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SUB-CHAPTER 17.4 - REVIEW OF PSA RESULTS: COMPARISON WITH NUMERICAL RISK TARGETS

1. INTRODUCTION

As noted in Sub-chapter 17.1, HSE guidance on application of As Low As Reasonably Practicable (ALARP) for new civil reactors [Ref-1] suggests that demonstrating that numerical risks meet the Basic Safety Objectives (BSO) specified in HSE Safety Assessment Principles (SAPs) [Ref-2] can be an important element of support to the overall ALARP demonstration. The BSO risk levels correspond to the Broadly Acceptable level of risk as defined in HSE guidance on tolerability of risk from nuclear power stations in [Ref-3].

For the UK EPR, Safety Design Objectives have been adopted for risk to members of the public and workers which correspond to the BSO risk targets from the HSE Safety Assessment Principles (see Sub-chapter 3.1).

The purpose of this sub-chapter is to review the results of the PSA for the UK EPR presented in Chapter 15 in order to confirm that EPR Safety Design Objectives for risk are achieved, and therefore that the risk from EPR operation is likely to be in the Broadly Acceptable region.

2. PSA RESULTS

2.1. DESCRIPTION OF PSA

Chapter 15 presents the results of the Probabilistic Safety Assessment (PSA) analysis for the UK EPR at the current stage of the GDA. It includes the following assessments:

- A Level 1 PSA analysis for internal initiating events.
- A Level 1 PSA analysis for internal and external hazards.
- A PSA for initiating events in the fuel pool that may lead to severe fuel damage and potential radioactivity releases.
- A Level 2 PSA, which takes as input all the core damage states identified in the Level 1 PSA studies. Containment event trees are used to predict the associated consequences, in terms of the frequency and environmental source term associated with different fission product release categories.

- A study presenting a radiological impact assessment for the UK EPR. This study considers the radiological consequences of the radioactivity releases in fission product release categories considered in the Level 2 PSA. Additionally it considers that potential radiological consequences of Level 1 PSA sequences which do not result in core damage, but which may have environmental consequences (e.g. containment bypass sequences), and the impact of sequences involving release of radioactivity which are not currently considered in the PSA (e.g. from sources of radioactivity other than the primary system and the spent fuel pool). This study will be updated as part of the detailed design and site licensing phase.

- A seismic margin assessment to show that the risk from seismic events considered within the EPR design basis is insignificant.

A summary of the PSA results and a comparison with UK EPR Safety Design Objectives for individual and societal risk are presented in section 2.2 below.

2.2. RESULTS FOR INDIVIDUAL AND SOCIETAL RISK

2.2.1. Individual Risk

Chapter 15 presents an assessment of the risk to a member of the public off-site due to radiation dose from postulated accidents. Comparison is made with numerical targets defined in HSE Safety Assessment Principles, which are adopted as Safety Design Objectives for the UK EPR (see Sub-chapter 3.1).

The radiological release risk is calculated by considering the risk contributions from 3 sources:

- fission product release categories associated with consequence cases in the Level 1 PSA that do not involve core damage, but could involve a significant environmental release of radioactivity due to partial or total failure of containment safeguard systems (e.g. ventilation/filtration systems),

- fission product release categories associated with Containment Event Tree consequences cases considered in the Level 2 PSA, all of which involve core damage events,

- fission product release categories associated with sequences not modelled in the Level 1 or the Level 2 PSA, which may or may not include core damage events. Examples are radioactivity releases in the auxiliary buildings.

To calculate the radiological consequences for comparison with UK EPR Safety Design Objectives, the study uses dose assessments for design basis faults carried out for the Flamanville 3 reactor (see Sub-chapter 14.6). These assessments are based on the effective dose to a hypothetical individual who remains at a fixed location 500 m downwind of the reactor for a period of seven days after an accident - clearly highly conservative for a real individual in an actual event.

