Hinkley Point C UK-EPR

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Introduction

EDF Energy and NNB plan to construct two UK-EPR units at its Hinkley Point C site. The UK-EPR is in essence a four-loop pressurized water reactor housed in a double containment (an inner pre-stressed concrete containment with steel liner, and an outer reinforced concrete containment) equipped with passive autocatalytic recombiners (PARs) for hydrogen protection and a core debris spreading area for ex-vessel cooling of core debris generated in a severe accident. The design power level for the EPR is 4,500 megawatts thermal.

The UK-EPR is acknowledged in the EDF Energy's Pre-Construction Safety Report to be "*a pressurized water reactor similar to other units currently in operation worldwide (for example within the French nuclear fleet)*".[1] The Pre-Construction Safety Report also states, "*The UK EPR is an evolutionary design, combining proven technology based on the most recent French N4 and German KONVOI PWRs.*"[2]

Are Severe Accidents for the EPR "Practically Eliminated"?

The short answer to this question is no, severe accidents for the EPR are not practically eliminated. Further discussion, however, is required with regard to considerations related to large release frequency (LRF) and large early release frequency (LERF).

WENRA has issued a report on the safety of new NPP designs[3] which states that "*accidents with core melt which would lead to early or large releases have to be practically eliminated*".

The report further states that "*for accidents with core melt that have not been practically eliminated, design provisions have to be taken so that only limited*

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1 EDF Energy and NNB GenCo, Hinkley Point C Pre-Construction Safety Report, Sub Chapter 1.2, General Description of the Units, Part of Chapter 1, Introduction and General Description, Issue 1.0, 25 April 2012, Document No. HPC-NNBOSL-U0-000-RES-000010, page 6.

2 EDF Energy and NNB GenCo, Hinkley Point C Pre-Construction Safety Report, Head document, Rev. 1, pages 36 and 38, December 2012.

3 Western European Nuclear Regulators Association (WENRA), Report: Safety of New NPP Designs, March 2013.

protective measures in area and time are needed for the public (no permanent relocation, no need for emergency outside the immediate vicinity of the plant, limited sheltering, no long term restrictions in food consumption) and that sufficient time is available to implement these measures".

The WENRA report considers accidents involving nuclear fuel at fuel storage locations that are included within the scope of what WENRA means by "*core damage*".

WENRA has not undertaken to state quantitatively what they mean by "*practically eliminated*". This situation leads to arguments from project proponents and stakeholders about what "*practically eliminated*" actually means.

WENRA cites requirements from the IAEA[4] to the effect that accidents with a large or early release can be considered to have been practically eliminated if it is physically impossible for the accident sequence to occur, or if the accident sequence can be considered with a high degree of assurance to be extremely unlikely to arise.

The only clarifications provided by WENRA with regard to practical elimination are three-fold:

1. Accidents can be considered to be practically eliminated if they are "*extremely unlikely to arise so that mitigation of their consequences does not need to be included in the design*".
2. WENRA defines an early release as "*a release that would require off-site emergency measures but with insufficient time to implement them*".
3. WENRA further defines large release means "*situations that would require protective measures for the public that could not be limited in area or time*". Unfortunately, WENRA does not specify what it means by either area or time.

The result of the use by WENRA and IAEA of "practically eliminated" as set forth above is that anybody – project proponent, regulator, and stakeholders – is free to argue about what it means. What is a "*high degree of assurance*"? Does this wording

[4] International Atomic Energy Agency (IAEA), Safety of Nuclear Power Plants: Design Specific Safety Requirements, SSR-2/1, February 2012. I was a member of the IAEA's Nuclear Safety Standards Committee (NUSSC) at the time that this standard was approved. I specifically urge the Committee to specify quantitatively what they meant by practically eliminated. The Committee refused to do so, and so IAEA as well as WENRA has not quantitatively defined what they mean by practically eliminated.

refer to a probability distribution of belief at the median (50th percentile value), the mean or average value, the 90th percentile value, the 95th percentile value, the 99th percentile value, or some other percentile or even “point estimate”? And to what type of probability distribution should we refer (lognormal distribution, beta distribution, or another)?

