that relate the RPV water levels and fuel temperatures during the first few hours following the arrival of the tsunami. However, the data now released is in stark contrast to the previous and daily updates that have shown, generally, a consistence and stable fuel core situation throughout the incident aftermath (about two-thirds under water, a managed and tolerable temperature regime and limited physical damage).

This newly released hard data reveals that the fuel core was completely uncovered of coolant within 3 hours and that the RPV was virtually empty of coolant within 12 hours of the tsunami striking, or about 14m below the top of the fuel bundle – FIGURE 2 - this contradicts the NISA daily updates that consistently show the RPV water level ~1.5m below the top of the fuel bundle. From this data alone, TEPCO could only have concluded that the Unit 1 RPV was damaged and leaking from the lower region, to the extent that the make-up water injection rates being deployed from about 12 hours into the incident were unable to fill and maintain coolant levels.

Similarly, whereas the NISA daily update reports featured only the RPV shell temperatures, it must have known that these temperatures were not at all indicative thermal events occurring inside the RPV. This is because the newly released data shows the fuel pellet temperatures - FIGURE 1 - initially dropped from the normal operating temperature of about 800 to 900°C to ~300°C as the earthquake invoked reactor SCRAM actioned but, thereafter, following the tsunami strike, a dwell whilst it is assumed the electrical power independent steam turbine driven pump (and, possibly, the isolation condenser) continued to engage cooling for about 1 to 2 hours. At this point in time, the fuel temperature soared to melt and then boiling levels (~2,800°C) within two hours with, physically, the fuel corium mass slumping and passing down through the fuel core support plate into the bottom of the RPV. During the early phases of 1 to 2 hours of melting, RPV steam temperatures would have been sufficiently high to provoke a Zircaloy-steam exothermic reaction, adding heat to the corium forming mix and liberating high volumes of hydrogen (that subsequently exploded at about +24 hours into the incident), and melting the boron alloy control cruciform plates triggering neutron activity within the corium.

As presented by TEPCO, for Unit 1 the full melt down of the fuel core, breach of the bottom of the RPV with some or all of the corium ejected onto the drywell floor, could result (or has already resulted) in further pressurisation of the PC space as non-condensable gases are generated by corium-concrete interactions, leading to further release of radioactivity into the environment until the corium has sufficiently cooled – this drywell corium-concrete reaction might continue further for weeks or months. For Units 2 and 3 the fuel core and radiological situations are more uncertain: the ground-level PC structure of Unit 2, and possibly Unit 3, is believed to be damaged and, judging from the high levels of contamination of the drain and sump waters, partially flooded. Fuel corium ejection into the PC runs the risk of molten metal-water explosion capable of severely damaging the PC and surrounding structure but, even in the absence of such a devastating event, direct exposure of the corium mass (which derives from the significantly large fuel cores of Units 2 and 3) to the groundwater will prove an effective pathway to the marine environment.

More surprising, therefore, that, with the sanction of NISA, TEPCO proceeded to implement its 'cold shutdown' plan for which it was absolutely essential that the lower portion of the RPV not to be at risk of a corium melt through (ejection) when it knew that the fuel core had already melted and slumped down to the bottom head of the RPV – FIGURE 3. The options available to TEPCO were clear: either flood the PC (Wet option) and take the chance that the corium would not eject through the RPV bottom head whilst the flooding level was raised to immerse the RPV – a period of about 3 to 4 weeks – or pump the PC dry (Dry option) and let the corium mass run its natural course, possibly ejecting out of the RPV onto the PC drywell floor.

The chances and outcomes of these two scenarios are very different for which neither NISA required or TEPCO undertook and reported any formalised analysis of the comparative risks, benefits and detriments. However, the balance is clear because if, as chance would have it, the corium ejected into a partially flooded PC then a molten metal-water explosion could have utterly devastated the containment yielding a very energetic and significant release of radioactive fission product, affecting many thousands of individuals in the Fukushima region and beyond. If, on the other hand, the corium run its course ejecting into a pumped-dry PC (which could still occur) then the radioactive release rate would been very significantly less energetic, occurring over a much longer time interval and, quite possibly, manageable with respect to mitigating the radiological consequences.

