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## TABLE OF CONTENTS

# SUB-CHAPTER 15.0 - SAFETY REQUIREMENTS AND PSA OBJECTIVES

Sub-chapter 15.0 outlines the purpose and scope of the UK EPR probabilistic safety assessment (PSA), and presents the numerical targets that are used to evaluate and verify the UK EPR design. Both the numerical targets defined in the HSE/NII Safety Assessment Principles, and quantitative probabilistic safety objectives in accordance with the French Technical Guidelines, are presented.

## 1. INTRODUCTION

One safety objective of the reactor design is to ensure that the risk of release of radioactive products into the environment is reduced to as low as is reasonably practicable. The identified sources of potential radioactive releases are:

- The reactor core,
- The spent fuel storage pool,
- The spent fuel handling facilities,
- The radioactive waste storage tanks.

In order to give confidence that the UK EPR design complies with this general safety objective, a probabilistic safety assessment (PSA) is performed, covering three levels of consequences.

- The Level 1 PSA considers both internal events (see Sub-chapter 15.1) and internal and external hazards (see Sub-chapter 15.2) that, together with total or partial failure of protection or mitigation measures, can lead to core damage, and evaluates the resulting core damage frequencies (CDF). Other, less onerous, endpoints are considered that do not result in a designated failure state such as core damage but lead to potential releases: these include those relating to the spent fuel pool (loss of cooling or fast draining) (see Sub-chapter 15.3).

- The level 2 PSA (Sub-chapter 15.4) evaluates the nature, magnitude and frequency of radioactive releases outside the containment boundary. It takes the Level 1 PSA failure states, analyses the containment response in those situations, and assigns a Release Category to containment fault sequences that present similar characteristics of activity release to the environment.

- The off-site consequence analysis (Level 3 PSA) presented in Sub-chapter 15.5 determines the risk to the off-site public from the potential releases, in terms of both individual and societal risk.

The initiating events studied include internal events or hazards originating inside the facility, and external hazards. The assessment is performed for the various plant operational states (i.e. full power, low power and shutdown).

Initiating events due to intentional maloperation or sabotage and malicious events like intentional aircraft crash are not considered in the PSA.

Sub-chapter 15.0 - Table 1 presents the scope of the UK EPR PSA. The full set of internal events is addressed at all PSA levels. Concerning internal hazards, fire and flooding are addressed at all PSA levels, whereas missiles and dropped loads are qualitatively analysed. Concerning external hazards, only those leading to the loss of ultimate heat sink (LUHS) are addressed at all PSA levels. The other external hazards have not been included due to their relatively low frequency of occurrence and/or consequences. More details about fault groups and initiating events addressed in the PSA are given in Sub-chapter 15.1.

In addition to its use in assessing the current design, the PSA has provided insights throughout the design process, leading to a number of design improvements, and has provided input to other aspects of the PCSR. More specifically, it has been used:

- To extend the deterministic design basis (RRC-A sequences – see Sub-chapter 16.1) in order to achieve a balanced design, ensuring that there are no ‘cliff edge’ effects.
- To confirm the appropriateness of protection of the plant against certain internal and external hazards (see Sub-chapter 15.2).
- To verify that the design of the severe accident mitigation features allows the risk of radioactive product release to be reduced to an acceptably low level (see Sub-chapter 15.4).
- To calculate the plant seismic capacity in order to demonstrate that the plant has sufficient margin beyond the safe shutdown earthquake (see Sub-chapter 15.6).
- To assess the improvement in the safety level in comparison with existing reactors (see Sub-chapters 15.1 and 15.7).
- To assess the impact of preventative maintenance (see Sub-chapters 15.1 to 15.7).
- To support the ALARP demonstration (see Chapter 17).

The UK EPR PSA follows the UK and international practices as principally described in the HSE Safety Assessment Principles [Ref], the IAEA Safety Series [Ref] and EUR generic requirements [Ref].

# 2. NUMERICAL TARGETS

In order to demonstrate compliance with UK statutory requirements and regulatory practices for Nuclear Installations, a number of Safety Design Objectives (SDOs) are adopted for the UK EPR (see Sub-chapter 3.1). Demonstration that these SDOs are met will confirm that the EPR design complies with key HSE Safety Assessment Principles (SAPs) [Ref]. In addition to the SAPs numerical targets, the design also considers probabilistic safety objectives in accordance with the Technical Guidelines (TGs) developed by the French and German safety authorities and major utilities (see Sub-chapter 3.1 - Table 1).

