THE APPLICATION AND CONFORMITY

OF THE

JAPANESE NUCLEAR REGULATION AUTHORITY'S

NEW SAFETY STANDARDS FOR NUCLEAR POWER PLANTS

THE ASSESSMENT GUIDE OF VOLCANIC EFFECTS TO THE NUCLEAR POWER PLANT

WITH

INTERNATIONAL ATOMIC ENERGY AGENCY'S

VOLCANIC HAZARDS IN SITE EVALUATION FOR NUCLEAR INSTALLATIONS SSG-21, 2012

Opinion and Statement of JOHN H LARGE

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This pdf version of R3229-E1 contains hyperlinks that directly link to other text sections of this document shown thus or specific paragraphs as [¶2] – mouse clicking on the highlighted text will jump to and bring up that text section. Hyperlinks shown thus *NRA Volcanic Assessment Guide* will display the whole of the paper, report, etc., referred to providing the host computer is internet connected. The printed hard copy of this document does not contain these links or full citation of the source references. During the course of preparing this Opinion I have relied upon a number of *'unofficial'* translations of Japanese language documents – I believe these translations to be true and reliable.

THE APPLICATION AND CONFORMITY OF THE NUCLEAR REGULATION AUTHORITY'S NEW SAFETY STANDARDS FOR NUCLEAR POWER PLANTS WITH THE INTERNATIONAL ATOMIC ENERGY AGENCY SPECIFIC SAFETY GUIDE SSG-21, 2012

SUMMARY

I am John Large, a United Kingdom citizen, a Chartered Engineer of the Consulting Engineers Large & Associates. I have considerable experience in and knowledge of nuclear matters.

Mr Shaun Burnie of Greenpeace Deutschland commissioned Large & Associates to provide an opinion on whether the NRA *Assessment Guide of Volcanic Effects to the Nuclear Power Plant* complies with the NPP site evaluation approach advocated by the IAEA *Volcanic Hazards in Site Evaluation for Nuclear Installations, Specific Safety Guide Nº SSG-21*.

A summary of my opinion is as follows:-

I find the IAEA SSG-21 approach to NPP site selection to be structured around a straightforward screening process, involving a step-by-step methodology that requires increasingly detailed input matched with increasing knowledge of the volcanic hazard(s). The method of assessment strongly advocated by the IAEA is the probabilistic approach and, integral with this, that the information and knowledge yielded should be deployed as the building blocks of one or more *design-bases* related to those volcanic effects likely to affect the NPP and its safe operation.

Prior to the formation of the NRA in 2012, there was no formalised Japanese regulatory guide or standard setting down a consistent procedure for evaluating the potential magnitude and frequency of occurrence of eruptions of volcanoes and volcanic fields and, similarly, there was no common methodology establishing how site licensees were to assess NPP resilience against volcanic effects. Before publishing the present version of its *Volcano Assessment Guide*, the NRA released a series of drafts strongly suggesting that its *Guide*, like the IAEA SSG-21, would adopt the methodological approach with the overall objective of establishing a set of *design-bases* to provide NPP resilience against the identified volcano hazards.

My first observation about NRA's *Volcano Assessment Guide* is that it considerably departs from all of the groundwork prepared and published prior to its inauguration - this is because the *Guide* makes no reference whatsoever, nor places any requirement upon the NPP licensee Kyushu Electric to establish a *design-basis* for each of the volcanic effects that are considered likely (ie probabilistically) to reach and affect the Sendai NPP and/or its critical supporting infrastructure.

In the main text of my opinion I set out a number of detailed reasons why and how the NRA *Guide* deviates from IAEA SSG-21 – these include inappropriate use of hard-and-fast screening criteria; the sole reliance upon a geologic record of just a single event of 12,800 years past; and use of the Volcano Explosivity Index (VEI) to screen out certain capable volcanoes – all screening techniques that do not at all feature in IAEA SSG-21 - and so on. I am also particularly critical of the over-reliance upon a single episode of relatively recent academic work that formulates a model whereby it is claimed possible to predict a forthcoming eruption – even if this this monitoring methodology is reliable, the tolerance of the timescales available could be either too long to provoke action, or too short in that there would be insufficient time to prepare and transfer from the NPP site the 400 to 1,000+tonnes or so of intensely radioactive fuel off the NPP site for safe and secure storage elsewhere in Japan, as I understand now to be the regulatory requirement.

My most fundamental criticism of the NRA *Guide*, compared to IAEA SSG-21, is that it does not, to my mind and professional way of doing things, instill sufficient discipline on the licensee to ensure that the volcanic hazards assessment is both comprehensive and meaningful. Moreover unlike IAEA SSG-21, the *Volcano Assessment Guide* does not require the licensee to explore and establish NPP-specific *design-bases*, so much so that, instead, the outcome of the site assessment exercise is more akin to tinkering around the edges than that of addressing the fundamental resilience and *defence-in-depth* of the NPP and its site.

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THE APPLICATION AND CONFORMITY OF THE NUCLEAR REGULATION AUTHORITY'S NEW SAFETY STANDARDS FOR NUCLEAR POWER PLANTS WITH THE INTERNATIONAL ATOMIC ENERGY AGENCY SPECIFIC SAFETY GUIDE SSG-21, 2012

WITNESS 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 am a Consulting Engineer, Chartered Engineer, Fellow of the Institution of Mechanical Engineers, Learned Member of the Nuclear Institute, Graduate Member of the Institution Civil Engineers, and a Fellow of the Royal Society of Arts.