Another radiological consequence of the *WET* or *'water sarcophagus'* option is that the leakage arising from continuing injection of cooling water provides contamination and release pathways to the marine environment, thereby adding to the thousands of tonnes of highly contaminated water that have been discharged to sea because of the lack of storage water capacity on the Fukushima Dai-ichi site. In contrast, the *DRY* option allows the reactor fuel cores to run their course over time isolating the source of the radioactivity from the immediate water dispersion pathway, although to limit the airborne radioactive release this option requires a *dry sarcophagus* containment to be erected around and over the Unit 1, 2 and 3 reactor buildings – even if the *DRY* option is not adopted some form of sarcophagus containment will be necessary to contain the spent fuel in the ponds of Units, 1, 3 and 4 (and possibly Unit 2). It is interesting to note that once the events at Chernobyl had run their course, a dry sarcophagus was applied to minimise the radioactive release in the absence of any extraordinary water cooling of the severely damaged Chernobyl reactor fuel core and containment structures.

In fact, the manner in which TEPCO has chosen not to demonstrate which of the *WET* and *DRY* options yields the greatest radiological benefits to the public beyond the Fukushima Dai-ichi site boundary, is emblematic of its narrow approach that fails to justify in advance its remedial actions. Indeed, some might opine that TEPCO's management of this ongoing, severe radiological situation has been kneejerk, that is stumbling from one crisis to the next.

It is not clear why TEPCO chose not to release the key instrumentation records of RPV and fuel core conditions during and immediately following the tsunami strike until 15 May. Certainly, TEPCO would have had access to these records at the time and, no doubt, the data could have been retrieved at any time thereafter from the continuously streamed information back-up systems commonly in place at hazardous plants. The role and judgment of NISA in presenting the daily updates of reactor conditions is also questionable, particularly in that it must have been aware that Unit 1, at least, had undergone a full melt within 16 hours or shorter of the earthquake but then, even in this certain knowledge, why it continued to publish its daily but unrelated readings of the RPV shell temperatures is baffling.

At best, what must be construed as mismanagement of information has frustrated observers and analysts following progression of the Fukushima Dai-ichi incident.

At worst, the information withheld most likely resulted in ill-informed and incorrect decision-making and management both on and off the Fukushima Dai-ichi nuclear site: On site, workers planning and implementing essential remedial works may have been denied key information that would have enabled them to minimise and/or optimise their individual radiation dose exposures; the consequences and/or knock-on effects of earlier actions might have been more reliably forecast; and bringing the radiological situation under greater control might have been speedier and more certain if this crucial information had been available. Off-site, holding back the extent of the Unit 1 fuel damage and melt down could have inculcated a false sense of TEPCO's competence to manage a severe radiological incident; and it might have resulted in inappropriate assessment of the prevailing risk and hazard that, itself, hampered the sheltering, evacuation and implementation of other countermeasures affecting many thousands of individuals in the region.

Beyond Japan where national nuclear safety regulators were pressed into re-examining the safety of such nuclear plants, the so-called *'stress tests'* were underway without full knowledge of how the Fukushima Dai-ichi nuclear power plants had actually behaved in a *station blackout* situation, suggesting in the absence of this key information, that the resilience of the fuel cores of light water nuclear power plants to be much stouter than had been hitherto assumed.

