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ON ASPECTS RELATING TO THE OPERATIONAL NUCLEAR SAFETY OF THE ŌMA NUCLEAR POWER PLANT, AOMORI

INSUFFICIENCIES AND INCOMPLETENESS OF THE DESIGN, CONSTRUCTION AND NUCLEAR SAFETY CASE SUBMISSIONS AVAILABLE IN THE PUBLIC DOMAIN

CLARIFICATION OF AND ADDITIONS TO THE 3RD STATEMENT

4th Opinion and Statement of JOHN H LARGE

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On Aspects Relating to the Operational Nuclear Safety of the Ōma Nuclear Power Plant, Aomori

Insufficiencies and Incompleteness of the Design, Construction and Nuclear Safety Case Submissions available in the Public Domain

Clarification of and Additions to the 3rd Statement

4th Statement of John Large

1 I am John H Large of the Gatehouse, 1 Repository Road, Ha Ha Road, London, United Kingdom SE18 4BQ.

2 I have stated my experience and professional qualifications in nuclear engineering and related matters in my 1st Statement to the Court of 29 December 2016.

3 I have been asked to clarify and/or add to three issues raised in my previous 3rd Statement of 21 February 2017 and an additional item on J-Power's prediction of volcanic activity.

4 These issues and topic are

5 i) the extent of document exchange between the licensee and United Kingdom (UK) nuclear safety regulator the Office for Nuclear Regulation (ONR) for a not that dissimilar advanced boiling water reactor (ABWR) presently awaiting construction in the UK, to that partially constructed at Ōma – see paragraphs 11 and 12 of my 3rd Statement;

6 ii) example of the reviews undertaken by *Multinational Design Evaluation Programme* (MDEP) – see paragraphs 21 to 27 of my 3rd Statement;

7 iii) on the design concept and practical application of the so-called post-melt corium catcher that I refer to in paragraph 34 of my 3rd Statement; and

8 iv) on the predictions of volcanic activity by Nobuhiro Denboya for J-Power.

9 On these issues I comment as follows:-

10 i) Document and Interrogatory Exchanges between the UK Regulatory and Hitachi-GE.

11 This relates to the proposed development of the ABWR nuclear power plant (NPP) at Wylfa Newydd (North Wales), UK. The developer, Horizon Power was inaugurated in 2009 to develop new NPPs in the UK, being subsequently acquired by Hitachi-GE in November 2012.

12 In the UK, before an organisation is able to build and operate a nuclear power station a number of permissions need to be in place, including an approval that the generic design of the NPP is acceptably safe and secure and, separately and specifically relating to the actual site location, a Nuclear Site Licence.

13 For the ABWR at Wylfa Newydd the permission and regulatory processes commenced proper in January 2013 with the UK government Secretary of State for Energy granting permission to start the *Generic Design Assessment* (GDA) process.

14 The GDA process comprises 4 distinctive steps or stages that lead to the NPP design being accepted in terms of nuclear safety compliance with UK statutory and regulatory requirements, namely the Nuclear Installations Act 1965 (as amended) and a host of accompanying Statutory Instruments, Regulations, etc., relating to safeguarding the radiological health and safety of the public at large, the environmental impact, security and proliferation safeguarding issues.

15 For the Hitachi-GE ABWR at Newydd Wylfa progress of the GDA was as follows:-

16 **TABLE 1 THE GDA PROCESS FOR NEWYDD WYLFA ABWR NPP**

STAGE	DATE COMMENCED	TASK	DATE COMPLETED
1	April 2013	Preparatory – Qualification, etc	January 2014
2	January 2014	Initial Assessment	August 2014
3	August 2014	Detailed Assessment	October 2015
4	November 2015	Detail Design, Safety Case and Security Evidence Assessment	December 2017
		Design Acceptance Certificate Granted (subject to timely and quality submissions by Hitachi-GE)	December 2017

17 TABLE 1 reveals the GDA process to have taken overall around 48 months and that the greatest effort is required at Stage 4 during which the detailed design is assessed.