Sub-chapter 17.4 - Table 1 shows the results of the PSA, expressed in terms of the frequency of effective doses in each of the five dose bands identified in Safety Design Objective SDO-6 in Sub-chapter 3.1.

Sub-chapter 17.4 - Table 1 results are plotted in Sub-chapter 17.4 - Figure 1 where they are compared with limits for Broadly Acceptable risk and Maximum Tolerable risk identified in SDO-6. It is seen that the UK EPR design achieves a Broadly Acceptable level of risk in all Dose Bands, meeting the Safety Design Objective.

A preliminary assessment of the PSA results in 2008 indicated that improvements in the determination of the risk to the public following failure of containment isolation might be possible. However, the radiological release risk associated with containment isolation failures has been significantly reduced due to improvements included in the PSA models (see Sub-chapter 15.4 section 4.4). Therefore, no further studies on design change alternatives or procedural amendments have been performed.

UK EPR Safety Design Objective SDO-5 in Sub-chapter 3.1 sets a target for the maximum risk of fatality to the most exposed individual off-site due to accidents on the site.

The risk of death to the most exposed individual can be estimated using the results in Sub-chapter 17.4 -Table 1, by making an assumption that an effective dose of 1 mSv will result in an increase in the risk of individual death due to effects of radiation of 5×10^{-5} [Ref-1].

The annualised probability of death of the most exposed individual due to accidents is then given by:

$$\sum F_i \times Min[1.0,\ 5 \times 10^{-5} D_i]$$

where

F_i = the frequency of an individual receiving an effective dose in Dose Band i,
D_i = magnitude of the dose in mSv,

and the summation is taken over the five Dose bands. To give a pessimistic result D_i is taken as the effective dose at the upper limit of the Dose Band except for Dose Band 5 where it is pessimistically assumed that the radiation dose is so large that there would be a unit probability of individual death.

Applying the above equation, using the data in Sub-chapter 17.4 -Table 1, results in a risk of individual death of 1.7×10^{-7}/yr, which is considered highly pessimistic. This meets Safety Design Objective SDO-5 (Sub-chapter 3.1), which gives a risk target of below 10^{-6}/yr, corresponding to the BSO risk level in the HSE SAPs.

UK EPR Safety Design Objective SDO-4 (see Sub-chapter 3.1) sets a target for the maximum risk of fatality to a worker on-site due to radiation from accidents. This target of below 10^{-6}/yr, corresponds to the BSO risk level in the HSE SAPs. Worker risk in accidents was analysed in Sub-chapter 17.3, section 3. This first analysis considered that the risk to workers will be lower than to individuals off-site due to measures available to protect workers from the effect of accidental radioactivity releases. This first analysis will be updated as part of the detailed design and site licensing phase.

However, given the fact that workers on site are more easily protected from accident consequences by emergency procedures (evacuation and sheltering), and the highly pessimistic method used for assessing the radiation dose for individuals off-site for the assessment against SDO-5, it is considered that the risk to workers would be smaller than the risk to the most exposed persons off-site, and the SDO-4 target would therefore be met.

2.2.2. Societal Risk

UK EPR Safety Design Objective SDO-7 in Sub-chapter 3.1 sets a target for the maximum risk of occurrence of 100 fatalities due to on-site reactor accidents. The target aligns with the Basic Safety Objective for the societal risk due to potential accidents in a nuclear facility defined by Target 9 in the HSE SAPs.

Chapter 15 uses the EPR Level 1 and Level 2 PSA results to estimate the societal risk due to accidental release of radioactivity from an EPR in the UK. Accident consequences are obtained from previous analysis results for major accidents on existing UK nuclear licensed sites containing operating reactors. The analysis of accident consequences is adjusted to take into account the larger fission product inventory in the EPR core compared with operating UK reactors. The analysis identifies the EPR fission product release categories that could result in off-site consequences involving more than 100 fatalities. The release categories are identified from:

- Release Categories from the Level 2 PSA that fall within dose band 5,
- Releases categories from the Level 1 PSA non-core damage sequences that fall within dose band 5 of the individual risk assessment (see section 2.2.1 above),
- Releases categories for the "additional events" fuel damage sequences following water drainage (see Chapter 15).