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UNIT 1 REACTOR CORE STATUS FUKUSHIMA DAI-ICHI – TEPCO 15 MAY 2011

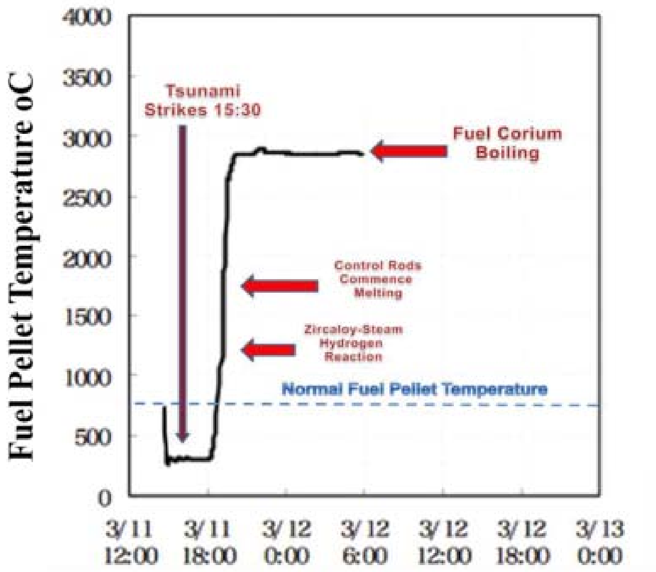

FIGURE 1 FUEL PELLET TEMPERATURES - UNIT 1 FUEL CORE

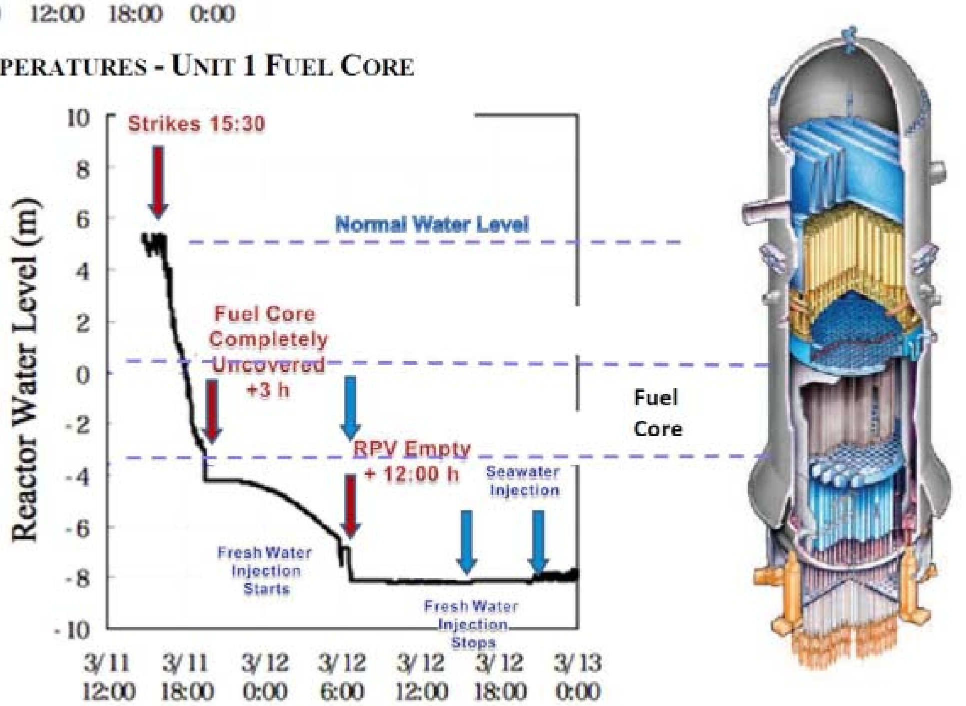

FIGURE 2 RPV WATER LEVELS AND COOLANT INJECTION TIMES

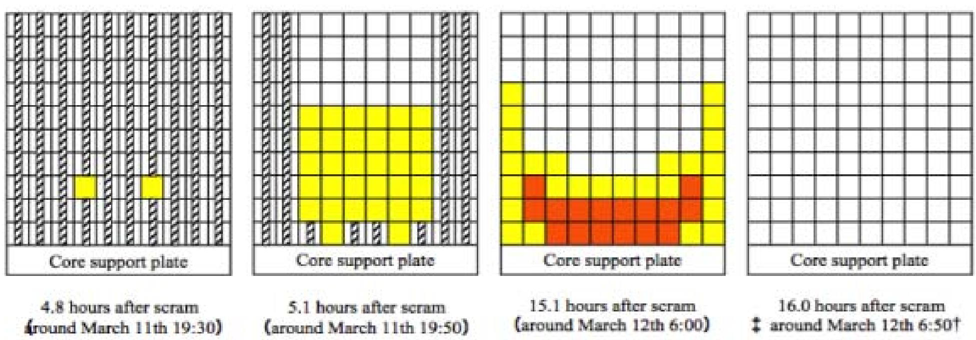

FIGURE 3 FUEL CORE MELT AND CORE AREA EXIT TIMES