18 The ONR and the Environment Agency (responsible for assessing the environmental impact) jointly publish a series of quarterly progress reports summarising the current position and highlight key challenges and issues of the GDAs then underway. For example, the quarterly progress report for the May to October 2016 period covers two NPPs under GDA evaluation at that time, the ABWR and a pressurised water reactor (PWR) proposed for another UK site.[1]

1 This particular quarterly progress report is available at http://www.onr.org.uk/new-reactors/reports/gda-quarterly-report-nov16-jan17.pdf and the whole series at http://www.onr.org.uk/new-reactors/quarterly-updates.htm.

19 In addition to the quarterly progress reports at the completion of each GDA stage a comprehensive summary report is published. For example, in August 2014 the Stage 2 report *'Summary of the design assessment of Hitachi-GE Nuclear Energy's UK Advanced Boiling Water Reactor (UK ABWR)'* was made publicly available, comprising an overview of the claims for the fundamental design, safety case and security of the Hitachi-GE ABWR.[2]

20 The proposed ABWR design and environmental impact assessments are subject to public consultation, being reported by 4 summary reports published by the UK government the most significant of which is UK Environment Agency's *'Generic design assessment of Hitachi-GE Nuclear Energy Limited's UK Advanced Boiling Water Reactor'* of 177 pages length.[3]

21 Prerequisite to the GDA evaluation, the ABWR developer, Horizon via Hitachi-GE, submitted to the ONR and Environment Agency around 100 or so technical reports and analyses, commencing at Stage 2 and as requested by the regulatory bodies during Stages 3 and 4.[4] The ONR also takes into account the findings and certification of the generic ABWR design, particularly the completed assessment, comprising several thousand pages of technical submissions, analyses, and reports,[5] undertaken by the United States regulator the *Nuclear Regulatory Commission* (NRC).

22 It is not unusual for one state regulator, like the ONR, to build upon the evaluation and findings of another like the NRC. However, my understanding is that there is a great reluctance to totally rely upon the evaluation and licensing outcome of an overseas regulator because, particularly, each regulator acts within and it statutorily bound by the host nation's domestic legal and governmental frameworks.[6]

23 The work of the ONR is split between a) nuclear safety issues and b) resilience and vulnerability of the proposed NPP against malevolent acts (ie terrorism).

24 Understandably, very little of the NPP resilience (b) is published but for nuclear safety (a) the ONR publishes *Regulatory Observations* providing its assessment and insight into the suitability and compliance of the detailed design of the Hitachi-GE ABWR.

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2 Available at http://www.onr.org.uk/new-reactors/uk-abwr/reports/step2/uk-abwr-step-2-summary-report.pdf.

3 Available at https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/576597/LIT10603.pdf.

4 These reports and analyses are available at http://www.hitachi-hgne-uk-abwr.co.uk/gda_library.html

5 Summary available at https://www.nrc.gov/reactors/new-reactors/design-cert/abwr.html#dcrule.

6 For example, relating to the quality assurance problems at the French le Creusot Forge in the manufacture heavy forged steel reactor pressure vessel and steam generator components, the French regulator ASN has recently stated that ASN has no responsibility whatsoever for defective components being manufactured at le Creusot Forge for oversees NPPs. This particular issue led to the MDEP working group (see later) visiting le Creusot Forge and each issuing their own independent reports drawn from the same inspections and meetings at le Creusot Forge works.

25 These ONR reports are the result of a series of paperwork, data and interrogatory written and meeting exchanges between the regulator and the licensee (in this case Horizon, Hitachi-GE). The publicly available reports are in the form of i) a *Regulatory Observation* (RO) in which the regulator specifies the shortfalls, items of non-compliance, etc.; ii) a separate *RO Resolution Plan* and, if appropriate, iii) a *Closure Letter* stating that the original RO has been adequately addressed.

26 Embedded within the *ROs* and *RO Resolution Plans* are source reports and analyses that have been prepared by the ONR and/or its *Technical Support Contractors* (TSCs being specialist consultants).

27 If the *RO* has not been addressed it is deemed to be an iv) *Outstanding Issue* that is generally referred to an appropriate hold-point in either or both the detailed design development and/or construction stages. Generally, a *'hold-point'* is a specific point in the construction programme beyond which the works may not proceed until the particular issue (or *RO*) has been resolved.

