UK EPR	Title: PCSR – Sub-chapter 17.5 – Review of possible design modifications to confirm design meets ALARP principle
	UKEPR-0002-175 Issue 04

Total number of pages: 26	Page No.: I / IV
Chapter Pilot: G. BODY *Name/Initials* [signature] *Date 24-08-2012*	
Approved for EDF by: A. MARECHAL *Name/Initials* [signature] *Date 29-08-2012*	Approved for AREVA by: G. CRAIG *Name/Initials* [signature] *Date 30-08-2012*

REVISION HISTORY

Issue	Description	Date
00	First issue for INSA review	22/4/2008
01	Integration of technical and INSA review comments	28/6/2008
02	PCSR June 2009 update: - section 3: inclusion of updated PSA results - minor technical supplements	27/06/2009
03	Consolidated Step 4 PCSR update: - Minor editorial changes - Sections 1 and 2, introduction of the “UK EPR ALARP methodology” and reference added - Sections 3.1, 3.2, 3.3, 3.4, 3.6, update of PSA results due to PSA model development - Section 3.5: Removal of design alternative analysis: “I&C system - introduce of a hard-wired back-up protection system” (superseded) - Section 3.5: New section added “Modification of the pre-stressed inner containment to adopt ungrouted greased tendons” - Section 3.7: New section added “Increase in the injection pressure of the Medium Head Safety Injection (MHSI) pump” - Section 4: Text updated consistent with Sub-chapter 17.4 and Sub-chapter 15.4 to add that no further ALARP analysis is necessary regarding the contribution of containment isolation failure to the PSA	28/03/2011

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REVISION HISTORY (Cont'd)

Issue	Description	Date
04	Consolidated PCSR update: - References listed under each numbered section or sub-section heading numbered [Ref-1], [Ref-2], [Ref-3], etc - Minor editorial changes - Modification of §3.3 to reflect that Main Coolant Lines are High Integrity Components (HIC) - Modification of §3.6 to include the ALARP analysis performed to support the design modification and proposed NDT of the Main Coolant Lines - Introduction (§1.1) and conclusion (§5) updated in line with changes to §3.6	30/08/2012

For information address:

AREVA NP SAS
Tour AREVA
92084 Paris La Défense Cedex
France

EDF
Division Ingénierie Nucléaire
Centre National d'Equipement Nucléaire
165-173, avenue Pierre Brossolette
BP900
92542 Montrouge
France

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SUB-CHAPTER 17.5 - REVIEW OF POSSIBLE DESIGN MODIFICATIONS TO CONFIRM DESIGN MEETS ALARP PRINCIPLE

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] recommends that there should be a clear conclusion that no further reasonable practicable improvements could be implemented in the reactor design, and that therefore the risk has been reduced to ALARP. In this guidance, the proposed approach is to compare the benefits of the risk averted by an additional design option, with the modification cost and its difficulty. If the cost and difficulty are grossly disproportionate to the benefit achieved, the modification may not be reasonably practicable to implement.

The USNRC process for design certification of new reactors requires designers to consider the cost and benefits of severe accident mitigation design alternatives (SAMDA) and provide reasons for not incorporating them in their designs [Ref-2]. The SAMDA process is similar to the quantitative ALARP process applied in the UK. The AREVA Standard Design Certification report [Ref-3] contains a SAMDA assessment for the EPR design submitted for design certification in the US, which concludes that no further modifications can be justified on cost/benefit grounds.

The current sub-chapter provides an ALARP assessment methodology and an ALARP assessment of several UK EPR design alternatives.

1.1. SELECTION OF DESIGN ALTERNATIVES

In order to confirm that no further reasonably practicable improvements could be implemented, design alternatives were selected for analysis. This selection is based on modifications required by international regulators in their assessment of the EPR, design variants belonging to the Sizewell B PWR design, or other potential improvements identified during the UK EPR GDA. The following design alternatives were selected and are assessed in section 3:

1. Addition of a third train to the Extra Boration System (RBS [EBS]),
2. Addition of a containment filtered venting system,
3. Increase in the capacity of the accumulators in the Safety Injection System (low pressure RIS [SIS]),
4. Modification of the Reactor Pressure Vessel (RPV) design to remove the circumferential weld at the core mid-height,
5. Modification of the pre-stressed inner containment to adopt ungrouted greased tendons,
6. Modifications to improve inspectability of the Main Coolant Lines (MCL) pipework subject to High Integrity Component (HIC) requirements,
7. Increase in the injection pressure of the Medium Head Safety Injection (MHSI) pump.

