Large and ASSOCIATES

EUROPEAN PRESSURISED REACTOR AT OLKILUOTO 3, FINLAND

REVIEW OF THE

FINNISH RADIATION & NUCLEAR SAFETY AUTHORITY (STUK) ASSESSMENT

(STUK OL3 INSPECTION REPORT)

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EUROPEAN REACTOR AT OLKILUOTO, FINLAND
GRANTING OF THE OL3 CONSTRUCTION LICENCE TO TEOLLISUUDEN VOIMA OY

SUMMARY

In this Review I examine aspects of the assessment carried out by STUK leading to the granting of the Construction Licence for the European Pressurised Reactor at Olkiluoto.

I have concentrated on STUK's approach to this first stage of licensing, particularly whether its examination of TVO's Preliminary Safety Analysis Report (PSAR) provided it with sufficient confidence to recommend to the Council of State the granting of the Construction Licence in January 2005, just about 12 months following TVO's first application to proceed with the EPR project. To my advantage, I have trawled through and cherry picked from STUK's voluminous PSAR Inspection Report (PSARIR), considering and highlighting those topics and aspects that I consider to fall short of the preparation and demonstration necessary for the project to progress to construction.

The substantive findings of my review relate inadequacies and incompleteness of the regulatory assessment at the Construction Licensing stage; if the speed at which STUK completed its assessment facilitated proper examination and testing of the nuclear safety case of this world-first installation of the Generation III EPR nuclear power plant; the failure to publish a full assessment of the plant's resistance to commercial aircraft crash (previously promised to be an essential nuclear safety prerequisite) and, similarly, the lack of demonstration in any aspect whatsoever that the plant will be sufficiently robust against all reasonably foreseeable terrorist action; and failure to give meaningful account to the radioactive waste management and eventual decommissioning of the plant and its nuclear island at some future time.

Overall, my opinion is that STUK's assessment of the Preliminary Safety Analysis Report is incomplete and there remain substantial uncertainties about the nuclear safety of the EPR project, so much so, that the Construction Licence should not have been granted in January 2005.

On the regulatory framework:

1) The regulatory requirement links, and so defines, the so-called abnormal operation events of *Anticipated Transients* and *Classes 1 & 2 Design Basis Accidents* in terms of fuel damage and not, as well, in account of the surety of the containments. This is inadequate in two respects, particularly for *Class 2 Accidents* with up to 10% fuel failure, because first there is a total dependence the intervention of measures to maintain the containments sound (irrespective of any weakening caused by the initiating event) and, second, the tolerability of any radioactive release seems to be based on a specified fuel damage level for uranium oxide fuel at the present burn-up ceiling of 45 MWd/kgU - should the EPR target 60MWd/kgU fuel irradiation level be permitted at some future date, or indeed, MOX fuel loading be adopted, the consequences of the *Class 1 & 2 Accidents* may have to be redefined upwards.

2) The compilation of the Probabilistic Safety Study (PSA), which is a regulatory requirement under YVL Guide 2.8, is incomplete with fire, flood, maintenance outages and certain external hazard contributions yet to be assessed (collectively, these are believed to contribute to the overall PSA risk by between 10% to 26%); STUK has found unspecified errors in TVO's *Design Phase* PSA submission; there remain uncertainties and/or incompleteness over the effectiveness of the corium (melted fuel core) management system; and vital aspects of structural performance within *Design Extension Condition* of the main reactor containment when subject to aircraft impact and explosive pressure waves are incomplete.

3) The regulator STUK has the discretion to recommend the granting of the Construction Licence whilst there remain significant areas of the nuclear safety case that have yet to be determined:-

    - Certain of these relate to the incomplete detail of the design of the structures and systems, which is understandable and most of which are unlikely to have significant bearing on the plant's final safety performance, but there are other areas that have a strong input into nuclear safety which have yet to be demonstrated and finally determined.
    - STUK itself notes that several key areas of the TVO PSAR nuclear safety case are incomplete and that these are not site- or local-specific issues, which must be taken to mean that the Areva design of the EPR has yet to be finalised. Indeed, there is a pervading sense throughout the PSARIR that the EPR design is still evolving, with important aspects of its engineered containment and systems design still requiring completion.

4) By leaving significant nuclear safety areas on hold points and by not having a larger pool of external consultants experienced and prepared in the EPR design, STUK may have placed itself at risk of running out of time and resource as the construction proceeds and the assessments demand a greater detail of consideration and involvement, so much so that this could result in a compromise having to be made over nuclear safety

Noting that the Olkiluoto 3 EPR is the first of this type of Generation III nuclear power plants to be built worldwide, it is of concern that the first licensing approval from design through to full commissioning is to be undertaken by, compared to other states, a relatively small national regulatory organisation that last licensed an established nuclear plant design (BWR) in the late 1970s.

Indeed, the accelerated pace at which STUK has reached the EPR Construction Licence design approval stage (starting from scratch) within just 12 months has resulted in the very short timescale from TVO's initial application of January 2005. In fact, at about the same time in 2005, Areva requested a pre-application EPR review by the well resourced United States Nuclear Regulatory Commission (NRC) who required two to three years to consider the generic safety issues, that is before it could consider any formal application to construct and commission an EPR in the United States. In effect, in recommending the granting of the Construction Licence for the first EPR, STUK has compressed into 1 year the 7 to 8 years taken by the very much larger and greatly more experienced NRC in licensing the not dissimilar and contending AP600/1000 Generation III PWR sourced in the United States.

On the projected performance and nuclear safety of the EPR plant at Olkiluoto:

5) It has not been possible to assess the plant resistance to large commercial aircraft impact because details of the analysis and plant response and/or its containment and equipment robustness have been not been released, according to STUK, for security reasons. However, it is interesting to note that the *design extension aircraft crash* is an 'add-on' to the EPR safety case, suggesting that the original EPR containment design, being pre September 11 2001, was not specifically designed to resist any impact loading greater than a light aircraft crash which was then (pre 9/11) the universally accepted design basis case drawn from the improbability or pure chance of a civil airliner accidentally crashing onto a nuclear power plant. Similarly, the resistance of the plant buildings to blast pressure waves has yet to be proven with, apparently, the main reactor containment building and other 'protected' building designs not being sufficiently finalised for the analysis to be undertaken.

6) Nothing whatsoever is included within the PSARIR on the resistance of the EPR plant and its operation to malevolent acts, although STUK acknowledges that Design Basis Threats (DBTs) have been taken into account in classified studies unavailable to the public. Without revealing any details, STUK goes so far as to state that the worse and most damaging reasonably foreseeable terrorist act (ie a nominated DBT) would not result in off-site radiological consequences greater than the *Design Basis Class 2* accident.

I find the absence of any publicly available details on aircraft impact (either deriving from an accident or deliberate targeting of the plant) of concern and, similarly, skirting around demonstrating that the EPR plant is sufficiently robust against terrorist attack (physical and/or cyber based) for reasons of security is disingenuous – this is particularly so in view of the number of public statements made by STUK that *'provision must be made for an impacting large passenger or military plane'*. So far as the claim that the worst foreseeable terrorist attack would result in a radiological outcome no greater than a *Design Basis Class 2 Accident* (2.5mSv compared to a maximum of 5mSv exposure effective whole body exposure at 1km over the year following,), this is entirely flawed and without any accountable demonstration, as is the STUK claim that the EPR plant safety and physical protection systems, designed and developed on the basis of *accidental* situations, will cope equally well when confronted with an intelligently driven, focussed and intentional terrorist attack.

On related matters:

7) Because plans for the Franco-German designed EPR build in France have been delayed and with the current nuclear build moratorium in Germany ensuring that any new-build in Germany in the near future is unlikely, the EPR at Olkiluoto 3 will be the lead prototype unit, that is the first of its kind operating ahead (in power generated) of later, if any, commissioned EPR power stations worldwide. Contractual arrangements between TVO and the Areva consortium are not publicly available and it is not clear from the PSARIR if Areva are contractually committed to monitoring and modifying the Olkiluoto 3 EPR in its role as the lead prototype, if not this could become a very demanding and additional burden on STUK.

8) STUK states that the decommissioning content of TVO's PSAR to be *'scarce and partly cursory'*, that the radioactive waste generated is *'based on a German 1,200 MW$_e$ plant'* compared to the EPR 1,600 MW$_e$ capacity, and that there is *'no estimate of the radiation dose to employees in connection with the decommissioning'*. In fact, such is the paucity of information provided by TVO that STUK, itself, can muster up only 2 pages of general comment on decommissioning in its 337 page PSARIR assessment and 102 page Safety Statement Annex. Thus the turning of a blind eye to the legacy of a defunct nuclear reactor site being passed to future generations is, I suggest, a failure of STUK to test whether the EPR project is a sustainable development.

9) There is nothing in the PSARIR that gives cognisance to any feedback from the Spring 2004 public and/or stakeholder consultation and, moreover, because of the acknowledged incompleteness of the TVO nuclear safety case, STUK's present PSARIR may not be considered sufficiently developed for a further round of public consultation. Indeed, now that the Construction Licence has been granted and works on the Olkiluoto site are underway, the public may find itself denied the opportunity to participate in the final decision to build and operate an EPR at Olkiluoto simply by reason of fait *accompli*.

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GRANTING OF THE OL3 CONSTRUCTION LICENCE TO TEOLLISUUDEN VOIMA OY

PART I REGULATORY ROLE AND THE CONSTRUCTION LICENCE

In January 2004, the Finnish electricity utility, Teollisuuden Voima Oy (TVO), submitted a Construction Licence application to the Finnish Government for the construction of a 1.63 GW_e[1] European Pressurised Water Reactor (EPR) nuclear power plant on the island of Olkiluoto.[2] Part of TVO's application was its *Preliminary Safety Analysis Report* (PSAR) in which it sets out how the EPR plant is to meet Finland's nuclear safety requirements.