The accident consequences are taken from results for the UK site with the highest number of fatalities.

Clearly the above approach can only give an approximate estimate of societal risk for a UK sited EPR, but the method is considered appropriate for the generic design assessment when no specific site is identified. A more detailed analysis of accident consequences will be provided as part of the site licensing taking into account actual site characteristics.

The analysis gives a summated frequency of the release categories, which have the potential to lead to more than 100 eventual fatalities, for a generic UK site, of $8x10^{-8}$ /yr. This meets Safety Design Objective SDO-7, which sets a target of 10^{-7}/yr for the risk of 100 fatalities.

Given the pessimistic approach in the current assessment, it is considered that UK EPR Safety Design Objective SDO-7 for societal risk, which corresponds to the BSO limit defined in the HSE SAPs, is likely to be met.

3. CONCLUSIONS OF PSA ASSESSMENT

For the UK EPR, Safety Design Objectives have been adopted for risk to members of the public and workers due to normal operation and accidents, which correspond to the BSO risk targets defined by HSE Safety Assessment Principles.

This sub-chapter has reviewed the results of the PSA for the UK EPR presented in Chapter 15 and has confirmed that EPR Safety Design Objectives for risk (SDO 1, 4, 5, 6 and 7) are achieved. It follows that the BSO risk targets defined by the HSE Safety Assessment Principles are likely to be met by the EPR.

Demonstration using a PSA model that the nuclear safety risk due an EPR meets the BSO risk targets is considered to be an important element in the overall demonstration that the ALARP principle is met by the EPR.

SUB-CHAPTER 17.4 - TABLE 1

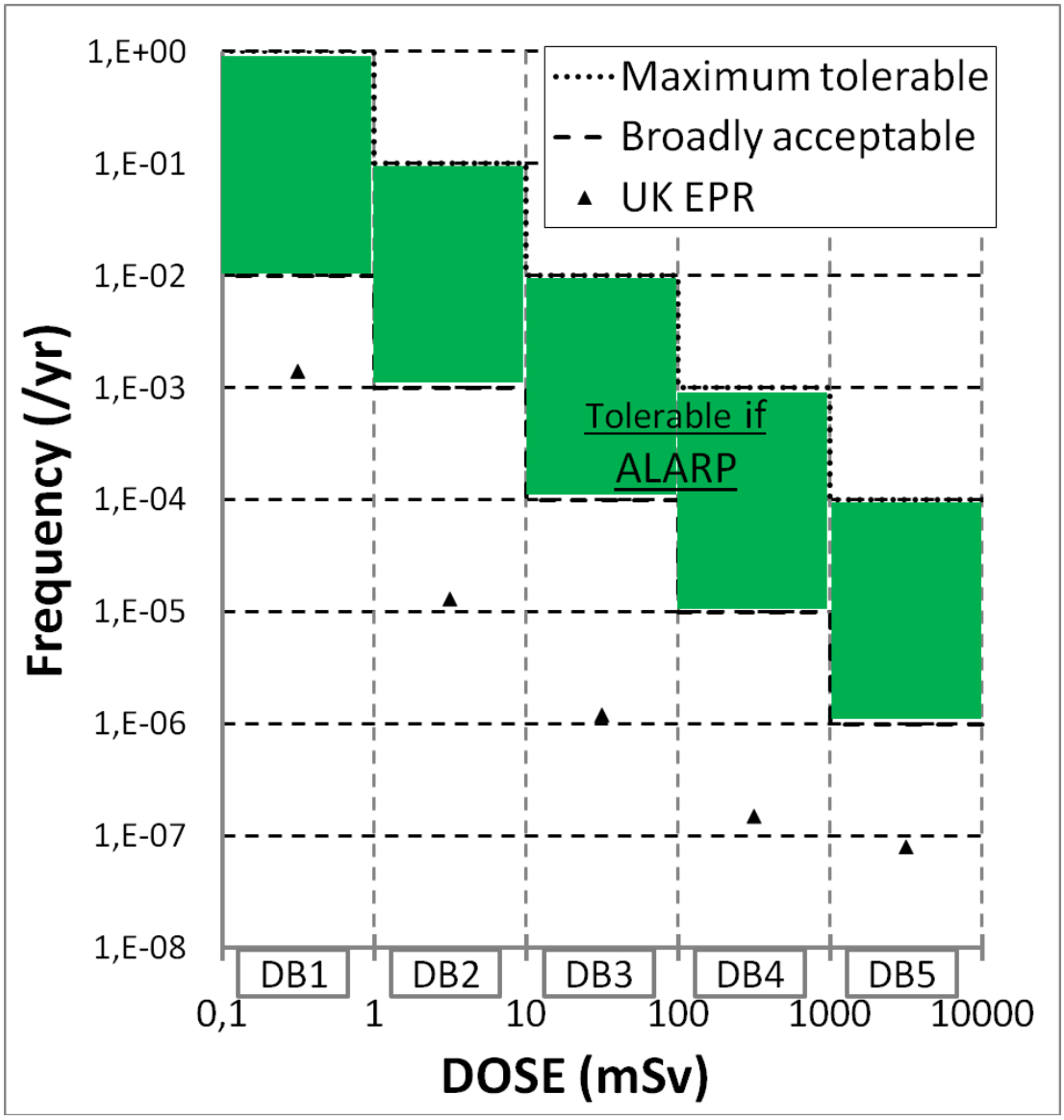
Results for Assessment of Individual Risk