1.2. SELECTION OF OTHER DESIGN ALTERNATIVES

The application of the ALARP methodology to the EPR design, consistent with UK practices, was new and not formally applied as an integral part of the EPR design process. Nevertheless, as stated above, design alternatives were selected for analysis to confirm that no further reasonably practicable improvements could be implemented.

As part of the detailed design and site licensing phase, other design alternatives may be selected and their reasonable practicability fully evaluated.

2. DESCRIPTION OF ALARP METHODOLOGY

The UK EPR ALARP methodology report [Ref-1] provides complete operational guidance on ALARP assessment.

The ALARP demonstration corresponds to a decision making process, which makes it possible to justify that the risks have been reduced as far as is reasonably practicable and to identify the ALARP design option that could resolve a safety issue. It should be fit for purpose and requires a formal and documented process, based on sound technical information.

Fundamentally, the ALARP process is based on five steps:

1. Presentation of the safety issue
2. Identification of the various possible options, which could resolve the safety issue
3. Qualitative assessment of each design option
4. Quantitative assessment of each design option
5. Conclusion and justification of the ALARP option

These five steps are detailed in the UK EPR ALARP methodology report [Ref-1]. Steps 3 and 4 are briefly introduced below.

2.1. QUALITATIVE ALARP ASSESSMENT

The aim is to assess each of the possible options, which could cope with the safety issue, using qualitative factors. This assessment aims at defining the benefits and disbenefits of each option, based on engineering judgement backed up by consolidated evidence/information.

The benefits to be considered are fundamentally safety benefits. The disbenefits to be considered are fundamentally safety and commercial disbenefits, which refers to ‘money, time and trouble’. Implementation and operational costs can be identified.

However, it may also be useful to supplement this assessment by using other factors, in particular, environmental factors.

2.2. QUANTITATIVE ALARP ASSESSMENT

The basis for the quantitative ALARP assessment is the comparison of the cost of a modification option with the value of the risk reduction achieved. The risk reduction value is an estimate in economic terms of the value of the risk averted by the plant modification. It is defined by the equation:

$$RRV = C \cdot A\,(\Delta F)\,T \qquad (1)$$

where:

- *RRV* = Risk reduction value (GBP)
- *A* = Accident cost at present values (GBP)
- *C* = Present value factor, allowing for discounting (see below)
- *ΔF* = Reduction in accident frequency achieved by plant modification (/y)
- *T* = Time over which risk reduction is achieved = operating life of facility (y)

If the cost of the plant modification is grossly disproportionate to the Risk Reduction Value obtained from (1), the implementation of the modification may not be reasonably practicable under ALARP principles.

According to the HSE guidelines, the accident costs should include all costs to society of the accident, including the health consequences to workers and members of the public, the cost of evacuation, relocation, land interdiction and the cost of land decontamination and food bans etc. Calculation of accident costs for an UK EPR for the purpose of the current ALARP assessment is described in Section 2.2.1 below.

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The number of years at risk in equation (1) is taken as the design life of the reactor (= 60 years).

2.2.1. Accident Cost Evaluation

As noted above, the HSE Technical Assessment Guide [Ref-1] states that accident costs should include the economic costs of radiation exposures to the public and workers and the cost of other detriments such as the need to decontaminate areas, evacuation, relocation and food bans. Commercial costs to the plant operator due to loss of the facility or loss of revenue from generation are excluded.

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3. ALARP ASSESSMENT OF DESIGN ALTERNATIVES

The design alternatives selected in section 1.1 were mainly assessed using the UK cost benefit methodology presented in section 2.2 and where possible, the Probabilistic Safety Assessment (PSA) model for the UK EPR has been used to quantify the risk benefit.

3.1. ADDITION OF A 3RD TRAIN TO EXTRA BORATION SYSTEM RBS [EBS]

The UK EPR Extra Boration System (RBS [EBS]) is an F1A safety classified system, which provides boron injection to compensate for the reactivity insertion due to cooldown in order to achieve a safe shutdown state in PCC events. It also provides a means of reactivity control in ATWS events at power and boron dilution events when the reactor is shutdown. The RBS [EBS] is described in Sub-chapter 6.7.

The RBS [EBS] comprises 2x100% trains. As the RBS [EBS] comprises two trains, it is only planned to carry out preventive maintenance on its mechanical components during a unit shutdown. In the Sizewell B PWR, a 4x100% train Emergency Boration System was provided for reactivity control in ATWS events, to meet the request of the UK regulatory authorities. Furthermore the Finnish safety authorities have requested an addition of a back-up pump in the RBS [EBS] for the Olkiluoto 3 EPR, installed in parallel of the two existing ones and intended to be available during preventive maintenance of one of the two others. In view of the regulatory concerns it was decided to carry out an ALARP assessment of the cost and benefits of a modification to increase the redundancy of the RBS [EBS] by adding a third fully functional 100% train.