The prerequisites for the granting of the Construction Licence are set out in Sections 18 and 19 of the Nuclear Energy Act[3] in that, essentially, to ensure nuclear safety it is required that that the plans of the nuclear facility shall entail sufficient safety (S19-1); that physical protection of the plant is adequate (S19-3); and that nuclear fuel management is satisfactory (S19-5/6). So, in a nutshell, S6 ,7 ,18 and 19 of the Nuclear Energy Act require that any nuclear plant that is to operate in Finland shall be accident free and sufficiently resistant against terrorist and other forms of malevolent action, all to the effect that no harm shall occur to people, the environment and/or property. The relevant sections of the Act are:-

> 6§ *The use of nuclear energy must be safe; it shall not cause injury to people, or damage to the environment or property;*

and

> 7§ *Sufficient physical protection and emergency planning as well as other arrangements for limiting nuclear damage and for protecting nuclear energy against illegal activities shall be a prerequisite for the use of nuclear energy.*

Approximately one year following the TVO application, in February 2005 the Finnish government in receipt of an *Inspection Report* (PSARIR)[4] from the Radiation & Nuclear Safety Authority (STUK), granted a *Construction Licence* for the Olkiluoto 3 project to proceed. STUK undertook the inspection (or assessment) principally by examining TVO's PSAR which would have involved an interrogatory process with meetings and exchanges between STUK, TVO and the plant design and construction consortia, although the records of the meetings and correspondence do not seem to be publicly available documents. STUK also engaged consultants to examine a number of generic, topical and specifically detailed issues,[5] although the reporting of these projects remains, generally, confidential.

The Construction Licence permits TVO to commence detailed planning and also proceed with the construction of the EPR nuclear power station at Olkiluoto, although on the proviso that the *Final Safety Analysis Report* (FSAR) addresses a number of outstanding and/or unresolved issues raised by STUK from its examination of the PSAR. Certain of the STUK issues have to be resolved by specific dates but, in the main, most issues raised by STUK are required to be addressed by the FSAR for which there seems to be no final submission date other than, it might be reasonably assumed, prior to nuclear commissioning of the EPR plant or before the first nuclear fuel loading of the reactor core.[6,7]

The construction of the Olkiluoto EPR will most probably complete in 2009 with the reactor commissioning to power generation in that year or the next, 2010. During the final years of construction and certainly prior to full commissioning the Finnish government would expect to receive, via STUK, a full evaluation of the nuclear safety case and, from the operator TVO, a statutory application for an operating licence.[8]

This Review considers if the timing of STUK's granting of the Construction Licence was apposite to the state of development of TVO's *Preliminary Safety Analysis Report* (the PSAR)[9] and, if STUK itself is sufficiently experienced, resourced and confident on its ability to pioneer the regulatory framework for the Olkiluoto 3 EPR which is to be the first nuclear power station of its kind. In this respect, I examine how STUK, in its OL3 PSAR Inspection Report (PSARIR)[10] and Statement of Safety (STUKSI),[11] gives regard to the novel features of design of the EPR, its safety systems and how these act to suppress and mitigate the effects of untoward events (of both accidental and malevolent natures) that could lead to radioactive release beyond the nuclear island.

All that said, I have not nor could I be expected to evaluate the role of Finland's government in promoting the adoption of the EPR. However, in this respect, I sense that the hidden hand of government seems to have been more amenable to adhering to TVO's quite demanding construction start timescale rather then permit STUK a longer and more commensurate period to build up its resources, to prepare for and complete its assessment.

PART II THE REGULATORY REGIME – STUK

Finland's experience of nuclear power commenced in the late 1970s with the installation of the two Soviet VVER-440 nuclear pressurised water reactor (PWR) plants at Loviisa (commissioned 1977 and 1981), and two boiling water reactor (BWR) plants at Olkiluoto (commissioned 1979 and 1982).[12] Since no new nuclear plants have been licensed since that time, in effect, the regulator has no recent experience of licensing a new nuclear power plant and no hands-on experience of modern, western PWR nuclear power plants, other than indirectly by association with PWRs operating outside Finland.

The detailed regulatory framework[13] centres on the YVL guides drawn up and issued by STUK, although the national Nuclear Safety Advisory Committee is involved via its stakeholder forum with the YVL guides. The YVL guides, there are 73 in total, set down rules by which the safety requirements for each YVL topic is to be achieved, although other methods of achieving the safety requirement may be acceptable to STUK[14] by demonstration.

a) Regulatory Approach & Licence Approval

Licensing approval is based on an acceptable (deterministically achieved) design of the plant's built structures and systems set against a prescribed envelope of accident and fault conditions that are bounded by the estimated probability or frequency of event, with these all within a framework of tolerability of consequences and with margins to avoid escalation to 'cliff-edge' situations.[15]

For Finland, which does not have a nuclear power plant design, development and manufacturing sector, the expectation would be that any incompleteness of the PSAR would relate mainly to site-specific factors. However, the Olkiluoto 3 EPR is the first of a new design of Generation III PWR plants worldwide, with the PSAR containing elements of conjecture, some scoping type calculations and incompleteness because the final detailed design has yet to be completed. The granting the Construction License on the basis of an incomplete PSAR, as reasoned by STUK, is that it has sufficient confidence that the plant will, when the design has been finalised, satisfy the nuclear safety objectives.

The FSAR is likely to be approved in stages, as those components of the design and/or system management are finalised and, once operational, any projected changes to the nuclear regime have to be incorporated into a revised FSAR and approved before implementation. For the final round of licensing the nuclear plant for operation, TTKE[7] approval is required but at this stage, as reported by STUK, the technical/administrational scheme is in its infancy so much so that it has no reason to review individual aspects of this very closely.[16]

b) Abnormal Event Classification

Abnormal events are classified to four groups according to the projected frequency of occurrence of the initiating event, these being i) *Anticipated Transients* at higher than 10^{-2} per year (frequency per reactor year of operation),[17] ii) and iii) *Classes 1 & 2 (Design Basis) Accidents*[18] at between 10^{-2} - 10^{-3}/y and less than 10^{-3}/y respectively, and iv) *Severe Accidents*. Extraordinary situations such as accidental aircraft crash require separate assessment and certain event circumstances are not classified solely on the predicted frequency of the initiating event, being considered to be *'Design Extension Conditions'* (DEC).

Abnormal events are directly specified in terms of the state of the nuclear fuel with *Anticipated Transients* mainly relating to fuel performance in the reactor core with, essentially, the fuel required to remain undamaged when subject to any $>10^{-2}$/y transient condition (thermal and mechanical). For *Class 1 Accidents* fuel damage (melting, fretting, etc) is limited to 1% of the reactor core load, whereas *Class 2* events tolerate up to 10% fuel failure with thermal and embrittlement limits imposed upon the fuel cladding.

Related to in-core fuel performance then, obviously, the safety rationale has to take into account the condition or robustness of the fuel to withstand abnormal and/or fault conditions. This introduces a rating of fuel properties based on the average (fuel core) irradiation history or burn-up, being determined presently at 45MWd/kgU[19] with any burn-up greater than this requiring demonstration although, that noted, the relationship between burn-up and fuel robustness under a variety of fault conditions is not at all linear.[20]

c) External Events

STUK claim that aircraft impact,[21] from both military and large passenger aircraft, have been identified and protected against to the extent that no immediate release of significant amounts of radioactivity will take place. Protection against aircraft impact relies upon strengthened containment of the reactor and other safety function buildings, together with wide physical separation of the safety systems and the enclosing building structures.

However, assessment and analysis of aircraft impact,[22] both accidental and intentional, together with other potential acts of malevolent intent (terrorism, sabotage, etc) are not available for public scrutiny because, as stated by STUK, *'This information is classified, because unless specifically otherwise provided, the following documents (amongst others) shall be secret according to Finnish law: To this category belong documents relating to or affecting the realisation of the security arrangements of persons, buildings, installations, constructions, and data and communications systems, unless it is obvious that access will not compromise the achievement of the objective of the security arrangements'*.[23] This blanket approach to security virtually denies any access whatsoever to aspects of analysis and/or the plant design that could possibly compromise, in the opinion of STUK, the security of Olkiluoto 3.[24]

Whereas detailed analysis and assessment of the resistance of the building structures and safety systems are not available, the general directive 395/1991[25] requires that the *'most important power plant safety functions shall remain operable'* and that *'the most important safety functions are reactor shutdown, residual heat removal from the reactor to the ultimate heat sink and the functioning of the containment building'.*

d) Severe Accidents

The regulatory requirement is that the plant will adequately respond to and cope with all reasonably foreseeable accidents, primarily on the basis that the containments will maintain surety and adequate leaktightness during and in the aftermath of *Anticipated Transients* and *Class 1* and *2 Accidents*, which are predicted to occur at relatively high frequency (up to 1E-2 to 1E-3/y).

The YVL Guide 2.8[26] acknowledges the possibility of containment failure by specifying probabilistic design targets for core damage and, separately, a large release beyond 100TBq[27] of Cs-137 equivalent to be less than 1E-5/y and 5E-7/y respectively - if these targets cannot be demonstrated achievable then the design has to be modified. These frequency targets have to be demonstrated by Probabilistic Safety Analysis (PSA) which is prepared and submitted by the operator, first in a preliminary design phase form (Level 1) and finally when the design has been finalised (Level 2).

e) Radiation Dose Exposure Limits

On the balancing side of the *Acceptable Risk -v- Tolerable Consequences* safety composite, the 'tolerable' consequences of normal operation and untoward events are specified in terms of effective radiation dose[28] to the most exposed member of the general public (from all uptake pathways).

For normal day-to-day operation, the permissible radiation dose is expressed as an annual limit 0.1mSv per year arising from normal operation of the plant.[29]

For *Anticipated Transients* the single incident dose limit is 0.1mSv, for both classes of *Design Basis Accidents* the single incident dose is 5mSv (over one year of exposure), and for *Severe Accidents* the atmospheric release of radioactivity must be less than 100TBq Cs-137 equivalent and with no consequential acute health effects, nor any long term restrictions on the use of extensive areas of land and water, where 'acute health affects' seem to be assumed to commence at approximately 500mSv.[30]

PART II COMMENT – ADEQUACY OF THE REGULATORY REGIME

Licence Approval to Date: The present situation for Olkiluoto 3 is that STUK considers the *'PSAR to provide an adequate description of the plant's principal design'*[31] and, specifically, that there are sufficient safety elements (redundancy, diversity and physical separation) included in the design for it to issue the Construction Licence, thus permitting construction works at Olkiluoto to proceed in accord with S5 and S7 of the Nuclear Energy Act.