28 For the UK GDA of the Hitachi-GE ABWR 80 *ROs* and *RO Resolution Plans* were raised for which 30 *Closure Letters* have been issued, leaving 50 *ROs* yet to be resolved. [7]

29 I understand that the resource and costs involved in completing a similar GDA for the European Pressurized Reactor (EPR) in the UK (then in 2012) involved around 27,000 days of assessment time for the regulator and its TSCs, at an overall cost of about £35 million.

30 Finally at completion of the GDA process the ONR and Environment Agency issue a *Design Acceptance Confirmation* (DAC) and a *Statement of Design Acceptability* (SoDA) respectively. Should the Hitachi-GE UK ABWR GDA process proceed to completion, I understand that the aim is to issue the DAC and SoDA grants by December 2017.

31 The final stage of the regulatory compliance process is the issue of a *Nuclear Site Licence* as required under the UK *Nuclear Installations Act 1965 (as amended)*, for which Horizon applied for the Newydd Wylfa NPP in spring 2017.

32 Essentially, the *Nuclear Site Licence* takes into account site specific issues (flooding risk, seismic characteristics, etc), licensee competence and other matters and factors relating to the compliant, safe and reliable operation of a nuclear facility at the Newydd Wylfa NPP site – this final licensing stage would not be expected to be issued until shortly before commissioning and first criticality of the UK ABWR NPP.

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7 A full list of *ROs* etc., is available at http://www.onr.org.uk/new-reactors/uk-abwr/ro-res-plan.htm.

33 On this issue of regulatory compliance, perhaps it would be helpful for me to comment on the matter of security and resilience against malevolent acts that is becoming an increasingly crucial aspect of NPP licensing.

34 The general approach to assessing the vulnerability of NPPs is, first, for the state (ie Japan) to assess the occurrence of a terrorist action at a national level; then define this as a threat on a sectorial basis (for example, the likelihood of the adversary taking action against the nuclear industry generally); and then identify and formulate a *design basis threat* (DBT) for each particular nuclear facility, hardening the pathways likely to be available to the adversary.

35 The International Atomic Energy Agency publishes a series of recommendations on the application of DBTs, how these should be regularly reviewed, and how certain aspects of the fundamental design of NPPs (and other nuclear facilities) should be modified in account of an evolving threat.

36 The term *'design basis threat'* means that the physical design of the plant includes features that provide resilience against certain malevolent acts (represented by the DBT), some of which may be implemented by well informed and knowledgeable *'insider'* saboteurs.

37 However, my examination of the submitted documentation for the Ōma NPP did not reveal any substantial changes that had been made to the present level of construction, layout, etc., to bolster resilience. This is contrary to my expectation that a NPP whose design process commenced around the year 2000 would not have by now, in account of the changing nature of terrorism, been subject to considerable amendment in its layout and structural design.

38 Finally, it may not be obvious why, if one national authority, such as the United States NRC, has approved the ABWR generic design, then it is necessary for another national authority, such as the ONR, to repeat the design, environmental and security approval processes?

39 Obviously national standards and codes of practice may differ from one country to another (although, essentially, the US, UK and Japan adhere to much the same version of the American Society of Mechanical Engineers (ASME) III standards for structural design of nuclear, pressurised equipment); the external events may occur at different frequency and severity (for example the seismic standards of the UK, where seismic events are rare and weak when compared to that in Japan); and the threat of malevolent acts might be heightened in one country when compared to another.

40 However, it is the timing of the evaluation and licensing processes that are so important. For example, the UK GDA was, unlike the NRC assessment, undertaken post-Fukushima Daiichi so it takes into account the weaknesses exposed by the accident, whereas the NRC ABWR pre-Fukushima Daiichi certification of around 1997 had to be substantially modified via the NRC Order EA-12-049 of 2012 to account for the lessons learnt rom Fukushima Daiichi. In fact, the final NRC Construction and Operation Licence (COL) for the two South Texas ABWR NPPs was not approved by the NRC until February 2016, although it is now doubtful, due to market conditions, that these NPPs will ever be built.