3 From the mid 1960s I undertook postgraduate research in the United States, thereafter from the late 1960s through to the early 1990s I was a full-time member of the academic research and teaching staff in the School of Engineering at Brunel University, United Kingdom, completing applications research in the nuclear area on behalf of the United Kingdom Atomic Energy Authority (UKAEA) and other government agencies.

4 In the late 1980s I established the firm of Consulting Engineers Large & Associates specialising in, along with other disciplines, analysis and advice in nuclear related activities, including assessment of the response of nuclear plants during abnormal operation and when confronted with internal and external challenges. In this role[1] I have provided evidence to the European Court of Human Rights in Strasbourg; advised and/or provided evidence to a number of governments; acted as Expert Witness at a number of Public Planning Inquiries; in the UK, presented to parliamentary Select Committees and, amongst other things, I headed up the expert team that evaluated the radiological hazards arising from the nuclear propulsion reactors and nuclear weaponry on board the sunken Russian Federation submarine K141 *Kursk* throughout the World-first successful salvage of a nuclear powered submarine during 2001.

5 In recent years, I have undertaken a number of projects and assessments of nuclear power plants (NPPs) relating to continuing operational safety as these NPPs near or exceed the originally prescribed *design life* and/or where the operational circumstances/environment have significantly changed.

1 For a full bibliography see http://www.largeassociates.com

6 Of direct relation to the preparation of this present advice, I received instruction from Mr Shaun Burnie of Greenpeace Deutschland to prepare a comprehensive review on the potential risks and hazards to the Sendai NPPs relating to the pyroclastic ash fall arising from a future eruption of one or more of the *capable* volcanoes of Kyushu Island, including Mounts Unzen, Sakurajima and Kirishima and/or from new vents developing from the magma reservoirs of these volcano fields.

7 In that work, which is presently at an advanced final draft stage, I examine the relationship between the Japanese nuclear regulatory framework and the *International Atomic Energy Agency's* (IAEA) nuclear site selection guide, particularly as it relates to the recent round of licensing submissions from *Kyushu Electric* and the *Nuclear Regulation Authority* (NRA) for the Sendai NPPs - my client has instructed me to make this draft report immediately available to all parties in this present Action should the Court so wish.

8 I should state here that I am not, and have never been, a member or active participant of any national or international environment and/or anti-nuclear lobbying non-governmental organisation.

9 I consider myself to be sufficiently qualified, experienced and practised in the topics relating to this matter to provide authoritative and independent advice relating thereto.

10 **INSTRUCTIONS**

11 On 25 January, 2015 Mr Shaun Burnie, acting on behalf of Greenpeace Deutschland, asked me to provide my opinion on whether the *New Safety Standards for Nuclear Power Plants* and its application by the NRA conformed with the precepts of the IAEA *Volcanic Hazards in Site Evaluation for Nuclear Installations'*, Specific Safety Guide Nº SSG-21, 2012.