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3.2. ADDITION OF A FILTERED CONTAINMENT VENTING SYSTEM TO THE REACTOR CONTAINMENT BUILDING

The EPR is provided with a dedicated system to provide heat removal and containment spray in order to maintain the containment pressure within design limits under severe accident (core damage) conditions. This system, which is referred to as the Containment Heat Removal System (EVU [CHRS]), is described in Sub-chapter 6.2.

Despite the provision of the EVU [CHRS] in the EPR design, the Finnish safety authorities have requested that a filtered containment vent is provided as an additional means of containment pressure control in the case of total loss of the containment cooling capability. The purpose of the filtered vent is to allow controlled depressurisation of the containment building through filters, in the event that overpressurisation occurs due to loss of all containment cooling capability. The containment vent would be actuated manually by operators to remove any overpressure caused by non-condensable gases possibly released in a later phase of an accident. This could be the case during shutdown states when reactor pressure vessel is open. In such cases, SRU [UCWS] system cannot be credited in the Olkiluoto 3 EPR design, which may require containment venting as an alternative containment heat sink.

The UK EPR is provided with a full diversified heat sink for the EVU [CHRS] system (normal SEC [ESWS] heat sink and diverse SRU [UCWS] heat sink), which significantly improves the overall reliability of the heat sink. Furthermore, the related environmental conditions are taken into account to design and qualify the equipments that operate during these postulated accidents.

The addition of a filtered vent was considered in the SAMDA assessment [Ref-1] carried out for the US EPR design and concluded not to be cost beneficial.

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Provision of a containment vent has some safety disadvantages in addition to the advantages cited above. In particular the fission product source term associated with venting would be significant, unless expensive filtering devices were implemented. This drawback further offsets the limited risk benefit due to the vent, providing further arguments that the vent is not a reasonably practicable modification.

3.3. INCREASE IN THE CAPACITY OF THE ACCUMULATORS IN THE SAFETY INJECTION SYSTEM

In the EPR design, guillotine failure of the main loop pipework (2A-LOCA) is excluded from the list of design basis accidents as the Main Coolant Lines (MCLs) are classified as High Integrity Components (HICs). The largest breach considered in the design basis accident (PCC) analysis is then a guillotine failure of the pressuriser surge line. However, to achieve defence in depth, the containment building and the Safety Injection System are designed with sufficient margins to withstand the effects of a 2A-LOCA, assessed with realistic assumptions, without exceeding design and safety limits applicable to the containment and core (Sub-chapters 6.2 and 6.3).

For the Olkiluoto 3 EPR, the Finnish regulator (STUK) required that account was taken of a guillotine break of the Main Coolant Lines (MCLs) in the design. Due to the inclusion of 2A-LOCA in the list of design basis accidents, it was then required to increase the capacity of the accumulators in the safety injection system.

A study was carried out to establish if it would be reasonably practicable to provide a similar increase in the capacity of the accumulators.

The Level 1 PSA has assessed the frequency of 2A-LOCA {CCI Removed} [b], such a low value being applicable due to the high design, construction and in-service inspection standards applied to the Main Coolant Lines (MCLs). For this event, the PSA assumes that two Medium Head Safety Injection (MHSI) pumps, three accumulators and two Low Head Safety Injection (LHSI) pumps are required to ensure the safety injection mission. Based on thermal-hydraulic success criteria for a large break LOCA up to a guillotine failure of the pressuriser surge line (see Sub-chapter 15.1), this is assumed to be sufficient to ensure the RCP [RCS] inventory control. This requirement is expected to be highly conservative.

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3.4. MODIFICATION OF RPV DESIGN TO REMOVE MID-HEIGHT WELD

The EPR RPV has a circumferential weld close to the mid-height of the core, similar to that used in currently operating Nuclear Power Plants (NPPs) in France. The peak neutron flux levels in the core occur at the core mid-plane. Positioning a weld in the high flux region potentially increases the vulnerability of the weld metal to radiation embrittlement; therefore a potential reduction in the risk due to RPV failure could in principle be achieved by redesigning the RPV with the mid-height circumferential weld relocated to be outside the region of highest flux. Such a modification was implemented in the Sizewell B PWR.

A study was carried out to establish if it would be reasonably practicable to modify the RPV of the UK EPR to relocate the mid-height weld.