41 The Ōma NPP, designed and part-constructed prior to the Fukushima Daiichi accident of 2011, will also require modification as a result of the lessons learnt from Fukushima Daiichi but, unlike the amendment to the NRC certification for the South Texas ABWR NPPs, which was a paperwork exercise because their construction had not started, the structures at Ōma are extant so the desired modification in account of Fukushima Daiichi might well be seriously compromised.

42 **i) Summary:** I have described the regulatory processes involved in the UK, which enable a particular reactor generic design to pass through the preliminary and intermediate stages of regulatory compliance. The process overall relies upon the past operation and experience of BWR and ABWR reactor plants that have been and/or are preparing to commission into service.

43 So, in this respect, the UK GDA and final licensing stages rely heavily on the acceptability of the design development of past generations of BWR NPPs; the approach endeavours to take into account significant departures from earlier designs, the introduction of new technology, and socio-cultural factors (such as the public acceptability of risk, the growing prevalence malevolent acts, and so on).

44 Other nuclear power plant operating nations, such as the United States via the *Nuclear Regulatory Commission* (NRC), and France with its *Autorité de sûreté Nucléaire* (ASN) adopt very similar and strictly codified systems in granting licences for NPPs.

45 A significant feature of the approach of the ONR, NRC, ASN and others, is transparency and accountability – this openness on the parts of the regulators seeks to win public assurance and, equally important, enables the public themselves, individually and through non-governmental organisations (NGOs), to scrutinise the effectiveness of the regulatory approach in its primary role of safeguarding the public against radiological consequences.

46 In my examination of the available documentation for the Ōma NPP I did not find the same degree of openness practiced by the Japanese *Nuclear Regulatory Authority* (NRA); I find the interrogatory questioning of J-Power by NRA to lack the incisiveness necessary, in my opinion, to fully test the Ōma NPP design; and, more generally, I find the regulatory framework documentation, as expressed by the NRA's *Draft New Safety Standards for Nuclear Power Stations* (1) and, separately, the *Outline New Regulatory Requirements* for the *Design Basis* (2), and *Severe Accident Measures* (3) insufficient in definition and application, especially when compared to similar standards, etc., of the ONR, NRC, ASN and others.

47 ii) EXAMPLE OF REVIEWS UNDERTAKEN BY THE MULTINATIONAL DESIGN *EVALUATION PROGRAMME* (MDEP)

48 MDEP was established by the *Nuclear Energy Agency* (NEA - OECD) in 2006 as a multinational initiative to coordinate and develop the resources and knowledge of the national regulatory authorities that are currently or will be tasked with the review of new nuclear power reactor designs. Presently, MDEP comprises the regulators of 15 countries, including the NRA of Japan.

49 There are 5 design-specific working groups amongst which is a group dedicated to the ABWR NPP design. This group, the ABWRWG was established in May 2012, comprises contributing members from the national regulators of Japan, Sweden, United Kingdom and the United States, and is charged with undertaking a safety review of the ABWR generic design.

50 As I noted in my 3rd Statement, MDEP has yet to publish its final recommendations on the revisions required for the tolerably safe operation of existing ABWR NPPs and, importantly here, it is yet to specify revisions to the regulatory framework for ABWR projects presently undergoing regulatory assessment stages.

51 The only substantive report published by the MDEP's ABWRWG web page[8] is a 'common position' paper of 21 pages.[9]

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8 MDEP ABWR Working Group web page at https://www.oecd-nea.org/mdep/working-groups/abwrwg.html.