12 Here follows my opinion on this:

13 **IAEA AND NRA REGULATORY GUIDES AND DOCUMENTS**

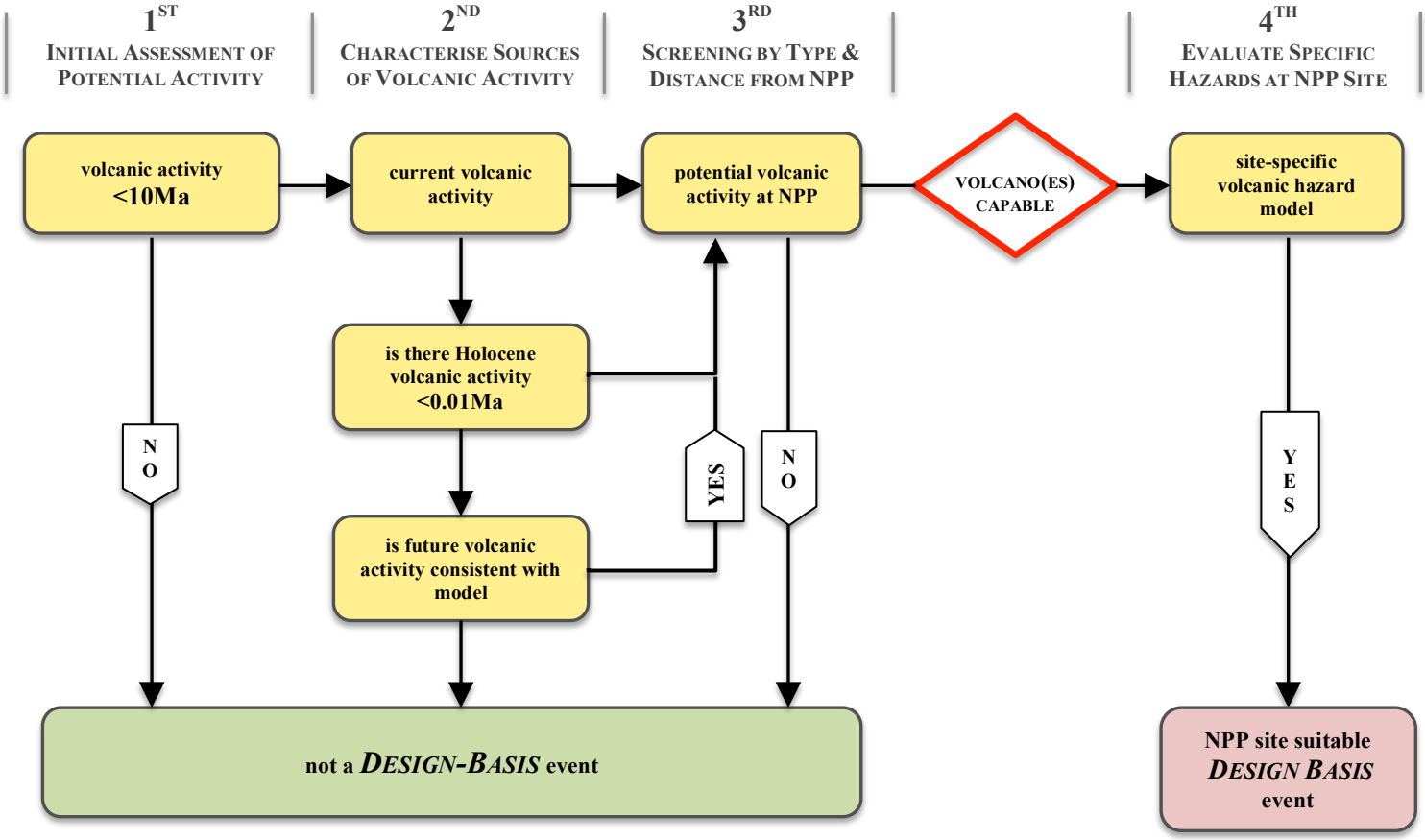
14 **IAEA**
VOLCANIC HAZARDS IN SITE EVALUATION FOR NUCLEAR INSTALLATIONS
SPECIFIC SAFETY GUIDE Nº SSG-21, 2012[1]

15 Volcanic eruptions are natural events that present a challenge in determining adequate regulatory safeguards for hazardous plants, such as nuclear facilities, including NPPs.

16 This is because, unlike other geologic hazards, such as seismic, flooding etc., developing adequate, reliable and generally acceptable methodologies to determine the surface hazard and risks of future volcanic events have been slow. This is understandable inasmuch that being rare natural events volcanoes that have not, to date, imposed significantly adverse conditions on an operating NPP.

17 The IAEA guide *Volcanic Hazards in Site Evaluation for Nuclear Installations* SSG-21 follows the so-called *Methodological Approach* for evaluating volcanic hazards at any nominated NPP site. The IAEA approach is shown schematically as follows:

SCHEMATIC 1 IAEA APPROACH TO NPP SITE VOLCANIC HAZARD ASSESSMENT FOR DESIGN



18 As shown by **SCHEMATIC 1** [after IAEA Figure 1, p16], the advocated site selection process is a sequential process, based upon and identifying the need for increasing levels of information relating to the increasing levels of potential hazard for at the NPP site.

19 The 1st, 2nd and 3rd levels or stages of screening evaluate the potential magnitude and frequency of occurrence of potentially active volcanoes and/or volcanic fields in the

region that are *capable* of affecting the candidate NPP site. As the screening process progresses through these stages, the information gained identifies, with increasing detail, the type and potential severity of the volcanic activity, for example whether the eruption will deliver pyroclastic flow, surges and blasts; tephra flows and fallout; tsunami and seiches, and so on.

20 If the outcome of these first three stages of screening is that the volcano or volcanic field is *capable*, then the IAEA approach moves on to the 4th stage in which the NPP site-specific hazards are evaluated for each of the potential volcanic effects identified and consolidated in the earlier three stages. For example, at the NPP site tephra or pyroclastic ash fallout from the overhead eruption plume could abnormally load existing structures, such as flat roofed buildings and storage tanks, and/or impede filters serving essential safety equipment, such as the air intakes to emergency diesel generators, and so on.

21 I can summarise the IAEA screening approach as follows – first, identify the volcanic effects and then determine how these effects, individually or in some combination, will affect the NPP:

22 1) The 1st stage volcanic assessment initially considers the possibility of future eruptions from sites of past eruptions during the last ten million years (10Ma).

23 2-3) The 2nd and 3rd stages apply to volcanoes with the potential for future eruptions, particularly with respect to recent past activity over the last ~10,000 years (Holocene), thus qualifying a hazard assessment that evaluates the ability of future eruptions to produce volcanic phenomena that could reach the NPP site – these are defined by the IAEA to be *capable* volcanoes - with the overall outcome that more explicitly evaluates the likelihood of future eruptions and the specific characteristics of the hazardous phenomena and effects.

24 4) The 4th stage involves assessment of the candidate NPP site and its surrounds, together with a detailed evaluation of the resilience of its plant and equipment design when confronted with the volcanic effects, thereby developing a NPP site-specific volcanic assessment that provides the volcanic effect *design-basis* for that specific NPP.