So far, STUK's assessment of the EPR design by its PSARIR, published just a year following TVO's application of January 2004, seems to be an impressive achievement particularly in view that the Olkiluoto 3 EPR is the first of a new generation of nuclear power plants and that STUK has no regulatory (hands on) experience of a modern western PWR plant. That said, there remains a considerable amount of STUK approval required for the detailed design of safety significant structures, equipment, etc., before TVO can proceed with these (ie there remain 'hold points' in the manufacturing, installation, commissioning and approval processes).

The point here is whether STUK's inspection to date has been a thorough and fundamental assessment or, at the other extreme, just a paper exercise largely dependent upon the information, data and assessments presented to it by the plant designers, via TVO?

- Judging the quality and comprehensiveness of the TVO safety submission is not practicable because, although the TVO PSAR submission is ostensibly a public document, the STUK caveat *'due to security and commercial reasons some sections of the PSAR are not public'*[31] is likely to exclude any independent scrutiny of the safety case.[32]

- It is not clear how much, and to what detail, the PSARIR assessment has been completed by STUK in-house. The PSARIR seems to have involved surprisingly few external consultants,[33] and that at least some of the consultants' work could not have contributed (in its final form) to the PSARIR report because the work was not finally reported to near or past the PSARIR publication date.[34]

- Also, it not clear how privy the consultants themselves have been to the design of the Olkiluoto 3 EPR in undertaking their work because, at least in the corium catcher facility that is unique to the EPR design, the consultants' work does not seem to be EPR-specific.[35]

- Leaving large parts of the EPR design subject to hold points and further assessment and by not having a larger pool of external consultants, STUK may place itself at risk of running out of time and resource as the construction proceeds apace and the assessments demand a greater detail of consideration. It is interesting to note that STUK itself seems to acknowledge this in that it requires TVO to *'guarantee STUK's opportunities for oversight, sufficient amount of time shall be reserved for the regulator to process the required matters . .'*.[36]

- Safety licensing of nuclear power plants is generally preceded by i) a pre-application conceptual review, thereafter followed by stages of ii) construction and iii) operational licence points. Following just one year from TVO's application, STUK's approval for the issue of a Construction Licence includes all of the conceptual review of i) and much of the prerequisites of ii) to enable construction to proceed. Such expedience compares to the two to three years required by the very much larger and greatly more experienced United States Nuclear Regulatory Commission to complete Areva's EPR pre-application request (i) of February 2005 and, for a similar Generation III AP 600/1000 design, seven to eight years to conduct construction (ii) and the generic operations (iii) safety cases.[37]

Abnormal and External Event Classification: Other than acknowledging that a system of *Design Basis Threats* (DBTs) is in place to prove the design and management of the EPR plant against terrorism and other malevolent acts, STUK draws a complete blanket of secrecy over how it is to ensure that TVO safeguards public health and safety in this respect. Indeed, STUK chooses not to release any details of how the plant is required to withstand aircraft impact, fuel fires, explosive and pressure waves, even although these may result from accidents and external events not necessarily related to malevolent acts.

- It is not possible to determine how the regulator stipulates the permissible severity of the damage (and hence to the tolerability of consequences) for all reasonably foreseeable accidental events.

- Whereas it is acknowledged here that a degree of confidentiality is necessary over the details of the types of malevolent act prepared for, to exclude completely any reference to terrorism, sabotage and other malevolent actions from the safety inspection assessment (PSARIR) is a major omission from the overall nuclear safety case for the EPR.

- As much as the operator is required to maintain the appropriate levels expertise and competence in nuclear technology, similar and publicly accountable requirements should be placed upon the operator, via the regulatory regime, in terms of the preparedness of the EPR to thwart malevolent acts, including transparency on how the DBTs are arrived at and specified, how these are to be reviewed and tested[38,39] and, importantly, how the on- and off-site emergency plans are to be resourced and whether these are to include for response to terrorist and other malevolent acts[40,41] and for which (as yet) there is internationally set down guidance.[42]

Radiation Dose Exposure Limits: The regulatory approach to minimising radiation dose exposure to members of public is not clearly presented in the PSARIR and the distinction between the *Design Basis* and *Severe* accidents is somewhat ambiguous.

- The permissible radiation dose exposures referred to in the PSARIR do not seem to directly relate to the emergency ratings (*'site emergency'*, *'emergency standby'* etc) specified in YVL guide,[43] nor indeed how and if these are to trigger the off-site emergency response plans as required under the European Council Directive 96/29/Euratom.[44]

- The 3-month delay before the long term dose exposure commences is not at all clearly related in the PSARIR and, as it is explained,[45] it seems to be nothing more than a ruse to separate short and long term exposures most probably to the same critical groups of individuals.

- The definition of the 100TBq Cs-137 equivalent release does not have a logical derivation, particularly applied to EPR with its large fuel core, 4,300MW thermal rating and (planned) high fuel burn-up of 60GWd/T. The Cs-137 fuel inventory would be at least 3.10^5TBq so the adopted 100TBq release represents a very small Cs-137 release fraction of 0.033%. Applied to the degraded core accident scenario, which is probably assumed to be the worst-case severe accident,[46,47] the potential EPR release would be well beyond the magnitude of the gradual release defined by YVL 2.2.[48]

- The general radiological protection requirement that any radiation release *'should not result in acute harmful health effects'*[31] is set too high at 500mSv exposure, particularly if this is to be used as the upper limit of exposure to be averted by countermeasures, such as evacuation of members of public.[49]

- Accordingly, the *'severe'* conditions somewhat loosely defined in YVL 2.2 are considered to be inappropriate (too mild) for a reasonably foreseeable accident in which a significant part of the fuel core degrades.

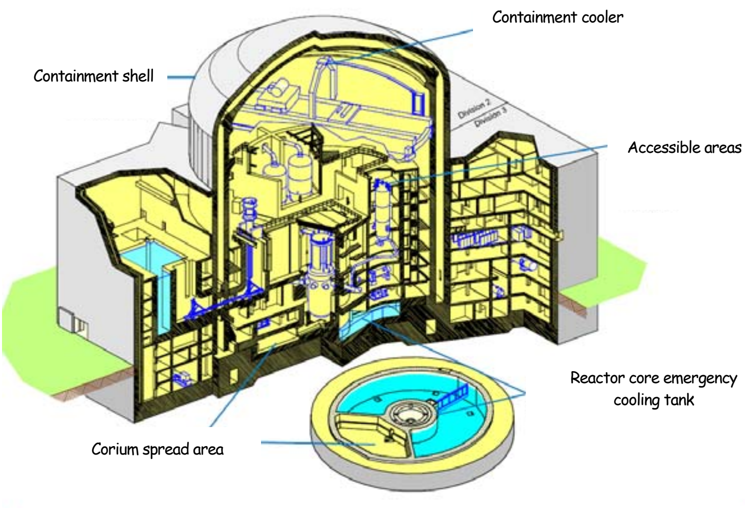
- Similarly, the YVL 2.2 conditions are considered totally inappropriate for a terrorist attack, an act of sabotage, or similar malevolent action where the combination of both primary and secondary containment failures might be achieved in order to maximise the radioactive release and consequences in the public domain.

PART III CLAIMS FOR EPR DESIGN, TARGET PERFORMANCE & NUCLEAR SAFETY

The EPR is an adaptation of the light water moderated reactor or pressurised water reactor (PWR) which, it is claimed, incorporates a number of improvements to facilitate greater performance, output reliability, and overall nuclear safety over the present generation of PWR power plants.

Performance

The claim[50] of improved performance centres around lowering the fuel cycle costs by operating the fuel at a much higher burn-up (up to 60GWd/T);[51] a lowering of the fuel enrichment



EPR Containment Structures and Corium Catchment level required in some of the fuel core zones; with provision for plutonium recycling (MOX) up to 50% of the total fuel core; with refuelling outages between 12 and 24 months, with an 18 month refuel period as the basic option; and a shorter refuel outage of 20 to 25 days. The EPR design also claims to achieve 90% availability over a projected 60 year lifetime with power generation costs of around 2.7 c€/kWh.

Nuclear Safety

In the nuclear system, the primary circuit loop configuration and detailed design of the main components is very similar to existing PWR units,[52] being based on an established separation and containment,[53] particularly 4-way redundancy and diversity approaches,[54] although some levels of redundancy have been reduced over the design base German plants.[55]

A key and central feature of the EPR design is the extended deployment of passive safety systems that are enacted only by 'natural' forces, such as gravity, natural circulation, compressed gas, etc.. For example, the valves and diverters deployed to align certain of the passive safety systems are 'failsafe', requiring power to stay closed for normal operation but which will open automatically upon loss of power (or vice versa).

The fuel building and reactor containment introduce elements of enhanced structural design to resist explosion overpressure wave and aircraft crash, and the containment dome includes a perimeter annulus extraction system to supplement cooling in the event of primary circuit failure. The principal means of safeguarding the nuclear island against malevolent acts (ie aircraft crash, placement of explosive devices, explosive packed vehicles, etc) seems to be that of segregation, with a series of safeguard buildings clustered around the most sensitive parts of the plant (reactor, spent fuel, emergency diesel, and seawater intake buildings), although no details of this are available.[31]

A novel feature of the reactor containment building is the introduction of a refractory-lined reactor pit from which is intended that molten fuel debris (corium) can be diverted, passively cooled over the long term, managed and eventually recovered; a facility to recombine any hydrogen generated by the zircaloy clad reaction with steam during and in the aftermath of a fuel core melt; and the location of the emergency core cooling water supplies being within the main reactor containment building. In the immediate aftermath of a severe core melt and failure of the reactor pressure vessel, the design intends to provide for 12 hours of passive cooling of the containment enclosure, following which enforced cooling of the containment must be evoked.