9 MDEP, *Design-Specific Common Position CP-ABWRWG-01*, (Public Use), October 2016

52 Although not particularly detailed and somewhat unrevealing, the ABWR working group paper[9] includes the following statements of *'common position'* shared by members of the ABWRWG, including the NRA of Japan:-

a) EVOLUTIONARY IMPROVEMENTS IN SAFETY

> "... *The ABWR today represents an evolution in safety compared with earlier generation BWR designs. Following the Fukushima Daiichi NPP accident, **further safety enhancements** are being considered, and/or designed and implemented, by the ABWR vendors and licensees to respond to national regulatory requirements and international expectations...*"

b) EXTERNAL HAZARDS

> "... *The accident at the Fukushima Daiichi NPP has reinforced the need **to undertake, as part of the safety review process for ABWRs**, a comprehensive analysis of external hazards, including consideration of relevant combinations of events. This should include an analysis to address the potential impact of the relevant hazards on all areas of the proposed NPP where significant amounts of radioactive material are expected to be present...*"

c) RELIABILITY OF SAFETY FUNCTIONS

> "... *Maintaining the integrity of the ABWR containment vessel is very important but can be challenging following loss of heat sink. **Design solutions should be implemented for this purpose**. These may be different depending on national requirements...*"

d) ACCIDENTS WITH CORE MELT

> "... *Although core melt accidents have been considered in the original ABWR designs, **further features and enhancements are being considered and implemented**, as appropriate, in accordance with the different regulatory requirements and international expectations.*
>
> *Safety features which ensure the adequate integrity of the containment in case of an accident with core **melt need to be included in the design**. These features need to have adequate independence from the other provisions of the plant. They should also include: provisions to avoid over pressurisation (relying for example on containment venting and/or containment spray systems); hydrogen management; and consideration of ultimate pressure strength in accidents...*"

e) SPENT FUEL PONDS

> "... *The structural integrity of the spent fuel pools **needs to be ensured** with adequate margin in case of external hazards...*"

my ***highlighting*** throughout

53 **ii) Summary:** The ABWRWG is charged with focussing on the safety of the ABWR NPP design, particularly relating to the shortcomings of the earlier BWR design exposed by the Fukushima Daiichi accident of March 2011. In this respect, the ABWRWG published its only report to date in October 2016, which, of course, is considerably after the final (pre-Fukushima Daiichi) ABWR design.

54 The recommendations of the ABWRWG report, expressed as common positions shared by all ABWRWG members, including Japan's NRA, were arrived at after the original design of the Ōma NPP was settled in or around 2000 or earlier. Indeed, the ABWRWG recommendations were published after the greater part of J-Power's submissions to the NRA as part of the regulatory process.

55 In paragraph 18 of my 3rd Statement, I opined that the final design of the safety upgrades had yet to be completed. Moreover, the highlighted sections of the MDEP ABWRWG common position recommendations (made so recently as October 2016) most probably have yet to be at all incorporated in J-Power's safety upgrades.

56 Referring to my **highlighted** text the MDEP ABWRWG recommendations of my paragraph 52 above, briefly, the item a) safety **enhancements** are likely require considerable technical effort to practicably implement and invoke further delays whilst any accruing safety case changes are evaluated; b) a further **safety review** will also incur time delays; c) the **containment design solutions** will require a fundamental root-and-branch approach that is likely to have 'knock-on' consequences throughout the design of the nuclear island; d) similarly, **structural and layout changes** in the reactor support pedestal and lower dry well area will give rise to modifications in the nuclear island lower and base structures; and e) ensuring **structural integrity** of spent fuel pool could (is likely to) require major structural revisions to the pool and surrounding structures.

57 Such major design revisions and additions (and the reconstruction works entailed) were not addressed in Tetsuro Kobayashi's written statement of 27 December 2016 and, once again, I must strongly disagree with Mr Kobayashi's opinion that *"Since Ohma nuclear power plant is currently under construction, it has the advantage of it being relatively simple to incorporate into the design new measures discussed".*

58 iii) POST- FUEL MELT CORIUM CATCHER

59 The heart of a nuclear power plant is the reactor pressure vessel (RPV) where the process of fission takes place in which individual atoms of the fissile uranium-235 are fragmented to form unstable (radioactive) fission products. The heat generated in the reactor uranium fuel core is a combination of the fissioning energy of the uranium-235 and the heat dissipated in the natural radioactive decay of the fission fragments or products.

60 When the NPP is generating power, the fuel core heat is carried away by water to be converted to steam in the higher sections of the reactor pressure vessel. Thence the steam is passed through a turbo alternator to produce electricity; the depleted steam is condensed and returned the RPV as feedwater to complete the recirculatory process.