Off-site effective dose band (mSv)	Cumulative Frequency (/y)			
	Non core damage sequences from Level 1 PSA	Additional non core damage sequences	Core damage sequences from Level 2 PSA	Total
DB5 > 1000	1.5×10^{-9} (2%)	2.5×10^{-9} (3%)	7.6×10^{-8} (95%)	**8×10^{-8}**
DB4 100 - 1000	6.4×10^{-10} (0.4%)	0 (0%)	1.5×10^{-7} (99.6%)	**1.5×10^{-7}**
DB3 10 - 100	1.8×10^{-7} (16%)	5.0×10^{-7} (43%)	4.84×10^{-7} (41%)	**1.2×10^{-6}**
DB2 1 – 10	2.8×10^{-6} (21%)	1.0×10^{-5} (79%)	0 (0%)	**1.3×10^{-5}**
DB1 0.1 - 1	1.2×10^{-3} (86%)	2.0×10^{-4} (14%)	0 (0%)	**1.4×10^{-3}**

SUB-CHAPTER 17.4 - FIGURE 1

Comparison of Dose/Frequency Levels with UK EPR

Safety Design Objectives



SUB-CHAPTER 17.4 – REFERENCES

External references are identified within this sub-chapter by the text [Ref-1], [Ref-2], etc 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-1] UK Health and Safety Executive (HSE). Technical Assessment Guide, ND Guidance on the Demonstration of ALARP (As Low As is Reasonably Practicable). T/AST/005 Issue 4 Revision 1. January 2009. (E)

[Ref-2] UK Health and Safety Executive (HSE). Safety Assessment Principles for Nuclear Facilities. 2006 Edition Revision 1. January 2008. (E)

[Ref-3] UK Health and Safety Executive (HSE). The Tolerability of Risk from Nuclear Power Stations. ISBN 0118863681. The Stationery Office Ltd. 1992. (E)

2. PSA RESULTS

2.2. RESULTS FOR INDIVIDUAL AND SOCIETAL RISK

2.2.1. Individual Risk

[Ref-1] UK Health and Safety Executive (HSE). The Tolerability of Risk from Nuclear Power Stations. ISBN 0118863681. The Stationery Office Ltd. 1992. (E)