The Safety Composite

In complex engineered systems, particularly hazardous plants where safety is central to the engineering design and development process, fundamental changes take time. So it has been with the development of the EPR deriving, as it does, from the presently operating French N4 and German Konvoi PWR plants that are, themselves, derivatives of earlier marques of the PWR power plants operating worldwide. As a rule of thumb, implementing a significant change to a generic reactor type takes about ten years with, invariably, the need to change being triggered by some previous event that has either directly affected nuclear plants, such as a serious accident, or indirectly by a trend, possibly such as global warming, or an untoward socio-political faction such as international terrorism.

The EPR safety design endeavours to tackle shortfalls in the human-machine interaction, such as those that contributing to the Three Mile Island meltdown in 1978, by providing an over-arching array of interactive safeguarding components, autonomous systems and passive design features that do not require, or so it is claimed, human intervention during the early and often crucial stages of the incident progression. The design claims to address the need for effective containment for severely damaging reactor incidents, such as Chernobyl in 1986, by endeavouring to structure the management of events beyond the normal performance envelope with, for example, the installation of quite complex containment structures and with post-incident management of a melted fuel core to thwart the size and impact of radioactive release.

Terrorism, Sabotage and Other Malevolent Acts

The defence against terrorist and other malevolent acts is not so obvious in the EPR design. This is most probably because the EPR structural design and layout was committed to well before the September 11 of 2001 acts of terrorism that highlighted the need for the engineered design of hazardous plants to take greater account of and to be resistant against malevolent acts. In this respect the anti-terrorism features will comprise, one has to assume because details have been withheld by STUK, mainly means (both physical barriers, etc and by intelligence gathering) by which ill-intended approach to the plant is restricted by security cordon and by the robustness of the plant generally to withstand physical intrusion (by explosive device, crashing aircraft, truck bomb, etc). The second anti-terrorism line of defence is the claim that any reasonably foreseeable malevolent act would not result in severity of damage and consequences of the nominated design basis accidents, including the DEC(A) conditions.

PART III COMMENT - EPR DESIGN, TARGET PERFORMANCE & NUCLEAR SAFETY

So, grandeur of size, independence from human intervention by reliance upon autonomous and passive systems providing absolute and prescribed safety, and a claimed economy of scale all herald the coming of this Generation III reactor system to be unsurpassed in efficiency, operating costs, and nuclear safety – or do they?

Performance and Safety: It is unarguable that nuclear safety and long-term economics of production must drive in the same direction because the costs of a major radioactive release are too large for this to be otherwise.

- However, this principle should not be extended to the assumption that a highly reliable plant (90^{+}% availability claimed for the EPR) is necessarily a safe plant, so much so that the claimed reliability of the EPR is not the principal safety indicator.

Nuclear Safety: Increasing demands on safety go hand-in-hand with increasing complexity of the safety systems and organisational structure that links the systems together, but for the EPR, and its US derived counterpart the Westinghouse AP600/1000 series, considerable effort has been put into simplifying the safety systems by deployment of passive devices.

- The EPR passive safety systems might be aimed at removing the unreliability and unpredictability of the human-machine interface, but in doing so there is risk that such largely autonomous safety system organisational structure could introduce weaknesses that are far removed from the interface, being hidden deep and laying latent in the safety organisational structure itself.

- Passive safety systems can remove or bar the opportunity for the human intervention to halt or redirect a prescribed and autonomous course of action, with the possible result that the situation is incorrectly analysed and acted upon by the system (or the system designer in the first instance) culminating in a run-away cascade to a serious incident.

- Some of the safety features of the EPR are entirely novel and cannot be tested in earnest, for example the corium catching pit which can never be pre-tested at full scale and under all of the extremely hostile conditions that might prevail in the immediate aftermath of a degraded core incident.

Safety Composite: The EPR is a very large commercial venture, it brings together a diverse range and number of companies, different nationalities, roles and interests, and it is to be the first of its kind.[56]

- The complexity of the EPR project could be such that it may not be possible to establish a single, well-defined safety review of the many and complex interactive processes involved.

- The novel design features of and new concepts that will be required to operate the EPR plant are likely to place extra demands on the independent regulator, particularly in that STUK might be expected to assume the role of a stern examiner and, indeed, the designers of the plant might well expect and, to a certain extent, rely upon the regulator to double-check their concepts, assumptions and designs – it has not been demonstrated that STUK has sufficient experience or human resource to undertake the first-time licensing of the first of a new generation of nuclear power plant design, nor that the regulatory framework is, itself, amenable to the role of double-checking the design.

- Similarly, the operator TVO will have to achieve and maintain appropriate levels of technical and managerial competence to operate safely the Olkiluoto 3 EPR and, in the absence of the technical and administration submission (TTKE) it is not clear how STUK is to assess this at this time.

Incomplete Verification of the Design to Date: Although the basis of STUK granting the Construction licence is that it has sufficient confidence that the current design of the EPR can be developed to meet the nuclear safety targets, the remain a number of key safety topics that require closure.

A key safety parameter is whether the maximum radioactive release is set at and limited to a realistic level. The release of 100TBq Cs-137 equivalent is entirely dependent (in a severe core degrade incident) upon continuing surety of the primary reactor circuit and then, ultimately, the secondary containment (dome). Putting aside a terrorist act that intentionally and successfully sets about breaching these containments (which, surely, is a reasonably foreseeable possibility), STUK requires the design of the containments to keep the radioactive release below limits set for each of the transient situations, design basis accidents, and severe accident circumstances previously discussed and as PSA targets specified in YVL Guide 2.8.[26]

- The probabilistic safety analysis (PSA) that demonstrates the achievability of these targets has only been completed to design stage, so further demonstration is required of the operator during the construction stage as the detailed design is developed – if the final design is such that the targets cannot be met (and STUK acknowledges that inaccuracies have been found in operator's PSA in this regard) then it may be necessary for STUK to re-examine if the risk has been reduced as far as reasonably practicable (ie change the rules).

- There are similar uncertainties (and/or incompleteness) relating to the demonstration of the effectiveness of the molten core management systems (the corium catcher) and the structural analysis of the secondary containment when subject to aircraft impact, both of which are subject to ongoing investigation so, at this time and until the respective designs are finalised, the effectiveness and risks arising from these two key safety topics cannot be fully demonstrated.

- Other risks (initiating events) that each contribute to the overall probabilistic targets for core damage and secondary containment failure, but at a relatively minor scale of a few percent each, including internal events such as fire (2% PSA contribution) and flood (2%) damage, annual maintenance outages (6%), falling objects, and so on, cannot be fully assessed until the detailed design of the plant has been completed.

- Similarly, certain external hazards (in total accounting for about 16% of the PSA risk) have yet to be subject to PSA including, surprisingly, seismic events for which the fire-fighting systems are not intended to be seismically qualified, although sources of fire ignition are.[57]

The point here is that in permitting the construction to proceed in the absence of a fully developed PSA might, if the detailed design and final installation cannot meet the PSA targets, result in STUK having to reach a compromise with the operator over nuclear safety.

Aircraft Impact: The PSARIR assesses two categories of aircraft crash being the *'design basis airplane crash'* which relates to the crash of a light airplane, although this is not defined in terms of mass and velocity, and the '*design extension airplane crash*' which relates to both a military aircraft and a large passenger carrying aircraft although, similarly, neither aircraft type is specified in any other detail. For the latter and obviously more demanding event (possibly, other than a military aircraft refuelling tanker) STUK place total confidence in the design of the reactor building, its containment, the fuel building and two other but unspecified safeguard buildings, noting that these buildings will also be protected against any fire resulting from the crash.[58] Pipe and cable communications between the respective buildings will be by underground tunnels with, again unspecified, sufficient protection against collision impact and fire. It is not clear in the PSARIR if it is meant for the reactor primary circuit pipework to be aircraft crash/fire resistant alone (should the outer containment building envelope fail).[59]

- In the event of a *design extension aircraft crash*, certain of the other 'protected' or 'safeguarded' buildings (valve stations of the steam and feedwater lines) are sacrificial with this being somewhat contrary to the robustness of the same line penetrations into the reactor containment building. STUK states, but does not quantify in any way whatsoever, that the complete release of radioactive materials from sacrificial and unprotected buildings would not result in a radiation dose uptake exceeding 5mSv.[60]

- STUK considers the design basis set out in TVO's PSAR is sufficient for and in accordance with STUK's requirements for aircraft impact and hence for the granting of the Construction Licence. However, the fact that the *design extension aircraft crash* is an 'add-on' the EPR safety case suggests that the original EPR containment design, being pre 11 September 2001, was not specifically designed to resist any impact loading greater than a light aircraft crash which was then (pre 9/11) the universally accepted design basis case derived from the improbability of a civil airliner *accidentally* crashing onto a nuclear power plant.[61,62]

Explosive Pressure Waves: The PSARIR states, but provides no further detail or substantiation, that the plant designer has adopted a standard for modelling the building structural resistance to explosion from a US military engineering report,[63] going on to state that *"the structures will be dimensioned such that the explosion pressure wave is one of the load cases"* and that *"no analyses of the impact of a pressure wave on the plant unit have yet been presented"*. In the absence of the assessment of the resistance to pressure waves, STUK argues that since the plant *has* been designed to endure an airplane crash (although, again, nothing is presented to substantiated that the *design extension* aircraft impact/fire features are in place at this time in the structural design of the plant – see Ref 58), it can be postulated on the basis of simple impulse assessments that the structures and components will also withstand an explosion pressure.

- This is entirely incorrect in that not only is the impulse model inappropriate for determining the structural response to an explosive overpressure, but that being versed only in terms of explosive overpressures there is no account whatsoever to ordnance and munitions devices that are specifically designed to penetrate (rather than to collapse) structures, including hard components of a crashing aircraft (turbo shafts, undercarriage spars, etc).[64]

- Performance of structures to explosive loading requires account of *shock* qualification of all components of the structure. Particularly vulnerable are entry points and penetrations into the main structure where the imposed dynamic stress may locally exceed that analysed for the main structure and the inclusion of internal fluid (eg inside isolation valve bodies and pipework) may induce stress factors of an order of magnitude greater than the supporting structure.[65] There is no reference whatsoever to any special treatment for the shock qualification analysis of the containments and penetrations in the PSARIR.