25 The IAEA suggests that both deterministic and probabilistic methods can be used to assess and screen volcanic hazards thereby contributing to risk-informed decisions on NPP site selection or how to mitigate the risk and hazards to existing nuclear facilities such as at the KE Sendai NPP site.

26 Although, deterministic methods can support the assessments and evaluations of the 1st, 2nd, 3rd and 4th stages outlined above, the probabilistic approach provides a more transparent basis to consider the wide range of data necessary for the evaluations.

27 Moreover using the probabilistic approach, uncertainties and the range (and diversity) of potential volcanic effects may be modelled and, importantly, incorporated into and/or compared with other external natural hazards, thus allowing for the development of a consistent series of *design-bases* to cover all external and internal (plant malfunction, human error, etc) hazardous events at the NPP.[2]

28 The IAEA SSG-21 Specific Safety Guide for volcanic hazard evaluation strongly advocates the probabilistic approach rather than determinism – I agree with this and, moreover, I would consider any such volcanic assessment, for both predicting the incidence and magnitude of an eruptive event, that overly drew upon the deterministic approach to be somewhat rudimentary and not entirely fit for purpose.

29 The other approach that features strongly in the IAEA methodology is that once the volcanic hazards have been categorised and assessed, then the appropriate *design-basis* or –*bases* can be established.

30 In nuclear jargon, the *design-basis* is the range of conditions and events taken explicitly into account in the design of the NPP (or modification thereto of an existing NPP), according to established criteria, such that the facility can withstand them without exceeding authorised conditions and limits. The NPP operator might achieve this by the planned intervention of safety systems and/or passive barriers.

31 Put another way, the *design-basis* is a set of conditions and/or circumstances that the NPP will withstand without yielding to an intolerable outcome – there might co-exist

2 Most States adopt an annual probability of 10^{-7} (one in ten million years for each year of NPP operation) for the hazard assessment of external natural events that could give rise to radiological consequences. Accordingly, on a probabilistic basis, a risk of volcanic event of 10^{-7} per year is a reasonable basis for the initial screening of volcanic sources. It is of interest to note that in its the screening assessment report of the Kyushu Electric Sendai submission,[11] the NRA endorses the Kyushu Electric statement *'the possibility that volcanic events exceeding the plant's design limit affect to the plant safety, is extremely low'* without giving a per year risk value.

several so specified *design-basis* circumstances or *design-bases*, each representative of a particular effect arising from an accident, an external natural phenomena, and so on.

32 Thus, the information obtained in following through the IAEA approach is used to establish a particular *design-basis* for each volcanic effect that might affect and challenge the NPP.

33 So, to summarise the IAEA approach to NPP site selection in account of volcanic risks and hazards:

34 i) the screening process is a straightforward, step-by-step methodology that requires increasingly detailed input matched with increasing knowledge of the volcanic hazard(s);

35 ii) the method of assessment strongly advocated by the IAEA is the probabilistic approach; and that, from this,

36 iii) the information and knowledge yielded should be deployed as the building blocks for one or more *design-bases* related to those volcanic effects likely to affect the NPP and its safe operation.

37 This overall, integrated and risk-informed approach to identify the type, magnitude and likely frequency of each volcanic effect and, then, to provide a set of *design-bases* to match can only be practicably achieved via probabilistic means.

38 Adopted into a national regulatory framework, IAEA SSG-21 provides the regulator, here the NRA, with oversight of the licensee's volcanic assessment process – it stipulates a tick-box, step-by-step assemblage that, if properly supervised and overseen, ensures a record that the assessment has been undertaken in a comprehensive and transparent manner.

39 **NRA**
NEW SAFETY STANDARDS FOR NPP[2]
NEW REGULATORY REQUIREMENTS – DESIGN BASIS[3]

40 To compare the regulatory requirements imposed by the NRA, first I shall very briefly examine how the present regulatory framework came into being.

41 My understanding is that prior to the catastrophic events at Fukushima Daiichi of March 2011, the nuclear regulatory framework in Japan was prescribed by the *Atomic Energy Basic Act*, Ministerial *Orders* and *Ordinances* attached to or associated with the *Reactor Regulation Act* and the *Electricity Business Act*, being the two main laws for nuclear safety applied to NPPs. These laws were applied via individual and issue/topic specific *Regulatory Guides* (NSCRGs) that were then, prior to September 2012, derived and applied by a statutory agency, *Nuclear Safety Commission* (NSC) functioning in parallel to the *Nuclear and Industry Safety Agency* (NISA), and the *Ministry of Economy, Trade and Industry* (METI).

42 Both NISA and NSC used the NSCRGs as a basis for the nuclear safety reviews, although these were not *'requirements'*, nor in my view were they legally binding. However, the assumption seems to have been that the NSCRGs, viewed as a whole, stipulated the minimal *'design-basis'* requirement for the NPP.

43 However, the Fukushima Daiichi catastrophe revealed fundamental flaws in the Japanese approach to hazard analysis, particularly in the area where it considered itself to excel, that is in defining and accounting for uncertainties in the probabilistic seismic hazard analysis (PSHA). Indeed, such a lack of disciplined account for natural hazards was compounded by the fact that at that time there was little compunction, in terms of laid down NSC guides and prerequisites, for the NPP operator to formalise and set out the risk and hazards of, amongst other things, volcanic effects.