The questions go still further – what does "*extremely unlikely to arise*" mean? Is extremely unlikely less than 1×10^{-6} per year, or 1×10^{-7} per year, or 1×10^{-8} per year, or some other figure altogether? Impossible has a common English language meaning – the Oxford dictionaries define “impossible” as "*not able to occur, exist, or be done*". But what type or degree of showing is necessary to show that some early or large release scenario is not able to occur?

Even if we could all agree what "*practically eliminated*" and a "*high degree of assurance to be extremely unlikely to arise*" mean, if probabilistic arguments are used then the probabilistic safety assessment has to be complete to give a basis for the judgment. The PSA for Hinkley Point C is demonstrably incomplete since it has no probabilistic assessment of either seismic hazard or seismic core damage frequency and containment performance.

The Hinkley Point C Pre-Construction safety report includes only a seismic margin analysis of the design which is based on a ground acceleration of 0.4 g. By this the seismic margin required of structures, systems, and components is only a factor of about 60% above the design basis earthquake with a peak ground acceleration of 0.25g.[5] (It should be noted that a peak ground acceleration of 0.3g is the level at which the power grid would be lost, probably for days at least, due to ceramic insulator failure.)

The seismic response spectra for the seismic margin analysis corresponds to an annual frequency of exceedance of 1×10^{-4} per year.[6] Since the PSA that was performed estimates a core damage frequency (CDF) of 8.6×10^{-7} per year[7], the seismic response spectra are anchored to an earthquake with a frequency 143 times lower than the CDF for events excluding seismic. With such a core damage frequency, it would be very

[5] EDF Energy and NNB GenCo, Hinkley Point C Pre-Construction Safety Report, Sub-Chapter 15.6, Seismic Margin Assessment, UKEPR-0002-156, Issue 5, 30 March 2011, page 1/62.

[6] EDF Energy and NNB GenCo, Hinkley Point C Pre-Construction Safety Report, Sub-Chapter 15.6, Seismic Margin Assessment, UKEPR-0002-156, Issue 5, 30 March 2011, page 7/62.

[7] EDF Energy and NNB GenCo, Hinkley Point C Pre-Construction Safety Report, Head Document, Version 1.0, December 2012.

difficult to demonstrate with high confidence – allowing for uncertainties – that the EPR core damage frequency is less than 1×10^{-6} per year.[8] Even an uncertainty factor of two on core damage frequency – which would be a remarkable achievement – would put the core damage over 1×10^{-6} per year.

The calculated large early release frequency (LERF) for Hinkley Point C is 4.9×10^{-8} per year.[9] The large release frequency (LRF, early or late release but still large) is calculated at 1.8×10^{-7} per year.[10] LERF is almost 6% of the Core Damage Frequency (CDF), and that the LRF is almost 21% of the (CDF). Large early releases account for almost 6% of the core damage frequency and large release accidents comprise almost 21% of the core damage frequency.

EDF Energy and NNB *appear* to be using a frequency of 1×10^{-6} per year to constitute the required high degree of assurance to be extremely unlikely to arise in order that the accidents and accompanying phenomena are practically eliminated. Evaluations of other Generation III and Generation III+ designs use much lower values, ranging from1×10^{-8} per year to 1×10^{-7} per year. However, as noted earlier, all of these values are merely suggestions or arguments from the designers since there is no quantitative guide value for what is meant by "practically eliminated". The only safety target cited in the Pre-Construction Safety Report is a target for core damage frequency of $\leq1\times10^{-5}$ per year.[11] This safety target for a Generation III design like EPR is at the same frequency as the average core damage frequency for Generation II designs.

The Pre-Construction Safety Report argues that the following scenarios are "*practically eliminated*":[12]

- High pressure core melt and direct containment heating
- Steam explosions leading to failure of the containment
- Hydrogen combustion processes endangering containment integrity
- Rapid reactivity insertion
- Containment bypass

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8 International Nuclear Safety Advisory Group (INSAG), Basic Safety Principles for Nuclear Power Plants 75-INSAG-3 Rev. 1, INSAG-12, International Atomic Energy Agency (IAEA), October 1999.

9 with 5th-95th percentile uncertainty values of 9.27×10-9 and 8.99×10-8 per year, respectively

10 with 5th-95th percentile uncertainty values of 4.75×10-8 and 3.23×10-7 per year, respectively

11 EDF Energy and NNB GenCo, Hinkley Point C Pre-Construction Safety Report, Head Document, Version 1.0, December 2012, page 150.