- In the absence of the structural design of the building containments and plant equipment being finalised and demonstrated to be sufficient to safeguard against explosive events (either accidental or deliberately targeted at the plant), commencing with the physical construction of the sub- and superstructures of the various 'protected' buildings carries with it the risk that the finished building structures might be structurally inadequate – this being quite contrary to the opinion expressed by STUK that the PSAR *"description of the strength analysis methods is sufficient for the purpose of processing the construction license"*.[66]

Other Internal Explosions: Setting aside explosion arising from hydrogen generation in the aftermath of a severe core melt for which the control burn and hydrogen recombiners, the hydrogen risk from the fuel clad in the spent fuel pool area (say, as a result of a loss of water in the fuel pond) or in the new fuel storage area, for whatever reason, does not seem to have been addressed by STUK.

- STUK considers the safeguard against internal explosions to be sufficient by restricting the use of explosive gases within the plant to the essential minimum,[67] and there is no reference whatsoever to explosions deriving from direct or indirect malevolent action, although the TVO final fire analysis is to be submitted *"once the design reaches as sufficiently advanced state"*.[68]

Loss of Coolant Accidents (Events): For LOCA situations the level of fuel clad failures is assumed to be 10% with the resulting overall radiation dose of 70.10^3Gy (Gray) over the 12 months following the incident, which STUK relates to be at a maximum for an incident at the sixtieth and final year of operation of the plant, although why such significance is placed upon the relatively small contribution of activation products is not at all clear.[69] For a severely damaging incident, where the entire fuel core inventory is released into the containment the 24 hour dose is 300.10^3Gy and $5,000.10^3$Gy over the twelve months following.

- These radiation dose burdens are estimates since the developer, TVO, has yet present the assumptions and detailed analysis for the two incident severities and other incident scenarios.

- Also, there is some ambiguity over the qualification of the steam loading in different areas of the reactor containment building which require to be resolved for the severe LOCA event with the extent and type of equipment qualification within the containment remaining to be determined, and it may be necessary to design and develop entirely new instrumentation and control components – the issues of qualification and instrumentation and control systems under LOCA generated conditions remain unresolved.[70]

Reactor Containment: Essentially, the reactor containment (the dome-like structure) serves three purposes: The first function is to contain any radioactive release to atmosphere emitted by failure of the reactor primary, circuit thereby stopping or delaying a release to the environment; the second containment function is to provide a protective barrier to the primary circuit and its safety systems against external events;[71] and the third function is, in the aftermath of a severe reactor fuel core degrade, to contain and manage the molten core after it has burnt through the reactor pressure vessel and then, over an extended time period, passively cool the melt or corium to a solidified state to prevent it burning through the building substructure base.

- **Containment Equipment Hatch:** Under a number of adverse circumstances, particularly during outages, the containment is effectively open via a large (8.3m diameter) equipment access hatch and should a radioactive release incident occur whilst the containment is incomplete (ie hatch open), then several hours may pass before the hatch can be closed and sealed - STUK require further justification of this, together with accessibility into sections of the containment during emergency situations.

  Access to this major penetration of the reactor containment also presents a security issue. If, for example, an insurgent group were able to penetrate the outer security of the power station[72] during a refuelling outage, then access into the main reactor area would be (physically) open. There are a number of DBTs that could be pursued once insurgents were inside the main containment, including direct action on the open reactor fuel core and/or drain down of the reactor-fuel pond canal and beyond – because STUK will not release any details relating to security, it is not known if this particular subset of DBTs have been addressed by STUK.

  Further and detailed information is also awaited by STUK with regard to conditions within the annulus of the inner and outer shells of the containment building, particularly relating to the leak rate, mid-winter temperatures, etc., and, particularly, the capability of the annulus to maintain its negative pressure function for 6 hours following a station black-out. Generally, the preliminary design and PSAR has not addressed the single-failure criterion required for the human and services access penetrations through the reactor containment building and these are awaited, and there are redundancy and diversity shortfalls in the manner in which the containment is isolated.

- **Core Melt (Corium) Catchment & Cooling:** In the closing stages of a severe incident culminating in core fuel melt, the corium penetrating through the bottom of the reactor pressure vessel is directed into an enclosed pit below. The catchment pit serves to collect the (100 or so tonnes of)[73] corium where it is retained until it burns through a dam to allow flow into an adjacent spreading and cooling area. The time lags between retention of the corium in the catchment pit, burn through of the dam gate and eventual spreading into the cooling area are critical in order to, first, collect as much of the molten fuel corium as possible, providing adequate mass (head) to achieve a sufficient mass flow, and hold a low viscosity (flowability) to maximum the spread over the cooling floor of the spreading area. The periods over which the corium is cooled to a solidified crust are reckoned to be:

RPV DISCHARGE	>>>	DAM BURN-THROUGH	>>>	CORIUM SPREAD	>>>	COOL TO CRUST
50 - 100 minutes		>2 hours		< 10 seconds		hours to a few days

  This entirely novel feature of the EPR has yet to be proven by reasonably scaled trials – the sole European facility at Cadarache (France) can melt a depleted uranium batch of simulated corium of just 80kg[74] compared to the 140,000+kg that could arise in a full fuel core melt of the Olkiluoto 3 EPR.[75] In reality, the formation, stability and transfer of the melt corium is likely to be quite complex, perhaps dominated by combined secondary influences that cannot be reliably modelled and, indeed, attempting to manage 100 or more tonnes of molten radioactive material in a highly charged steam atmosphere may introduce other deleterious factors, some of which do not seem to have been identified by STUK in its assessment of PSAR

- **Fuel Ponds – Unirradiated & Irradiated Spent Fuel:** Two fuel ponds are included in the EPR plant design, both received irradiated and new fuel assemblies and operate at a maximum design temperature of 45^{o}C. All components of the fuel pond cooling system are located in the fuel pond building.

  In the event of a complete loss of electrical power, including standby diesel generators, the fuel pond water commences boiling after 5.4 hours if a total reactor fuel core has been transferred to the pond (ie during a RPV inspection outage). If no make-up water is added, about half of the fuel pond water would have evaporated by 24 hours, leaving about 2m of water above the racked irradiated fuel assemblies. With further loss of pool water and with the fuel racks uncovered, cooling is via the steam generated from the remaining sump water in the pond, under which circumstances the abnormal operation design temperature is 100^{o}C. The scope of the abnormal situations and operation of the fuel ponds adopted by TVO's PSAR seems somewhat limited: It assumes that there will always be some level or effective cooling and time to arrest and rectify any deteriorating situation; if operable the pond cooling systems do not seem to have diversity and sufficient redundancy, particularly with the principal means of cooling (pumped circulation, etc) being house in the pond building enclosure; and no account seems to have been given to situations and circumstances that could arise from well planned and executed acts of terrorism specifically targeted at the fuel pond area.

Terrorism, Sabotage: Catering for potential terrorism since 11 September 2001 requires the plant design (and its operation) to provide adequate safeguards to mitigate the outcome of a well thought-out, determined and seen-through terrorist attack.

Generally, the PSARIR implies that the deterministic design of the plant is such that the outcome of any reasonably foreseeable malevolent act would not result in severity of damage greater than any of the accident circumstances already catered for by the design. However, this assumption might be considered somewhat disingenuous because a would-be terrorist might plan the malevolent act to achieve a specific outcome beyond that of the consequences of reasonably foreseeable accidents.[76]

- Protecting a nuclear plant against terrorist attack requires more than increased vigilance at the plant perimeter, moreover protecting against a previous mode of terrorism, ie aircraft crash, is no guarantee that the terrorist might adopt an entirely different but equally ingenious modus operandi.

- The terrorist threat might next come from an insider employed at the plant, acting in either a passive or active role, or it might be a missile attack, a helicopter laden with explosives, a contrived off-site event, or an intellectual act such as a cyber attack hacking into the plant's computer and software systems, and so on and so forth, to the extent of who knows and who can reliably predict if a particular nuclear plant will be targeted, when and by what means.[77]

- Also, the STUK approach to explosive resistance of the structures derives from a basis that does not appear to directly account for acts of sabotage and/or terrorism and there seems to be no cognisance (in the publicly available safety case) to malevolent acts which is an intrinsic requirement via the *Design Basis Threat* (DBT) system enforced in other nuclear countries.[78,79] In addition to the pressure wave analysis, there are a number of DBTs that should be applied to the EPR to demonstrate its resistance to malevolent acts - these include air-fuel explosions, direct impact by ordnance, explosive charges being placed within the nuclear island complex, and isolation of emergency supplies (diesel generators) and incoming/outgoing connections (pylons, transformers, switchgear).

- Designing specifically to counter such DBTs is likely to require significant civil engineering (structural) input at the design stage, thus modifying the pre-11 September 2001 design of the EPR.

In Conclusion: My review of the PSARIR has shown there to be a number of areas of incompleteness and uncertainty relating to assurance of the nuclear safety of the future operation of the EPR at Olkiluoto. I am concerned that proceeding with the civil engineering works in the absence of certain of these may result in some compromise to the effectiveness and reliability of the overall nuclear safety regime. In view of STUK's somewhat limited human resources and lack of recent experience of new reactor technology, I am also concerned that the first of this new generation of nuclear reactor design may not be subject to the exacting level of regulatory review required.

Overall, my opinion is that STUK's assessment of the Preliminary Safety Analysis Report is incomplete and there remain substantial uncertainties about the nuclear safety of the EPR project, so much so, that the Construction Licence should not have been granted.

REFERENCES & NOTES

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[1] At 1630 MWe output (excludes about 90MWe internal load and with a total thermal capacity of 4,300MW) the proposed Olkiluoto 3 is larger that then the 1300-1450MWe of the design base German and French reactors.

[2] Finland presently operates four existing reactors (2656 MWe net total - generated a 21.4 billion kWh in 2002). Of these, two BWR units (of Swedish manufacture) are operated by Teollisuuden Voima Oy (TVO) and two (Russian PWRs) by Fortum Power & Heat Oy (Fortum).