44 The concern over these regulatory shortfalls was such that the Japanese parliament (Diet) *Investigation Committee on the Accident at the Fukushima Nuclear Power Stations of Tokyo Electric Power Company* [4] in July 2012 recommended immediate root-and-branch changes to the laws and regulations governing nuclear power and its safety, including that:

> *". . . Once such new systems, laws and regulations are established, they must then be retroactively [retrospectively] applied to existing reactors. It should be explicitly stated in the laws that reactors that do not meet the new standards should be decommissioned or otherwise dealt with appropriately. . . "*
>
> my *emphasis* and *[added explanation]*

45 Inaugurated in September 2012, the Japanese *Nuclear Regulation Authority* (NRA) in February 2013 issued the *Draft New Safety Standards for NPPs* [5] acknowledging certain vulnerabilities and failures in the existing NPPs, following in April, 2013 with a further outline of the *New Regulatory Requirements* (NRRs) – *Design Basis.*[3] This diktat added

more substance to defining the natural phenomena and that these were to contribute to the *design-basis* under *Guideline 2*, for example:

> *". . . 2. General Technical Requirements for Nuclear Reactor Facilities*
>
> *(1) Design Considerations against Natural Phenomena*
>
> *. . .*
>
> *(Natural phenomena other than earthquakes)*
>
> *. . . the safety of the NPP nuclear reactor facilities will not be impaired and be of design that reflects appropriate safety considerations against the severest conditions of anticipated natural phenomena . . ."*
>
> my truncation . . . and *emphasis*

46 The natural phenomena referred to in the NRRs were then clarified to be:

> *". . . D. "Anticipated natural phenomena" refer to on-site natural phenomena possible to occur including flood, wind (typhoon), tornado, freezing, rainfalls, snowing, lightning, landslide, volcanic effects, biological effects, forest fires, etc*
>
> *E. "The severest conditions" refer to the conditions assumed to be the severest according to the latest scientific and technological knowledge concerning the natural phenomena under consideration . . ."*
>
> my *emphasis*

47 The development of the *New Regulatory Requirements* up to this point in time pointed towards a probabilistic approach centred about establishing the *design-basis* – this being consistent with the practical implementation of the *Diet Investigation Commission*'s [4] final report recommendation that:

> *". . . 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*

48 The next step in development and inauguration of NRRs saw the introduction a series of draft guides, [6] such as of interest here *'The Assessment Guide of Volcanic Effects to the Nuclear Power Plant'* issued as a draft revision in June 2013 [7] – hereafter referred to as VAG.

49 **ASSESSMENT GUIDE OF VOLCANIC EFFECTS TO THE NUCLEAR POWER PLANT - VAG**[7]

50 The June 2013 VAG, or a substantially unmodified version thereof, is the subject of Court's interest.

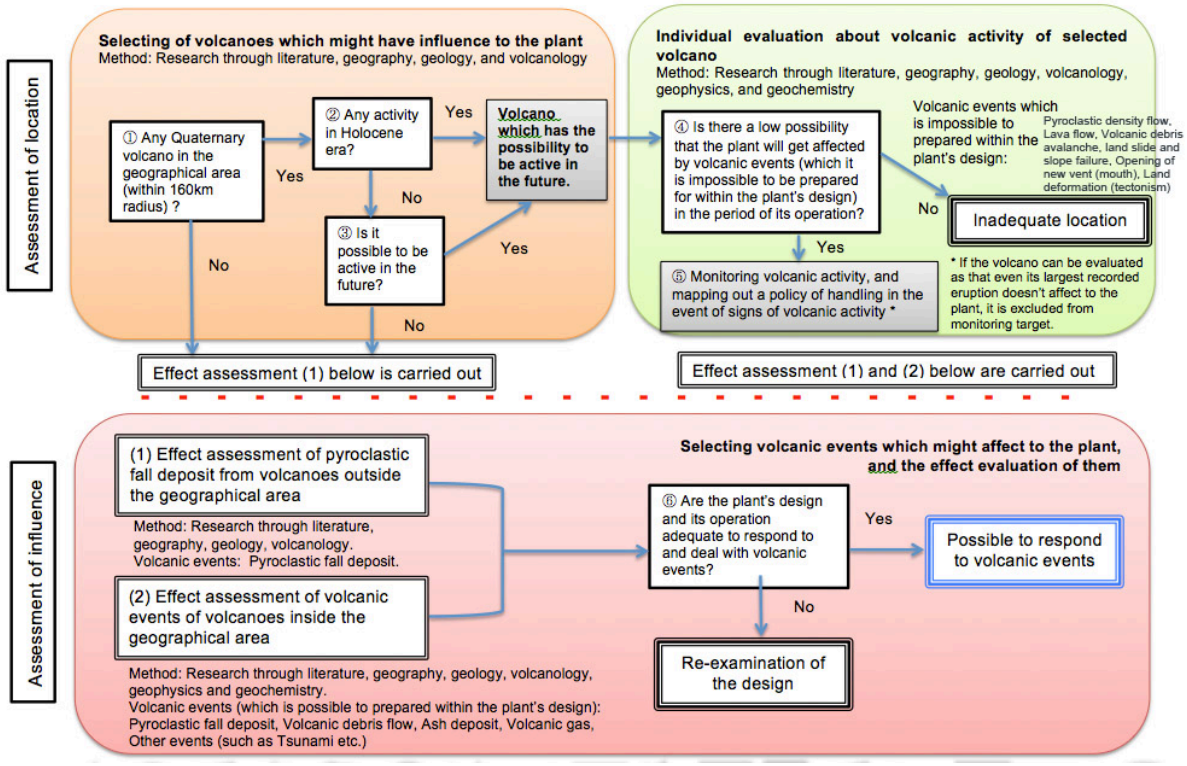
51 My first observation about VAG is that it considerably departs from all of the groundwork prepared and published [2,3,5] prior to its inauguration and, most certainly,