61 If the NPP shuts down abruptly the energy immediately stored within the fuel core of the RPV has to be dissipated by some means other than the turbo-alternator - there are a number ways of achieving this although there is no need to explain these here.

62 Even when fissioning has ceased, the fuel core continues to generate heat by virtue of the natural radioactive decay of the fission products, producing at the instance of reactor shut down or SCRAM, about 7 to 8% of the maximum thermal rating of around 4,000MWt (for the Ōma NPP rated at 1,358MWe). As the short-lived fission products decay, within a few hours and days this 'residual' heat reduces down to a level that can be managed by a relatively low (pumping) powered residual heat recovery (RHR) system.

63 So, immediately following reactor shut down electricity is required to power the circulation pumps – as a matter of course this is imported into the NPP site by reversal of the very same lines through which electricity is exported from the NPP during normal operation. If there is a loss of off-site power supplies (LOOP) then on-site emergency diesel generating sets automatically start to provide the minimum power requirement to operate the RHR and other emergency core cooling systems.

64 If, for whatever reason, the emergency diesel generators do not start or have been shut down then, save for some localised steam driven pumps and battery reserves for remote valve shifting and monitoring the systems, the NPP enters a complete station blackout (CSBO).[10]

65 It is at this point of time forwards, with the fuel core continuing to generate residual decay heat, that the reactor fuel core is at risk of overheating and 'melting down'.

66 The thermodynamics and chemistry of a fuel core meltdown is complex.

67 Unless the residual decay heat is continuously extracted from the fuel core, the fuel core and surrounding water temperature within the RPV rapidly increase - this increase of temperature is accompanied by a corresponding increase in pressure within the RPV.

10 At Fukushima Daiichi, first the NPPs were isolated from off-site power (LOOP) because the Great *East Japan Earthquake* disrupted the regional electricity grid serving Fukushima Daiichi and then, about 40 or so minutes later a severe tsunami swamped the site, disabling the emergency diesel generators leaving the Fukushima Daiichi NPPs in CBSO from which the fuel cores of the 3 operating NPPs entered into irrevocable *'melt down'*.

68 The RPV pressure is relieved, either automatically by self-operating steam relief valves, or intentionally by the control room operator using reserve battery power to operate relief valves – the aim of intermittent relief of RPV pressure is to maintain the water coolant in the RPV in a liquid state thereby enabling a high rate of heat transfer of the fuel residual heat to the water coolant.

69 If, however, a failure of the RPV pressure boundary occurs, the pressure collapses and the water coolant in the RPV flashes over to steam. At this point in the sequence, the operator will endeavour to make up the RPV water by injecting water into the RPV core using an *emergency core cooling system* (ECCS). If ECCS injection fails to quench the fuel core the presence of steam, instead of water in intimate contact with the nuclear fuel pin surfaces, results in the heat transfer from the fuel pin surfaces being stifled and, as a result, the temperatures of the fuel body (the uranium dioxide), the fuel cladding (zirconium alloy – Zircaloy) and the surrounding steam atmosphere within the RPV very rapidly (almost instantaneously) escalate.

70 From this point on, the thermo-chemistry kinetics situation is very unstable:-

- First, as the fuel pin temperatures rise, the gas pressure inside the normally sealed zirconium-based Zircaloy cladding (a thin-walled tube) can cause the cladding to balloon out and rupture.

- At steam temperatures of around 600°C, the corrosion of the Zircaloy cladding accelerates, being strongly exothermic (heat generating) adding to the reaction temperature which liberates large quantities of hydrogen stripped by the oxidation process from the steam,[11] with the reactions being autocatalytic (self-sustaining) – this is generally referred to as a *Zircaloy Cladding Fire* or *Flare*.

- At higher temperatures (around 1,800°C), the Zircaloy cladding reacts with the uranium oxide fuel pellets forming a complex molten phase containing zirconium-uranium oxide, the result of which is the fuel core metamorphosing into a white-hot, heat-generating sludge referred to as *corium* – the reactions and outcome for a mixed oxide (MOX) fuelled ABWR (as planned for the Ōma NPP) are very much the same.