## 2.1. SAFETY DESIGN OBJECTIVES

With regard to the PSA results, the UK EPR design must meet, in particular, SDOs 6 and 7, described below, which define the tolerable doses to members of the public off-site in case of accidents. Compliance with SDOs 6 and 7 respectively will ensure compliance with HSE SAP Targets 8 and 9.

The SAPs define two types of safety level with different numerical targets. These are the Basic Safety Levels (BSLs) that must, as a minimum, be met and the Basic Safety Objectives (BSOs): more stringent benchmarks that reflect modern safety standards and expectations. The BSOs also mark the start of the ‘broadly acceptable’ range of risk.

**Target 8**

To confirm compliance with Target 8 of the HSE SAPs, the summated frequency of accidents for the UK EPR leading to individual doses of different magnitudes will be assessed against the limits given in the table below.

| **Effective dose mSv** | **Total predicted frequency per year** | |
|---|---|---|
| | **BSL Maximum Tolerable Limit** | **BSO Broadly Acceptable Level** |
| 0.1 – 1 | 1 | $1 \times 10^{-2}$ |
| 1 – 10 | $1 \times 10^{-1}$ | $1 \times 10^{-3}$ |
| 10 – 100 | $1 \times 10^{-2}$ | $1 \times 10^{-4}$ |
| 100 – 1000 | $1 \times 10^{-3}$ | $1 \times 10^{-5}$ |
| > 1000 | $1 \times 10^{-4}$ | $1 \times 10^{-6}$ |

***SDO-6: The EPR design will ensure that the total frequency of accidents in each of the different dose categories in the above table is below the Maximum Tolerable Limit. The design objective will be to achieve an accident frequency in each dose category that is below the Broadly Acceptable level.***

**Target 9**

Target 9 in the HSE SAPs proposes limits on societal risk due to potential accidents in a UK nuclear installation, expressed as a risk of occurrence of more than 100 fatalities. To comply with this target the following Safety Design Objective is adopted for the UK EPR:

***SDO-7: The total risk of 100 or more fatalities, either immediate or delayed, from on-site accidents that result in exposure to ionising radiation, will be below $10^{-7}$/yr.***

More precisely the corresponding BSO and BSL for Target 9 are:

- BSL: 1 x $10^{-5}$ pa
- BSO: 1 x $10^{-7}$ pa

It is not possible within GDA to evaluate fully the levels of defence dedicated to worker protection in the event of an accident, as procedures and site organisation are not yet defined. Nevertheless, the evaluation of the radiological impact on people living off-site should bound the radiological impact on workers due to the fact that protection and evacuation procedures will be applied quickly and efficiently thanks to regular training.

Additionally, the facility safety should be balanced, that is, no single class of accident should make a disproportionate contribution to the overall risk, e.g. more than of the order of one tenth of the frequency in each dose band.

Note: The comparison of the PSA results with the SAPs numerical targets is presented in Sub-chapter 15.7.

## 2.2. PROBABILISTIC SAFETY OBJECTIVES

In addition to the SAPs numerical targets, quantitative probabilistic safety objectives are considered in the PSA in accordance with the Technical Guidelines:

- PSA Safety Objective 1: The design of the nuclear island is such that the overall core damage frequency (CDF) should be less than 1E-05 per reactor per year (/ry). This takes into account uncertainties, all the reactor states and all types of event (internal events, internal and external hazards). (Paragraph A1.1 of the Technical Guidelines, Sub-chapter 3.1 – Table 1).

- PSA Safety Objective 2: Unavailability due to preventative maintenance should not represent a large part of the overall CDF (Paragraph C2.2 of the Technical Guidelines, Sub-chapter 3.1 – Table 1).

- PSA Safety Objective 3: As a general rule, design measures must be taken for external hazards consistent with those taken for internal events and hazards. Thus the external hazards should not make up a large part of the overall core damage risk (Paragraph A.2.5 of the Technical Guidelines, Sub-chapter 3.1 – Table 1).