it is not compliant with the Diet Committee's recommendation [4] – see ¶44 and ¶47 above. This is because VAG makes no reference whatsoever, nor places any requirement upon the NPP licensee Kyushu Electric to establish a *design-basis* for each of the volcanic effects that are evaluated to be likely (ie probabilistically) to reach and affect the Sendai NPP and/or its critical supporting infrastructure.

52 My second observation is that in a number of detailed respects VAG is quite different to and therefore does not comply with the IAEA SSG-21 [1] – I arrive at this conclusion for the following reasons, including:

53 Consider the English language version of Figure **1** of VAG, reproduced below, which purportedly mimics Figure 1 of IAEA SSG-21 (as reproduced in ¶17).

Figure 1: Basic flowchart for effect assessment of volcanoes affecting the nuclear power plant



54 Under item 5 (in the right hand green box ■ above) the asterisked caveat states that

> *"... If the volcano can be evaluated as that even its largest recorded eruption doesn't affect to the plant, it is excluded from the monitoring target'.*

55 In effect, by excluding volcanoes on the basis of the magnitude of past events alone, this runs counter to the IAEA approach that evidence of an eruption during the Holocene (last 10,000 years) is a widely accepted and reliable indicator that future eruptions are

credible, meaning that the evaluation should proceed to the next stage referred to as *Assessment of Influence* (IAEA equivalent 4th stage).

56 In fact, the IAEA recognizes that the geologic record, as wholly relied upon in item 5 VAG above, is usually incomplete and smaller past eruptive events may have not been preserved in the geologic record. The possible absence of some past events from the geologic record are sources of uncertainties, giving rise to aleatory variability[3] that needs to be properly addressed in the NPP site volcanic hazard assessment.

57 For this reason, the IAEA encourages the use of *alternative conceptual models*[4] that have capability to compensate for a poor and/or unreliable geological record; changes in the tectonic setting, such as where individual volcanoes in a volcanic arc might have changed over a relatively short geologic period; and so on.

58 Another example in which VAG significantly departs from the IAEA SSG-21 methodology and approach is given in **Chart 1** of VAG. In this tabulation distances are set out as screening thresholds beyond which the particular volcanic effect with not affect the NPP.

59 I have a number of reservations about this somewhat inflexible and deterministic screening of volcanic effects by distance alone, including:

60 i) Footnote 1 of **Chart 1** states the screening distances relate to the center of the eruptive event although this may not necessarily be an existing caldera but, indeed, a new vent or vents freshly forming at some point in a volcanic field.

61 My understanding is that the volcanic activity on and around Kyushu is likely to comprise a series of volcanic fields and linked magma reservoirs, from which the formation of new vents could open up closer to the Sendai NPP site. If the screening distances fail to take into account the potential for new vents to form at some considerable distance from existing and past-established caldera, then the NPP site could be brought within the distal range of several types of volcanic activity.

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3 *Aleatory Variability* is the natural randomness of a process, ie it is pure chance contrasted to *Epistemic Uncertainty* which is the uncertainty due to limited data and knowledge of the phenomena –IAEA SSG-21 stresses the importance of understanding and distinguishing between sources of uncertainty in characterizing the volcano and its potential activity.

4 In circumstances where the geologic record is to be relied upon to provide a reliable sense of future events, then confidence is built up with the so-called *alternative conceptual model* allows the introduction of factors, parameters and circumstances that may not be fully understood. In this way, the basis skeletal knowledge provided by the geologic record might be supplemented by modeling in other data and circumstances to improve understanding of future events, etc..

62 ii) Footnote 2 notes that

> *". . . Regarding pyroclastic fall deposit, volcanic fall deposit, volcanic ash shall fall in an equivalent mass and thickness to that of the ash obtained from research in/around the plant, regardless of the source of eruption . . . "*

63 This condition enables the NPP licensee to rely solely upon the geologic record of a single, past tephra fall irrespective of the quality of the remaining ash residues (in account of past erosion, etc) and, importantly, for managing the ash fall at the NPP site, which requires knowledge of the rate and duration of the fall that are most unlikely to be available from the geologic record.

64 In fact, reliance upon the geologic record of a single past event is most unreliable. Far better, and again as encouraged by IAEA SSG-21, is the deployment of a probabilistic approach using a numerical simulation of tephra fallout at the NPP site. For such a tephra fall hazard analysis, a Monte Carlo simulation of the ash fall deriving from ***each*** capable volcano should be conducted, including for variations of eruption or ejecta volume, eruption column height, ash grain particle size and size distribution, wind and atmospheric stability – none of these requirements are set out in VAG.