11 The Zircaloy corrosion process can occur in both air and steam air being respectively Air: $Zr+O_2 \rightarrow ZrO_2$ with heat liberated 1.2E+7 joules per kilogram and Steam: $Zr+2H_2O \rightarrow ZrO_2+2H_2$ liberating 5.8E+6j/kg. In a severe situation the hydrogen liberation rate could occur at 100 to 5,000 grams per second – the volume of Zircaloy in the core (in fuel pin cladding, fuel assembly channel boxes and grillages, and the RPV fuel supporting core thimble) totals around 70 to 80 tonnes and the potential hydrogen generation from this Zn mass is around 3,000 to 3,500 kg hydrogen.

71 The next stage of the fuel melt down involves the physical interaction between the molten corium (at a temperature of between 1,400 to 3,000°C) and, first, the steel RPV, and, second, if the corium burns through the RPV its interaction with the base mat forming the bottom of the reactor pit:-

- The molten corium and its entrained remnants of the RPV fuel core thimble slumps to the bottom of the RPV where it interacts with and oxidises the carbon steel RPV wall.
- In burning through the RPV wall the corium liberates more 'free' hydrogen during oxidation of metallic structures and, particularly, from the boron carbide rods that feature in the ABWR RPV control mechanisms.[12]
- Eventually the molten slug of corium, possibly of around 100 to 130 tonnes mass, is forcibly ejected to the floor of the reactor pit where it aggressively interacts with and decomposes hydrates and carbonates in the matrix of the concrete base mat
- Gases liberated from the concrete, mainly carbon dioxide (CO_2) and superheated steam (H_2O), are chemically reduced to carbon monoxide (CO) and hydrogen (H) during percolation up through the corium slump.[12]
- The percolation of superheated steam and carbon dioxide products from the concrete base mat through the corium slump, serves to scavenge very finely divided particles of radioactive, metallic fission products (radionuclides of caesium, strontium, ruthenium, etc) releasing these into the secondary containment atmosphere.
- If, as proposed for certain variants of the ABWR, the slumped corium is sprayed with cooling water, then any 'unburnt' Zircaloy remnants remaining in the corium are prone to oxidation and the release of more hydrogen into the lower dry well containment space.

72 The upshot of these processes (paragraphs 70 - 71) is the secondary containment filling and pressurising with a non-condensable gas (CO), adding to the presence of a very large mass of explosive hydrogen (H), in a dry well space charged with airborne radioactive particles.

73 Hydrogen atmospheres have the potential to violently explode-deflagrate when there is a sufficient concentration of oxygen (ie a stoichiometric mix) and source of ignition. The resulting overpressure, particularly as the blast front travels through and is shaped (concentrated) by the containment geometry, can be very strong and challenging on both the lower and upper dry wells

12 Estimates suggest that around 15% of the total hydrogen released would be liberated in the RPV burn-through process and, following burning through the RPV when the corium is lumped on the base mat under RPV, upwards of 2,000 kg of hydrogen might be expected to be liberated from the concrete.

containments of the ABWR.[13]

74 In the above sequence, I have assumed that the dry well remains free of any substantial pool of water. However, there are situations in which the corium remains within a top-breached RPV with a pool of water accumulating in the lower dry well from the ECCS injection intervention. In these circumstances there is risk that the corium mass will eventually plunge into the water pool to generate a molten metal-water explosion as the water is virtually instantaneously converted into a superheated gas of greatly increased volume – I briefly review this possibility in paragraph 33 of my 3rd Statement.

75 Should a breach (structural opening) of the ABWR dry well containments occur – which I believe to be a strong possibility under the fuel melt-down circumstances that I describe above – then a direct path is available for the radionuclide fission product content of the dry wells to be forcibly ejected into the atmosphere for immediate dispersal and disposition in the environment – such an event would be likely to result in very onerous radiological consequences.

76 In my 3rd Statement (paragraphs 28 to 34) I am critical of J-Power's technical representative's (Tetsuro Kobayashi) confidence that the existing design and extant structures at the Ōma NPP can be adapted to reliably and safely cope with a melt-down and melt-through of the RPV fuel core.

iii) Summary: The foregoing explanation (paragraphs 70 to 75) demonstrates the complexity of the fuel core melt processes and outcomes that cannot be entirely resolved by Mr Kobayashi's unpublished and, I believe, unprepared proposal to shoehorn a corium catcher into the area of the lower dry well of the Ōma NPP.