12 EDF Energy and NNB GenCo, Hinkley Point C Pre-Construction Safety Report, Head Document, Version 1.0, December 2012, page 162.

- Fuel damage in the spent fuel pool

Are There Other Generation III and III+ Designs With Lower Calculated Frequencies of Core Damage (CDF), Large Release (LRF), and Large Early Release (LERF)?

Among other Generation III and Generation III+ designs there are PWRs and BWRs whose calculated frequencies of core damage, large early release frequency, and large release frequency are lower than for the EPR. Examples include AP1000 and ESBWR (see next page):

- AP1000
  - Core damage frequency of 2.1×10^{-7} per year
  - LERF of 1.9×10^{-8} per year
  - LRF of 3.9×10^{-8} per year
  - AP1000 has a passive containment cooling system, a passive decay heat removal system, a passive emergency core cooling system, and passive autocatalytic recombiners for severe accident hydrogen control
  - Note that, like for the EPR, the AP1000 generic design approval application substituted a seismic margin analysis in lieu of a seismic PSA

- ESBWR
  - Core damage frequency of 1.7×10^{-8} per year
  - LERF of 1.4×10^{-9} per year
  - LRF of 1.4×10^{-9} per year
  - ESBWR has a passive gravity-driven cooling system and a passive containment cooling system
  - Note that, like for the EPR, the ESBWR design certification application substituted a seismic margin analysis in lieu of a seismic PSA

"Inherent Safety" Provisions

Inherent safety provisions avoid hazards by physically concepts. Whenever an active or passive safety system is needed there is no inherent safety. The IAEA has specifically defined a wider “inherent safety” as "*the achievement of safety through the elimination or exclusion of inherent hazards through the fundamental conceptual design choices made for the nuclear power plant*" (underlining emphasis added).[13]

[13] International Atomic Energy Agency (IAEA), Safety Related Terms for Advanced Nuclear Plants, IAEA-TECDOC-626, September 1991, page 9.

IAEA went on to state:

> *Potential inherent hazards in a nuclear power plant include radioactive fission products and their associated decay heat, excess reactivity and its associated potential for power excursions, and energy releases due to high temperatures, high pressures and energetic chemical reactions. Elimination of all these hazards is required to make a nuclear power plant inherently safe. For practical power reactor sizes this appears to be impossible. Therefore the unqualified use of "inherently safe" should be avoided for an entire nuclear power plant or its reactor.*

IAEA also stated, "*As described, inherent safety is equivalent to absolute safety; i.e., an inherent safety characteristic is not subject to failure of any kind. Stated another way, an inherently safe feature represents conclusive or deterministic safety, not probabilistic safety.*"

Active safety systems are by definition not inherently safe since they require operation of pumps, valves, initiation circuitry, electric power (AC and/or DC), and control power (DC), for example.

The Pre-Construction Safety Report for Hinkley Point C is very careful not to claim inherent safety. There are no inherently safe design provisions in the EPR design. The only qualitatively new passive safety provision in the EPR design (compared with existing plants) is the core debris spreading area to limit the possibility of containment basemat melt-through.

The EPR containment is not a passive system – it is an active system. It depends on active valves and control circuitry. If the containment is not successfully isolated in a severe accident, you automatically get a large early release of radioactivity. This is true irrespective of how structurally strong the containment is. In addition, within the EPR design there are still – like current generation plants – accident scenarios in which containment bypass occurs. Containment bypass accidents have nothing to do with how structurally strong the containment may be.

Summary

- For the EPR, severe accidents are not practically eliminated.
- There are Generation III and III+ PWR and BWR designs whose calculated frequencies of core damage, large early release, and large release are lower than for the EPR.
- There is no agreed quantitative understanding in the nuclear safety community (including WENRA and IAEA) regarding what "extremely unlikely" actually means. Thus, the values that EDF Energy and NNB appear to be using for arguing an extreme unlikelihood of accidents and large releases are merely suggestions from the designers.
- The probabilistic safety assessment for Hinkley Point C is demonstrably incomplete since it has no assessment of either seismic hazard or seismic core damage frequency and containment performance.
- The EPR containment depends on active components which are by definition neither inherently safe nor passive.