- PSA Safety Objective 4: Accident situations, which may lead to large early releases, should be “practically eliminated” by design (Paragraph A1.3 of the Technical Guidelines, Sub-chapter 3.1 – Table 1) (see Sub-chapter 16.3).

- PSA Safety Objective 5: Low-pressure core damage sequences (Paragraph A.1.1 of the Technical Guidelines, Sub-chapter 3.1 – Table 1) have to be dealt with so that the associated maximum conceivable releases would necessitate only very limited public protection measures in both area and in time. This means that there should be no permanent relocation, no need for emergency evacuation away from the immediate vicinity of the plant, limited sheltering, and no long-term restrictions on food consumption (see Sub-chapter 16.2).

In addition, the UK EPR being a new generation nuclear power plant, the following safety objective has been considered in the design:

- PSA Safety Objective 6: For internal events only, i.e. with internal and external hazards excluded, the overall CDF should be less than 1E-06/ry.

## SUB-CHAPTER 15.0 - TABLE 1

### Fault group scope in PSA

| Fault group | | Addressed in Level 1 PSA [Y/N] | Addressed in Level 2 PSA [Y/N] | Addressed in Level 3 PSA [Y/N] |
|---|---|---|---|---|
| **Internal events** | | | | |
| Loss Of Coolant Accident (LOCA) | 2A-LOCA | **Y** | **Y** | **Y** |
| | Large primary break [180 – 830 cm²] | **Y** | **Y** | **Y** |
| | Medium primary break [45 - 180 cm²] | **Y** | **Y** | **Y** |
| | Small primary break [2 – 45 cm²] | **Y** | **Y** | **Y** |
| | Pressuriser leak (pressuriser safety valves stuck open) | **Y** | **Y** | **Y** |
| BYPASS | LOCA leading to containment bypasses | **Y** | **Y** | **Y** |
| RPV | Reactor Pressure Vessel Failure | **Y** | **Y** | **Y** |
| Secondary Side Break (SSB) | Large Secondary line breaks inside containment | **Y** | **Y** | **Y** |
| | Large steam line breaks downstream of Main Steam Isolation Valves | **Y** | **Y** | **Y** |
| | Small feedwater line breaks inside containment. | **Y** | **Y** | **Y** |
| | Small feedwater line breaks inside containment, located between the last feedwater line check valve and the SG | **Y** | **Y** | **Y** |
| | Spurious opening of a Main Steam Relief Isolation Valve | **Y** | **Y** | **Y** |
| | Main Steam Safety Valves (VVP) [MSSS] stuck –open | **Y** | **Y** | **Y** |
| | Steam line rupture with steam generator tube(s) rupture | **Y** | **Y** | **Y** |
| SGTR | Steam generator tube rupture – 1 tube | **Y** | **Y** | **Y** |
| | Steam generator tubes rupture – 2 tubes | **Y** | **Y** | **Y** |
| Secondary Transients | Total loss of main feedwater supply | **Y** | **Y** | **Y** |
| | Loss of start-up and shutdown system | **Y** | **Y** | **Y** |
| | Loss of Condenser | **Y** | **Y** | **Y** |
| | Turbine Trip | **Y** | **Y** | **Y** |
| LOOP | Total loss of offsite power (2 h) | **Y** | **Y** | **Y** |
| | Total loss of offsite power (24 h) | **Y** | **Y** | **Y** |
| | Induced LOOP | **Y** | **Y** | **Y** |
| | Homogeneous boron dilution | **Y** | **Y** | **Y** |