[3] *The Nuclear Energy Act 1994* (as amended) defines a Construction Licence under Sections 18 and 19, viz:

***Section 18** - Construction of a nuclear facility having considerable general significance*

A licence to construct a nuclear facility referred to in section 11 may be granted:

1. *if a decision in principle, as referred to in section 11, has deemed the construction of a nuclear facility to be in line with the overall good of society, and Parliament has decided that the decision in principle remains in force; and*
2. *if the construction of a nuclear facility also meets the prerequisites for granting a construction licence for a nuclear facility as prescribed in section 19.*

***Section 19** - Construction of other nuclear facilities*

A licence to construct a nuclear facility other than referred to in section 18 can be granted:

1. *if plans concerning the nuclear facility, its central systems and components entail sufficient safety and protection of workers and the population's safety has otherwise been taken into account appropriately when planning operations;*
2. *if the location of the nuclear facility is appropriate with respect to the safety of the planned operations and environmental protection has been taken into account appropriately when planning operations;*
3. *if physical protection has been taken into account appropriately when planning operations;*
4. *if a site has been reserved for constructing a nuclear facility in a town plan or building plan in accordance with the Building Act (370/58), and the applicant has possession of the site required for the operation of the facility;*
5. *if the methods available to the applicant for arranging nuclear waste management, including the final disposal of nuclear wastes and the decommissioning of the facility, are sufficient and appropriate;*
6. *if the applicant's plans for arranging nuclear fuel management are sufficient and appropriate;*
7. *if the applicant's arrangements for the implementation of control by the Radiation and Nuclear Safety Authority (STUK) as referred to in subsection 1, point 3 of section 63 in Finland and abroad, and for the implementation of control as referred to in subsection 1, point 4 of section 63 are sufficient;*
8. *if the applicant has the necessary expertise available;*
9. *if the applicant has sufficient financial prerequisites to implement the project and carry on operations; further*
10. *if the applicant is otherwise considered to have the prerequisites to engage in operations safely and in accordance with the obligations under Finland's international treaties; and the planned nuclear facility otherwise fulfils the principles prescribed in sections 5–7.*

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***Section 63** - Supervisory rights*

The Radiation and Nuclear Safety Authority (STUK) shall be entitled, in order to carry out the supervision required by this Act, and by the provisions issued hereunder and by Finland's international treaties in the field of nuclear energy, to:

1. *inspect and control operations referred to in subsection 1, points 1–4 of section 2, and for this purpose have access to any place where such an operation is being carried out, as well as to carry out measurements required for supervision, take and receive samples and install equipment necessary for such supervision;*
2. *oblige the licence applicant to arrange entry for the Radiation and Nuclear Safety Authority (STUK) to carry out inspections and measurements and to take samples on the premises where, according to the application, the operation referred to in subsection 1, points 1–4 of section 2 will be carried out;*
3. *require that nuclear fuel or the buildings and equipment intended as parts of the nuclear facility be manufactured in a manner approved of by the Radiation and Nuclear Safety Authority (STUK), and oblige the licence-holder or licence applicant to arrange for STUK sufficient opportunity to control manufacture of the fuel or such buildings or equipment;*

> 4. *receive necessary information and be provided with the plans and contracts and their grounds concerning the manufacture, quality control or processing of nuclear materials, nuclear waste, the nuclear facility and its buildings and equipment, as well as any material, device and equipment referred to in subsection 3 of section 2;*
> 5. *oblige any person carrying out the operation referred to in subsection 1 of section 2 to submit reports in the prescribed form, as well as other necessary information and notifications, and to keep nuclear material accounting and operating records in the prescribed forms and to inspect these accountings; as well as*
> 6. *issue prohibitions on measures concerning real estate when this is necessary in order to secure safety, when that real estate includes premises referred to in point 5b of section 3.*
>
> *What is prescribed above in points 1 and 2 and 5 of subsection 1 shall also apply, to such extent as required by the control referred to in Finland's international treaties in the field of nuclear energy, to such persons approved by the Finnish Government, who in the presence of a representative of the Radiation and Nuclear Safety Authority (STUK) carry out the supervision referred to in such treaties.*
>
> *The licence-holder shall see to it that the obligation to give notification referred to in chapter VII of the EURATOM Treaty is fulfilled, and he shall keep nuclear material accounting and operating records as required in the Treaty. The licence-holder shall, to the extent required by supervisory activities, provide access for inspectors mentioned in article 81 of the Treaty to facilities and quarters in his possession which are subject to inspection. (29 Dec. 1994/1420)*

[4] Statement of position by the Finnish Radiation and Nuclear Safety Authority regarding the construction of the third unit at Olkiluoto Nuclear Power Plant 1/330/2004 16.1.2004 (Section 23 of the Nuclear Energy Act (NEA)) 24 January 2005 – this appears to be a preliminary assessment of the nuclear safety case with remaining issues awaiting to be addressed by STUK.

[5] Juha Häikiö, *Fin5-OL3-research*, STUK 14 April 2005 – response to a request from Large & Associates

[6] Or it might be prior to unirradiated nuclear fuel being delivered to the EPR site.

[7] The approval is in three distinct stages: First, a *Construction Licence* is required for physical works to commence at the Olkiluoto 3 site and for this STUK examines the *Preliminary Safety Analysis Report* (PSAR) submitted by the operator (TVO) presenting its findings on this in the PSARIR, second, prior to first fuel loading of the reactor core, a *Final Safety Analysis Repor*t (FSAR) has to be approved and, third, TVO has to submit a scheme of technical and administrative requirements (technical specification - TTKE) for the plant operation.

[8] In October 2003 TVO indicated that Framatome ANP's 1600MWe EPR to be the preferred plant on the basis of operating cost. Siemens AG will provide the turbines and generators and Framatome the nuclear island. TVO signed a 3B Euro contract with Areva and Siemens for a 1600 MWe EPR unit in December 2003. The construction-commissioning costs, but excluding fuel supply and recovery, is €3.2B with the French Credit Agency underwriting this to €610M.

The French Nuclear Safety Authority (ASN) issued design approval for Areva's 1600 MWe EPR in October 2004 and, shortly following, Electricite de France confirmed the existing nuclear power plant site at Flamanville in Normandy to be the preferred site for the first French based EPR, but any EPR development on that site now seems to have been delayed.

[9] *Preliminary Safety Analysis Report*, TVO January 2004 – in principle the PSAR is a public document but certain (unspecified sections) are not available for reasons of commercial confidentiality and/or security and the release of any section of the PSAR is considered on a case-by-case basis.

[10] *OL3 PSAR Inspection Report, Radiation Nuclear Safety Authority*, G241/31 21 January 2005 – referred to as PSARIR in this text.

[11] *Statement Issued by the Radiation and Nuclear Safety Authority Concerning the Construction of the Olkiluoto Nuclear Power Plant Unit 3, Annex 1*, 21 January 2005 – referred to as STUKSI

[12] There is also a small research reactor (TRIGA FIR1 – first powered in 1962) at the Technical Research Centre.

[13] For a fuller description see J Laaksonen, K Valtonen *Regulating the EPR*, Nuclear Engineering International, V50 N^{0} 610, May 2005

[14] The nuclear safety philosophy adopted is that of 'the so-called 'Defence in Depth' principle as described by INSAG-10. Essentially, this involves specifying transients and accidents that are representative of a range of abnormal events and malfunctions to the reactor function, these being the drivers to a deterministic design approach and which, it is argued, build on operating experience of nuclear reactors worldwide. The adoption of this approach, again so it is claimed, provides a protective envelope that is sufficiently robust to cater for abnormal events that have not been experienced although, that said, the events leading to Chernobyl of 1986 challenges such confidence.

[15] In nuclear jargon, the nuclear safety composite is referred to as 'Acceptable Risk and Tolerable Consequences'. The 'acceptable risk' element essentially enables the designers to discount accidents that are consider to occur very infrequently to be 'incredible' events so the design is not require to cater for these. For credible events (ie accidents that are expected to occur more frequently) the design has to provide a defence to the extent that the consequences (ie the radiation dose received as a direct result of the accidental release of radioactivity) has to be tolerable (usually expressed in societal terms). Of course, whereas accidents are by their very nature accidental (and unintelligent) events that occur largely as a matter of chance, a terrorist act is both intentional and intelligent that will seek out system vulnerabilities, thus the probabilistic reasoning of acceptable risk cannot properly apply.

[16] PSARIR S16.2, para 1, p320

[17] 10^{-2}/year is a chance of one in one hundred years for each year of reactor operation.

[18] *Class 1 & 2 Accidents* are defined by severity with, for example, loss of coolant accidents (LOCA) of less than $20cm^2$ breach being *Class 1* and breach areas larger than this being *Class 2* – the largest LOCA is assumed to be a double guillotine failure of a main primary coolant circuit pipe. Similar *Class 1 & 2* classification of accident severity is applied to reactivity excursions, etc., reactor scram failures, and so on.

[19] MWd/kgU – a measure of the energy generated by the fuel in Mega Watts (1,000,000 Watts electrical) days per kilogram of uranium metal in the fuel.

[20] Of course there is the added dimension that Finland has yet to operate a PWR of western design, particularly western fuel design since its PWR operating experience is confined to the two Soviet designed VVER units. High burn-up usually prolongs the time-period, over which the fuel elements are kept under operation and this results in additional requirements concerning materials, layout and reliability of the fuel elements. Parameters other than simply fuel burn-up that may contribute to or detract from robustness include fuel type (uranium -v- MOX),

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quality, temperature and temperature gradients, stressing. It is not made clear by STUK from where it draws its fuel performance data to set the 45MWd/tU limit.

[21] STUK has often stated that *'Provision must be made fro an impacting passenger or military plane'*, see http://www.stuk.fi/english/npp/5th_npp.html. and in adopting the EPR is in, in fact, adopting a pre 9/11 design, nor has it modified the built structures of its existing nuclear power plants at Olkiluoto and Loviisa.

[22] Light aircraft impacts are designated to be within the design basis adverse or abnormal events, whereas impacts from large military and large passenger aircraft are considered to be design extended events (DEC).

[23] Note that this restriction of certain information being supplied by STUK should not be taken to imply any uncooperativeness on its part in responding to the requests of Large & Associates and, indeed, STUK have been co-operative and helpful in responding to Large & Associates for which, particularly, I thank Petteri Tiippana of STUK for his patience and helpfulness in responding to my enquiries on the PSARIR and other matters..