65 My most fundamental criticism of VAG, compared to IAEA SSG-21, is that it does not, to my mind and professional way of doing things, instill sufficient discipline on the licensee to ensure that the volcanic hazards assessment is focused, comprehensive and meaningful.

66 Moreover unlike IAEA SSG-21, VAG does not require the licensee to explore and establish NPP-specific *design-bases* so much so that, instead, the outcome of the VAG exercise is more akin to tinkering around the edges than that of addressing the fundamental resilience and *defence-in-depth* of the NPP.

67 **THE OVERALL NUCLEAR SAFETY REGULATORY PROCESS**

68 Of course, I should note that the regulatory process steps beyond the regulator setting out guides and the standards to be achieved. This is because the licensee is required to demonstrate that adequate design safety has been achieved, ie there is in place an appropriate *design-basis*. This final stage is often interrogatory with, in this case, the NRA overseeing and approving, or otherwise, the submissions of Kyushu Electric.

69 The records of the meetings and submitted assessments between the NRA and Kyushu Electric, [8, 9, 10] together with the NRA wrap-up or *Screening Assessment Report*, [11] provide a revealing insight into and reflect the deviation of VAG from IAEA SSG-21.

70 Surprisingly, there is no requirement in the VAG nor any subsequent direction from NRA for Kyushu Electric to establish a *design-basis* for any of the volcanic effects that could affect the Sendai NPP – this overriding objective of establishing the appropriate *design-bases* is strongly elucidated throughout IAEA SSG-21, although it is not at all present in the VAG or regulatory process overall.

71 A specific example of clear deviation from IAEA SSG-21, is Kyushu Electric's reliance upon a single past event of about 12,800 years ago (BP 12800a) to determine the potential tephra ash fall (see ¶62-63). This selection limits the ash deposition layer to 12 to 15cm over an unspecified time, whereas a properly conducted probabilistic simulation would have provided a more realistic range of ash fall rate and deposited layer thickness with which to seed and define the *design-basis* for this particular volcanic effect.[5]

72 Another example is Kyushu Electric's nomination of the volcanic eruption in terms of the *Volcanic Explosivity Ind*ex (VEI).[6] Without much substantiation, the 2nd Stage screening (see ¶21-24) assumes that the Sendai NPP will be unaffected for VEI ranked eruptions up to and including VEI 6, assuming that the dominant volcanic effect (ie pyroclastic surge) is the only effect that can, either directly or indirectly (or both), at VEI 7 magnitude result in damage and malfunction at the NPP site.

73 I have three difficulties with this: First, the VAG does not specify that the volcanic activity under consideration should be selected and screened on the basis of VEI alone or, indeed, if at all; VEI itself is a somewhat crude and empirical measure, the derivation of which does not include all of the attributes that may contribute to the volcanic effects affecting the NPP site; and, at the VEI cut-off equal to or greater than 7 the volcanic effects would be intercontinental

5 Indeed, not even the most rudimentary probabilistic analysis has been undertaken by Kyushu Electric when considering the BP12,800a data set. The data of the geologic record shows that simply realigning the tephra deposit pattern to suit a change of wind direction at the time (ie turning the pattern ~90° to the east) would have resulted in a doubling of the tephra deposited layer thickness of 35+cm at the locality of the present Sendai NPP site.

6 The VEI scale is logarithmic, that is with each interval above VEI 2 being a tenfold increase in the ejecta mass criterion. Weaknesses of the VEI scale projection include that all ejected material are treated alike, so the influence of larger fragments (of more or to a lesser extent) are not taken into account in the distal tephra ash fallout and, importantly if VEI is adopted as a probability or threshold value for hazard and risk analysis, since it does not directly take into account the power of the eruption and includes qualitative observations, it is difficult to compare with historic and/or unobserved past eruptions. To my knowledge only two past volcanic events could be considered to have possibly been ≥ VEI 7.

in scale of consequences, so much so that any pre-prepared countermeasures at and around the NPP would pale into insignificance – in this respect, the work that I have presently underway (see ¶6-7) shows that, if VEI is taken to be a reliable indicator of volcanic effect, then the Sendai NPP will require some *design-basis* adaptions in account of volcanic activity on the range of VEI 3 to 6 and beyond.

74 The use of VEI is surprising because it is not generally presented as a specification yardstick when assessing the suitability (or vulnerability) of NPP sites. In this respect the IAEA SSG-21 only defines but does not explicitly recommend the use of VEI for NPP site assessment studies.