77 iv) PREDICTION OF VOLCANIC ACTIVITY BY NOBUHIRO DENBOYA (J-POWER)

78 I have read the translations into English of the Written Statement of 20 January 2017 and cross examination of 21 and 22 February 2017 of Nobuhiro Denboya representing J-Power – I believe

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13 Past accidents of light water reactor NPPs bear witness to the devastating force of hydrogen explosion-deflagration events:

1) At Chernobyl (1986) the hydrogen blast forces toppled the reinforced concrete reactor cap, weighing upwards of 1,000 tonnes from its intended horizontal through 90° to an upright position.

2) Of the three operating Mk I containment BWR NPPs operating at Fukushima Daiichi (2011) hydrogen accumulating in the upper charge halls of Units 1 and 3 severely breached the containment and had a knock-on effect on Unit 4 that was not in operation at the time, and the dry well containment of Unit 2 was severely damaged at basement level by (probably) a hydrogen burn in the dry well.

3) At Three Mile Island PWR (1979) the core melt was confined to the RPV but hydrogen formed and detonated in and was confined to the secondary containment dome.

these translations to be accurate and reliable.

79 First, I admit to having some difficulty in following Mr Denboya's reasoning as to why, specifically, that both the Toya caldera and Zenigame volcano have no potential for future activity.

80 Although previously I have been critical[14] of the NRA the NPP site selection guide in account of future volcanic activity,[15] it is the NRA's compliance requirement but, that said, Mr Denboya's reasoning, so far as I can follow it, does not adhere to the NRA guide.

81 I also refer to the authoritative report and recommendation of the *Diet Investigation Commission* final report[16] that:

82 "...

> *Nuclear operators should conduct comprehensive risk analysis encompassing the characteristics of the natural environment. In the analysis, they should include the external events, not only earthquakes and their accompanying events but also other events such as flooding, volcanic activities or fires, even if their probabilities of occurrence are not high, as well as the internal events having been considered in the existing analysis. Nuclear regulators should check the operators' analysis . . ."*

my *emphasis*

83 This recommendation clearly requires, like the IAEA volcanic hazards NPP site selection recommendations,[17] that low probability external events should be considered in any risk analysis.

84 This is particularly important to avoid so-called *'cliff edge'* effects where, for example, the NPP might undergo a sudden, unanticipated variation in plant conditions and behavior caused by a relatively small external event. Since Mr Denboya's thesis rules out all future activity of both the Toya caldera and Zenigame volcano, it follows that he also dismisses any need to account for cliff edge effects

85 **iv) Summary:** In other words, Mr Denboya and J-Power sre turning a blind eye to all possible future volcanic activities on what seems to be a single data point, this being that since there has been no significant activity in the immediately recent Holocene period (ie the past 11,700 years or so), there is no probability whatsoever of any future activity (severe, moderate or slight).

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14 Large J, *Conformity of the NRA New Safety Standard for Nuclear Power Plants, The Assessment Guide of Volcanic Effects To The Nuclear Power Pant with the IAEA Volcanic Hazards In Site Evaluation For Nuclear Installations*, SSG-21, 2012

15 Nuclear Regulation Authority, *The Assessment Guide of Volcanic Effects to the Nuclear Power Plant (Draft)*, 3 June 2013 – in Japanese.

16 The National Diet of Japan Fukushima Nuclear Accident Independent Investigation Commission, *'The Fukushima Nuclear Accident Independent Investigation Commission'*, July 2012

17 IAEA, *'Volcanic Hazards in Site Evaluation for Nuclear Installations'*, Specific Safety Guide No SSG-21, 2012

86 I state here that I confirm that I have made clear which facts and matters referred to in this Statement that are within my own knowledge and those which are not. Those that are within my own knowledge I confirm to be true. The opinions I have expressed represent my true and complete professional opinions on the matters to which they refer.

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