[24] STUK rejected Large & Associates' request (of 24 May 2005) for the following papers and reports on security ground: 1) 'Design Extension Airplane Crash' – see S3.3.2 of OL3 PSAR Inspection Report G241/31 21 January); 2) Operation of Emergency Diesel Generators after an Aircraft Impact, 3) Short-term Combustion of Jet Fuel after an Aircraft Crash, 4) Olkiluouto 3 NPP Aircraft Crashes, all commissioned from VTT Industrial Systems; and the 'Provision Against Aircraft Crashes' by Gesellschaft für Anlagen- und Reaktorsicherheit (GRS) mbH; 5) those sections of TVO's PSAR that set out the design basis and probabilistic reasoning for aircraft crash frequency and structural resistance of the buildings and equipment; 6) Silde A, Lautkaski R & Huhtanen R 'Dispersion and Combustion of Jet Fuel in Aircraft Crash into a Multi-Storey Building', VTT Processes Project Report PRO5/7836/03; 7) Topical Report TR68 (total destruction of an unprotected building containing the highest inventory of radioactivity; 8) Definitions of Design Basis Threats (DBTs) and 9) Assessment Robustness of the plant against DBTs forming part of the nuclear safety licensing qualification; 10) equivalent OL3 Inspection Report for DBTs effectiveness, etc.; 11) TR84, 12) TR98 (open reactor pressure vessel); and 13) TR87 (full core in fuel pond and loss of water).

[25] Decision of the Council of State 395/1991 as given in the STUK Y211/13 unofficial translation of 7 January 2002.

[26] Guide YVL 2.8, *Probabilistic Safety Analysis in Safety Management of Nuclear Power Plants*, May 2003

[27] TBq – tera Becquerel or 1.E+12 disintegrations – 3.7.E+10 Bq = 1 Curie (Ci).

[28] Where 'effective' means the radiation dose accruing from external exposure and internal emitters from all uptake paths.

[29] Here it is assumed that this 0.1mSv/y limit applies to the combined Olkiluoto site and the operation of the two nearby BWR units.

[30] The equivalent limit of 500mSv exposure from a *Severe Accident* seems somewhat high, being higher than the UK upper Emergency Reference Level at which members of the public have to be evacuated in order to avert a dose exposure of 300mSv, although emergency planning in Finland also requires evacuation of those in the vicinity of the nuclear plant but the procedures and evacuation implementation dose adopted have not been reviewed here.

[31] Extracts from the STUK response to Large & Associates' enquiry M3123-A1 of 24 May 2005.

[32] Which means that to determine if a section of the TVO is available for public scrutiny it has to be identified, but how to do this is not at all straightforward because the contents list of the TVO PSAR does not seem to be available publicly – ie you need to know before you can ask?

[33] Only 4 organisations (or 6 if the 3 VTT divisions are included in the tally) have been engaged completing about 66 separate work tasks in a range of subject areas – see FIN5-OL3-research (undated but c. January 2005) – STUK allocates about €2M per year on external consultants and services, although it is not clear what proportion of this has been spent on Olkiluoto 3 specific contracts and last year STUK allocated about 232 man-years to the Olkiluoto 3 project, that is about 25% of the staffing resource in the Department of Nuclear Reactor Regulation (which employs approximately 95 people).

[34] PSARIR is date 21 January 2005, whereas the final report of the *Independent Comparative Analysis During Severe Accidents* was published 10 January 2005, but none of the other 66 work tasks of the external consultants file FIN-OL3 [Ref 33] are dated. A copy provided of *Erosion of Sacrificial Content in the Dry Cavity of EPR/FIN5* carries a date of 10 January 2005 so, again, hardly sufficient time to consider and incorporate the findings into the PSARIR.

[35] For example, the VTT *Erosion of Sacrificial Content in the Dry Cavity of EPR/FIN5* makes no reference to any TVO or Framatome/Siemens data and seems to rely mainly on data from the US Sandia and Argonne laboratories.

[36] Para 2, p102 STUKSI

[37] The NRC took 7 to 8 years to approve the AP 600 licensing review and has recently completed the AP 1000 review which, although based closely on the AP 600 design NRC certified in December 1999, required a further 4 years to complete. The NRC is presently developing a combined Construction and Operating Licence (COL) although this is unlikely to be fully developed for new build plants until 2011.

[38] The approach in the United States is quite different and much more transparent where the US Nuclear Regulatory Commission requires nuclear plant operators to submit to *force-on-force* trials simulating intentional malevolent actions. Since 1991 the NRC has conducted 91 trials or *Operational Safeguards Response Evaluation* tests, of which about 45% of the tested nuclear plants failed. Most disturbing is that three plants tested shortly before 11th September, Farley, Oyster Creek and Vermont Yankee, were the worst on record. In another assessment, the NRC notes that between 15 to 20% of US nuclear plants would sustain safety critical levels of damage from vehicle bombs accessing close to the supervised boundary of the plant.

[39] Lyman E, *Terrorism Threat and Nuclear Power: Recent Developments and Lessons to be Learned,* Rethinking Nuclear Energy and Democracy after 09/11, Int Symp, PSR/IPPNW Switzerland, Basel April 2002).

[40] Large J H *A Review of Local Authority Off Site Emergency Planning for UK Nuclear Power Plants,* Greenpeace UK September 2002.

[41] Of course, both on- and off-site emergency planning should include for planned acts aimed at disrupting the emergency response and countermeasures.

[42] External Events Excluding Earthquakes in the Design of Nuclear Power Plants, Safety Guide NS-G-1.5 International Atomic Energy Agency Vienna, 2003

[43] Guide YVL 7.4, *Nuclear Power Plant Emergency Preparedness*, January 2002

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[44] *Council Directive 96/29/Euratom* May 1996 which lays down basic safety standards for the protection of the health of workers and the general public against dangers arising from ionising radiation, *Official Journal of the European Communities* (1996) 39, No L159, 1-114

[45] 4.6 S12, p31 STUKSI

[46] In fact the Cs-Rb group (alkali metals and metals – Group C) is a more representative release grouping.

[47] USNRC, *Reactor Safety Study: An Assessment of the Accident Risks of US Commercial Nuclear Power Plants,* WASH-1400, 1975 – see also *An Assessment of the Radiological Consequences of Releases from Degraded Core Accidents for the Sizewell PWR*, NRPB-R137, July 1982

[48] Guide YVL 2.2, *Transient and Accident Analyses for Justification of Technical Solutions at Nuclear Power Plants*, August 2004 (draft)

[49] In the UK this would be referred to as the Upper Reference Level (URL) by which evacuation of members of public had to have been completed in order not to reach and exceed (ie averted) – the UK whole body dose equivalent URL is set at 300mSv with the Lower Reference Level (LRL) set at 30mSv at which exposure consideration should be given to evacuation from the radiation area.

[50] None of these performance 'claims' have been proven and, as such, these should be considered to be targets, even if somewhat optimistic, particularly with regard to the unit generation cost.

[51] This level of fuel irradiation is not yet permitted under the STUK licensing regime for Olkiluoto 3 and the STUK permission for the Construction License. Presently limits in-core fuel irradiation to 45 MWd/kgU shall be used, unless the higher value can be experimentally demonstrated to fulfil all pertinent safety criteria Similarly, at this time no consideration has been given to MOX fuelling of the Olkiluoto 3 reactor – 45MWed/kgU burn-up is the present level approved (YVL Guide 6.2) for existing plants using this type of M5 clad fuel assembly.

[52] Essential design details are: primary circuit design pressure 176b and outlet temperature at 327°C (311.7°C and 155b average at 60 to 100% power output), RPV internal dimensions 4.85m diameter and 12.78m height, with 250mm wall thickness, fuel core 241 17x17 rod assemblies, each of 533kg Uranium at 4.4% single zone enrichment, total core fuel load ~128.5t.

[53] The design pressure of the secondary reactor containment (the domed building) is 0.53Mpa with a design volumetric leakage rate of 0.5% over the first 24 hours. This containment comprises inner and out domed structures in reinforced concrete with the inner containment fitted with an internal steel plat liner. The annulus between the two containment skins provides cooling in the aftermath of a severe accident, venting via HEPA and iodine filters.

[54] Essentially, the EPR is a descendant of the French N4 (Chooz and Civaux) and German Konvoi nuclear reactors (Isar 2 and Neckarwesttheim 2), both models currently in service. From the N4, the new reactor derives its designs for containment and the primary system, its instrumentation and control system, and its control room. The EPR's in-core measurement system and four-train architecture are taken from the Konvoi design of plant.

[55] Hirsch H, *Ongoing Dangers of Operating Nuclear Technology in the 21st Century*, Greenpeace International, April 2005

[56] The development of the generic EPR design commenced in 1993 but in earnest following an agreement for the Basic Design development of February 1995 between Framatome ANP and Siemens, with second stage design work commencing in 1997. In July, 1999 Electricité de France, Framatome and Siemens joined in an additional agreement to reinforce their nuclear cooperation and more specifically to further develop EPR. Several of the larger nuclear island components, the ROV and steam generators, are to be manufactured in Japan.