75 I consider the adoption and use of VEI to nominate the volcano event inappropriate.

76 Finally, I note that the *NRA Screening Assessment Report* [11] endorses Kyushu Electric's reliance upon its interpretation of Druitt,[12] claiming that advance warning from monitoring the nominated volcanoes will provide sufficient time to remove the irradiated fuel assemblies, including short-cooled fuel,[7] from both Sendai NPP reactors and spent fuel ponds, transferring these to a secure storage at some as yet specified location elsewhere in Japan.(see Sections 2 and 3 of the *Screening Assessment Report*)

77 As much as I admire Druitt's work,[12] particularly its innovative approach, I believe it somewhat reckless to rely solely upon what is, after all, very recent and largely untested work.[8] The NRA's reliance upon this single piece of recent, largely theoretical work to

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7 So-called *short-cooled* fuel is recently irradiated fuel where the extremely volatile iodine fission product (I-131) has not had sufficient time to naturally radioactively decay before it is transported from the NPP to storage or for reprocessing elsewhere – the volatility of I-131 and the higher rates of heat generation of the fuel heighten the radiological impact if a transportation accident should occur. Normally, short-cooled fuel taken from the reactor is held in the spent fuel ponds for 3 to 5 years before being moved, so for each of the Sendai PWR NPPs, each reactor would discharge upwards of 80 or so tonnes of fuel and there would be at least 100 tonnes of spent fuel in each pond, so around 400 tonnes of fuel would have to be moved in specialized transportation flasks, each carrying a load of 4 to 6 tonnes – moving this amount of intensely radioactive spent fuel in the short term would present a considerable logistical challenge of Kyushu Electric. The foregoing estimates are the expected spent fuel mass inventories under normal conditions, however at this time (2013) the *METI Agency for Natural Resources* reports that the spent fuel holdings at Sendai NPP total 890 tonnes, including dry cask storage but excluding reactor core fuel.

8 The Druitt, et al 2012 work[12] examines the pre-eruptive processes occurring in the magma reservoir of a past (17th C) eruption of the Santorini Volcano in Greece. It evaluates the timing for changes in silicic crystals in the magma reservoir of a volcano perched on the edge of a caldera-forming eruption. For the Santorini volcano a recharge of and increase in volume (by at least a few km3) of the magma reservoir with a silicic magma is shown to have occurred rapidly (at >0.05km^3/y compared to typically ~0.01km^3/y) during the relatively short and transient volcanic timescale of about 100 years prior to eruption following an 18,000 year gestation period since the previous major eruption. However, the authors of this innovative work acknowledge that it is based on a limited study of a single volcano; that the high magma reservoir recharge rate of 40 to 60km^3 requires a low viscosity melt and very efficient mixing at a high convective Reynolds No; and, amongst other things, that the addition of a few km^3 of magma into the reservoir would require a significant total uplift of tens of meters, at an average rate of ~1m/y over 100 years, compared to observed rates of sustained uplift of 0.15 to 0.2m/y (Iwa Jima caldera), so the absence of such significant caldera uplift means that the accommodation of the reservoir growth has to be by an equally rapid rate of subsidence or downsagging, which is not readily detectable.

safeguard the Sendai NPP when it, itself, acknowledges the volcanoes to be monitored by Kyushu Electric have been chosen

> *'. . . as their volcanic effects exceeding the plant's {Sendai's} design limit may have reached to the plant {Sendai} in the past . . .'*
>
> my added *{explanation}*

78 This is totally at odds with the overriding principle and absolute screening criteria of IAEA SSG-21 stipulating that any capable volcano that *could* affect an NPP beyond the limits of its *design-basis* should rule out that particular site for NPP development or, for an existing NPP, prohibit continued operation of any NPP at that site.

79 **IN CONCLUSION:**

80 In this opinion I have given a number of general and specific examples of how the *Assessment Guide of Volcanic Effects to the Nuclear Power Plant - VAG*[13] departs from the methodology recommended by the International Atomic Energy Agency *Volcanic Hazards in Site Evaluation for Nuclear Installations'*, SSG-21 – I could have cited many more.

81 In my opinion, adoption of VAG does not, and has not for the Sendai NPP site evaluation, produced the optimum assessment of the risks and hazards arising from potential volcanic activity on and around Kyushu Island in future years.

82 As a result, I consider the Sendai NPPs to be ill-prepared to resume reliable and safe operation of the basis of the volcanic risk and hazard assessment alone.

83 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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2 Nuclear Regulation Authority, '*Overview – Draft New Safety Standards for Nuclear Power Stations*' NRA Japan, January 2013 - https://www.nsr.go.jp/english/data/new_safety_standards.pdf

3 Nuclear Regulation Authority, *'Outline of New Regulatory Requirements (Design Basis)'*, April 3, 2013 - https://www.nsr.go.jp/english/data/new_regulatory_requirements1.pdf - an earlier version of this draft is dated 6 February 2013 but this, apparently, is the version before amendment by the ongoing separate study team(s).

4 The National Diet of Japan Fukushima Nuclear Accident Independent Investigation Commission*, 'The Fukushima Nuclear Accident Independent Investigation Commission'*, July 2012 - https://www.nirs.org/fukushima/naiic_report.pdf

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11 NRA, *'Sendai NPP of Kyushu Electric Co. Screening (assessment) report for permit application to change installation of power reactor (change of facilities of power reactor No.1 and No.2) (The Law for the Regulations of Nuclear Source Material, Nuclear Fuel Material and Reactors; under Clause 1-3 and 4, Clause 1-2 (parts related technical capacity) of Article 43-3-6)'* (in Japanese), 10 September 2014 – in Japanese – 0910-01-02

12 Druitt T H, Costa F, Deloule E, Dungan M, Scaillet B, *'Decadal to monthly timescales of magma transfer and reservoir growth at a caldera volcano'*, Letter, Nature 482, 77–80 2012 - http://www.nature.com/nature/journal/v482/n7383/full/nature10706.html#contrib-auth

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