| Fault group | | Addressed in Level 1 PSA [Y/N] | Addressed in Level 2 PSA [Y/N] | Addressed in Level 3 PSA [Y/N] |
|---|---|---|---|---|
| Primary Transients | Heterogeneous boron dilution | Y | Y | Y |
| | Total loss of RIS [SIS] cooling in RRA [RHR] mode, | Y | Y | Y |
| | Uncontrolled drop of primary level | Y | Y | Y |
| | Spurious reactor trip | Y | Y | Y |
| LOCC | Partial or total loss of cooling systems | Y | Y | Y |
| ATWS | Total loss of the normal feedwater system | Y | Y | Y |
| | Turbine Trip | Y | Y | Y |
| | Loss of main electrical network | Y | Y | Y |
| | Spurious safety injection | Y | Y | Y |
| | Spurious pressuriser spray | Y | Y | Y |
| | Primary Breaks | Y | Y | Y |
| | SGTR 1 or 2 tubes | Y | Y | Y |
| | Transient of steam overflow | Y | Y | Y |
| **Spent Fuel Analysis** | | | | |
| Loss of SFPC | Loss of cooling of the spent fuel pool | Y | Y | Y |
| Fast draining | Drainage of the spent fuel pool | Y | Y | Y |
| - | Fuel handling accident (spent fuel pond) | N | N | Y |
| - | Fuel handling accident (in reactor building) | N | N | Y |
| - | Rupture of RCV [CVCS] tank | N | N | Y |
| - | Rupture of other radioactivity- containing tank/pipe in radwaste systems | N | N | Y |
| **Internal Hazards** | | | | |
| Fire | Fire in UK EPR buildings | Y | Y | Y |
| Flooding | Flooding in UK EPR buildings (failures of vessels, tanks, pumps and valves…) | Y | Y | Y |
| Missiles | Missiles generated inside containment, inside structures or compartments containing safety equipment outside containment, and externally generated missiles | Qualitative analysis | N | N |
| Dropped loads | Due to handling device(s) failure | Qualitative analysis | N | N |
| **External Hazards** | | | | |
| Meteorological events | ME 01: Strong Winds | Y | N | N |
| | ME 02: Tornado | Y | N | N |
| | ME 03: High air temperature | Y | N | N |

| Fault group | | Addressed in Level 1 PSA [Y/N] | Addressed in Level 2 PSA [Y/N] | Addressed in Level 3 PSA [Y/N] |
|---|---|---|---|---|
| | ME 04: Low air temperature | Y | N | N |
| | ME 05: High sea water temperature | Y | N | N |
| | ME 06: Low sea water temperature | Y | N | N |
| | ME 07: Surface ice | Y | N | N |
| | ME 08: Frazil ice | Y | Y | Y |
| | ME 09: Extreme rain | Y | N | N |
| | ME 10: Extreme snow | Y | N | N |
| | ME 11: Extreme hail | Y | N | N |
| | ME 12: Soil frost | Y | N | N |
| | ME 13: Humidity – Mist | Y | N | N |
| | ME 14: Drought | Y | N | N |
| | ME 15: Lightning | Y | N | N |
| Man-made events | MME 01: Fire on-site and off-site | Y | N | N |
| | MME 02: Explosion on-site and off-site | Y | N | N |
| | MME 03: Chemical release off-site or on-site | Y | N | N |
| | MME 06: Electromagnetic interference | Y | N | N |
| | MME 07: Accidental Aircraft Crash | Y | N | Y |
| | MME 08: Missiles | Y | N | N |
| | MME 09: Direct impact from heavy transportation within site | Y | N | N |
| | MME 10: Solid or fluid impurities from ship release | Y | N | N |
| | MME 11: Direct impact from ship collision | Y | N | N |
| Biological events | B 01: Animal infestation | Y | N | N |
| | B 02: Organic material in water | Y | Y | Y |
| Geological and seismotectonic events | GS 01: Earthquakes | N | N | N |
| | GS 02: Land rise and other geological phenomena | Y | N | N |
| Flooding | F 01: External flooding | Y | N | N |

# SUB-CHAPTER 15.0 – REFERENCES

External references are identified within this sub-chapter by the text **[Ref]** at the appropriate point within the sub-chapter. These references are listed here under the heading of the section or sub-section in which they are quoted.

## 1. INTRODUCTION

**[Ref]** Safety Assessment Principles for Nuclear Facilities. 2006 Edition Revision 1. UK Health and Safety Executive (HSE). January 2008. (E)

**[Ref]** Procedures for Conducting Probabilistic Safety Assessments of Nuclear Power Plants (level 1). Safety Series No 50-P-4. IAEA. August 1992. (E)

**[Ref]** European Utility Requirements for LWR Nuclear Power Plants, Volume 2: Generic Nuclear Island Requirements, Chapter 17: PSA Methodology, Revision B. EUR Document. November 1995. (E)

## 2. NUMERICAL TARGETS

**[Ref]** Safety Assessment Principles for Nuclear Facilities. 2006 Edition Revision 1. UK Health and Safety Executive (HSE). January 2008. (E)