[57] PSARIR, S 3.3.1, p39

[58] In the absence of access to TVO's PSAR and the aircraft impact studies undertaken on behalf of STUK [Ref 24], the approach to the analysis of aircraft impact on structures cannot be deciphered, although the STUK assertions that if the buildings are strong enough for one set of circumstances then they will be strong enough for another entirely different set of circumstance might suggest a somewhat simplistic approach. As a result of impact (kinetic) energy is transferred from the aircraft to the building.[58] The energy transferred is absorbed by the building components in the form of strain energy whilst each component is deforming elastically and beyond up to the point of permanent yielding. The impact can be segregated into two regimes: First, at the moment of impact the aircraft can be considered to be a very large but relatively 'soft' projectile which, by self-deformation' will dissipate some fraction of the total kinetic energy being transferred during the impact event. Second, some components of the aircraft will be sufficiently tough to form rigid projectiles that will strike and commence to penetrate, again by kinetic energy, components of the building fabric and structure. The first of these damage regimes involves quasi-impulsive loading, so the response of the structure is obtained by equating the work done by the impacting load to the strain energy produced in the structures. Setting aside localised damage in which individual structural components are removed (blasted away), the most probable failure mode of the structure overall is that of buckling and collapse in response to the impact. The types of building structure featured at nuclear power plants, for example the radioactive waste and spent fuel buildings, would not withstand the impulse magnitude delivered by a crashing commercial aircraft. For impact damage the aircraft, more particularly parts and components of it, have to be considered as inert projectiles. The energy transfer upon impact relates to the kinetic energy (KE) and the key parameter in determining the target (building component) response is the kinetic energy density which relates the KE and the projected area of the projectile. In terms of projectile velocity, a diving civilian aircraft is unlikely to exceed 500 knots so the damage mechanism falls below the so-called hydrodynamic regime where the intensity of the projectile-target interaction is so high that a fluid-to-fluid damage mechanism prevails (as utilised by tungsten tipped and depleted uranium sarab or long rod penetrator armour piercing rounds).[58] In the sub-hydrodynamic regime more conventional strength of materials characteristics (ie strength, stiffness, hardness and toughness) will determine the penetration mechanism. For uniform, elastic materials, such as low carbon steel used in steel-frame construction such as diesel generator sheds, radioactive waste stores and, sometimes, irradiated fuel storage buildings, a good first estimate of the penetrating power of a projectile can be obtained from the Recht equation which, for certain hard components of the aircraft engines, could be as high as 200mm. For a steel framed industrial building structure, typical web and flange thicknesses of the steel section girders and beams is typically about 20 to 40mm so, even with penetrator break up, this and other projectiles would be more than sufficient to structurally damage, if not catastrophically collapse the building steel frame. The failure of reinforced concrete (rc) to ballistic loading applies to the different ways in which this common building structural material is used: For very thick walled structures the concrete is considered to be a semi-infinite mass, for concrete walling and flooring (and roof) slabs the account has to be taken of the flexure of the slab, and to prevent scabbing (where the back face of the concrete surface detaches) the reflective characteristics have to be modelled. The first two of these applications are important in respect to the whole structure remaining intact, and the last that in even where complete penetration is not achieved, the detached scab can form a missile in itself damaging and/or disabling safety critical plant within the concrete containment. The derivation of the ballistic loading of ferro-concrete (steel reinforced concrete) structures is a little more empirically derived,[58] although even with broad brush assumptions about the detailed design of the ferro-concrete structures the hardened projectile striking most of the concrete structures of a nuclear power plant would achieve full penetration. For example, a glancing impact on a typical rc framed building would be sufficient to possibly penetrate

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the rc roof slabs which are not practicably greater than 400mm thickness, (because of selfweight loading considerations over the 4m spans). The point here is that the building structures of a nuclear plant require to maintain complete containment during an aircraft crash because even relatively small penetrations will permit the inflow of aviation fuel with the almost certain fire aftermath which would, in itself heighten the release and dispersal of any radioactive materials held within the building structure.

[59] PSARIR, Section 3.3.2 p40

[60] Ibid, p41 – it is not clear how the 5mSv dose is defined and whether or not it is to the greater public in the location of Olkiluoto, over a one year post-release period as define by Euro Directive 26/96, or at any time during the projected 60 year lifetime of the plant over which radioactive materials and operational wastes are likely to accumulate on the power station site, that said, in correspondence [Ref 31] STUK states that operational ion-exchange wastes held at Olkiluoto 3 in an unprotected building will not exceed 15 years worth of arisings and that, similarly, other operational wastes will be periodically transferred to a final radioactive waste repository. The quantity of spent fuel to be held on site, albeit in a protected building, is not specified although over the projected 60 year life this could be as high as ~3,000 tU equivalent.

[61] Military aircraft are considered as exceptional because they are not restricted to fixed air corridors and can effectively freely roam the skies.

[62] For example see *Accident Analysis for Aircraft Crash into Hazardous Facilities*, DOE-STD-3014-96, 1996 see also for practical application *NUREG-0800, Section 3.5.1.6 Aircraft Hazards*, Nuclear Regulatory Commission, 1981 which suggest a crash rate in the absence of other data to be 3.66×10^9 per flight mile, *Evaluation of Aircraft Crash Hazards for Nuclear Power Plants*, Kot C A, et al, Argonne National Laboratory, 1982 which gives a chance of crash into a nuclear plant 11.5 miles to the south of an air corridor at 33,000 ft to be about 2.36×10^7 per year and *Evaluation of Air Traffic Hazards at Nuclear Power Plants*, Hornyik K, Nucl Technology 23, 28, 1974, *Aircraft Impact on Sizewell B, Part 1 Safety Involvement of Buildings on Site*, PWR/RX774 (pt 1) 1987, *Sizewell B PWR Supplement to the Pre-Construction Safety Report on External Hazards, Aircraft Crash*, CEGB Report No GD/PE-N/403, 1982, *Aircraft Impact on Sizewell B*, Part 2(a), *The Effects of Impact of Heavy Aircraft Adjacent to but not directly on Vulnerable Buildings. (b) Light Aircraft on the Vulnerable Buildings*, PWR/RX774 (Pt 2), 1987 and *Aircraft Impact on Sizewell B* Part 3 *Fire Following Aircraft Crash*, PWR/RX774 Part 3, 1987 – a detailed introduction to the methodology assumed by the nuclear industry of the probabilistic approach to aircraft crash is given in Large J H *The Implications of September 11th for the Nuclear Industry*, Monitor, Royal United Services Institute, London, February 2003, V2 N^o 1.

[63] US Army, Accidental Explosion Task Committee, *Structures to Resist the Effects of Accidental Explosions*, Dept of Army, Technical Manual No 4-1300, 1992 – see also IAEA Safety Guide NS-G-1.5.

[64] After R F Recht, *Ballistic Perforation Dynamics of Armor-Piercing Projectiles*, NWC TP4532, 1967. which, for a blunt nose ogive, is

$$x = 1.61M/(bA)[V-a/b\ln([a+bV]/a)]$$

where a and b relate to the material properties of the target, M is the mass of the projectile and V the projectile closing velocity. For an aircraft impact, if it is assumed that a sufficiently robust penetrator will present itself in the form of a main turbine shaft of an aero engine which, with its blades and other attachments, might represent a mass of 0.25 tonnes of 150mm projected diameter (stub end of shaft), typical strength of materials properties give $a = 2.10^9$ and $b = 10.10^6$, so that the final penetration thickness into a steel element (ie a building stanchion) is about 200mm. See also *MOD Assessment, Strengthening, Hardening, Repair and Demolition of Existing Structures*, Army Code No 71523, MoD 1992 which the reinforced concrete slab penetration is about 1,100mm.

[65] Thompson P R et al *Shock Qualification of Submarine Hull Valves using Numerical Methods*, Warship 2005, Naval Submarines 8, June 2005, London

[66] Ibid, Section 3.3.5, para 1 makes it quite clear that the analysis of the plant response to and robustness of the structures and plant equipment against external events has yet (January 2005) to be undertaken.

[67] *OL3 PSAR Inspection Report, Radiation Nuclear Safety Authority*, G241/31 21 January 2005 – Section 3.4.4 p52 – here referred to as PSARIR

[68] Ibid, Section 9.6.1 p189

[69] Ibid, Section 3.7, p66

[70] Ibid, Section 3.7, p68 – includes a requirement for qualification of the electrical, instrumentation and control components within the reactor containment building by type testing and analyses and, for this and other key safety components STUK have yet to receive even a preliminary management programme for component ageing over the sixty year projected life of the plant.

[71] The reactor primary circuit containment building is a large, double walled building of about 80,000m3 capacity. The inner containment shell is about 1.3m thick, prestressed concrete lined with 6mm steel plating and the prestressed concrete outer shell varies in thickness of 1.3m at the base increasing to 1.8m thick in the dome. The containment is sub-divided into accessible and non-accessible sections whilst the reactor is operational. The annulus between inner and outer shells is 1.8m, being gas tight and maintained at negative pressure it serves as a filtered route from the inner containment for any air suspended radioactive particles.

During outages there is a large containment access hatch that is normally open into the reactor area of the containment and should a release incident occur during an outage then the hatch has to be closed with closure and sealing times varying between 30 minutes to 6 hours depending upon prevailing conditions.

[72] For example, during the early morning of 14 January 2003 about 12 Greenpeace UK campaigners were able to penetrate the Sizewell PWR nuclear power station outer security cordon and gain access into the instrumentation and control areas of the main reactor complex, also scaling the outer reactor containment dome and occupying this for 2 days.

[73] UO2 core fuel load is 145.66 tonnes with the first batch of corium falling from the reactor core is reckoned to be about 104 tonnes.

[74] Pascal Piluso, et al *Corium Behaviour Research at CEA Cadarache: The PLINIUS Prototype Corium Experimental Platform*, Nuclear Energy for New Europe, Slovenia September 2002.

[75] Of course, the corium management system could never be proven by full scale and realistic trial.

[76] It should not be assumed that prior to the 9/11 events that nuclear power plants did NOT have incorporated anti-terrorism measures, although such measures varied from country to country – the events of 9/11 heralded a new dimension of international terrorism prompting an international response although for nuclear facilities a common international standard of defence has yet t be achieved.

[77] Large J H *The Implications of September 11th for the Nuclear Industry*, Monitor, Royal United Services Institute, London, February 2003, V2 N^o 1

[78] For example, in the United States nuclear facility operators are required to identify security problems and report these to the nuclear regulator, the Nuclear Regulatory Commission (NRC) and, in addition, the NRC requires each operator to protect against a specified level of threat or DBT from outside attackers and insider conspirators using extensive security measures, these DBT requirements were formalised by the NRC in April 2003 and

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operators are required to conduct *'force-on-force'* exercises at least once every three years – Subcommittee on National Security, Emerging Threats, and International Relations, United States Congress, September 2004 - http://reform.house.gov/UploadedFile /September%2014%20Nuclear%20Briefing%20Memo.pdf. In the UK the pertinent legislation is Nuclear Industries Security Regulations 2003 (NISR)

[79] For an example of nuclear security assessment see Timm R E, *Security Assessment Report for Transport of United States Nuclear Materials (PuO2) in France*, Greenpeace International, February 2005 - http://www.greenpeace.fr/stop-plutonium/en/TimmReportV5.pdf