Although the mid-height weld is at the axial peak flux region, the neutron fluence at the weld is reduced to a low level by the heavy reflector surrounding the reactor core. Compared with previous French NPP designs, the fluence over life is considerably reduced, as indicated below:

- 900 MWe NPP Design: 6.5×10^{19} n/cm² (40 years)
- 1300 MWe NPP Design: 4.6×10^{19} n/cm² (40 years)
- N4 NPP Design: 3.7×10^{19} n/cm² (40 years)
- EPR (FA3): 1.2×10^{19} n/cm² (60 years)

As no significant degradation of weld material has been experienced in the previous designs, there is confidence that the EPR design will also not experience significant degradation over the plant life.

As noted above the Sizewell B PWR RPV design was modified to have a single core shell containing no mid-height welds. However, due to the absence of the shielding effect of a heavy reflector, the 40 year (lifetime) fluence experienced by the two welds closest to the core is expected to be similar to the 60 year (lifetime) fluence experienced by the EPR RPV mid-height weld. Therefore there is no reason to expect that the weld failure risk in the EPR will be higher than in the Sizewell B unit.

A major design improvement of the EPR RPV compared to previous designs is the use of a single forging for the flange and nozzle shell (upper part of the RPV body). This avoids the need to locate a weld in the thick part of the RPV, giving a significant benefit with regard to in-service inspection and weld controllability. This advantage would be lost if the RPV design was modified to relocate the central weld.

It is further noted that current worldwide forging capabilities would not allow the forging of a single core shell large enough to remove the weld from the core zone: a shell of the required diameter could not be forged to the required height, due to ingot size and forging limitations. Therefore there is limited potential for re-designing the RPV to further reduce the fluence on the affected welds.

In conclusion, the current EPR RPV design based on two core shells, results in a fluence on the most central weld that is less than or comparable to that on similar vulnerable welds in previous RPVs. Additionally, the EPR design enables a single flange and nozzle shell to be used, which avoids the need to locate a weld in the thick part of the RPV, giving a significant benefit with regard to in-service inspection and weld controllability. On balance it is considered that the net effect is a reduction in the risk of RPV failure.

The UK EPR PSA has quantified the risk due to catastrophic failure of the RPV, which is assigned a frequency of 10^{-8}/y.

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It is concluded that removing the mid-height weld in the RPV design would not be justified under UK ALARP principles based on both qualitative and quantitative considerations.

3.5. MODIFICATION OF THE PRE-STRESSED INNER CONTAINMENT TO ADOPT UNGROUTED GREASED TENDONS

Within the UK all the previous pre-stressed concrete pressure vessels performing a nuclear role have used ungrouted greased tendons. The UK EPR inner containment pre-stressing is provided by an arrangement of fully cement-grouted bonded steel tendons. A study, summarised in Sub-chapter 3.3, was carried out to justify this new design and consistency with the ALARP principle, by assessing some design alternatives and improvements.

The study has concluded that:

- the grouted tendon design will provide adequate reliability of pre-stressing through the life of the EPR containment structure;
- the adoption of an alternative pre-stressing system utilising ungrouted tendons would not be consistent with ALARP;
- a modified layout of strain gauges in the containment wall of the UK EPR is proposed to improve the ability to detect hypothetical tendon failures;
- no further reasonably practicable improvements have been identified.

3.6. MODIFICATIONS TO IMPROVE INSPECTABILITY OF MAIN COOLANT LINES (MCL)

In the UK EPR, the Main Coolant Lines (MCLs) are classified as High Integrity Components (HICs) - implying that guillotine failure of these lines is excluded from the design basis. The claim that the likelihood of guillotine failure is so low it may be discounted requires high confidence that no significant defects will develop during the plant lifetime, implying high standards of design, manufacture and pre-service and in-service inspection.

For the manufacturing inspection of the welds in the MCL pipework, it was initially proposed to use Radiographic Testing (RT) combined with Ultrasonic Testing (UT). However, with the MCL pipework geometry initially proposed, some shortfalls were identified which prevented UT inspection objectives from being fully realised, especially relating to the detection of hypothetical narrow near-vertical planar defects in welds which must be considered to meet UK safety requirements [Ref-1]:

- For a certain number of welds, optimal beam incidence angles cannot be achieved by scanning from either side of the weld using available UT inspection techniques. The shortfalls are mainly due to an insufficient length of straight pipe at the end of some of the forged sections.
- ‘Errors of form’ due to the induction bending process used to form the MCL elbows can create surface undulations in the scanning region, potentially preventing effective UT examination in some zones.
- The presence of counterbores may affect the scanning and inspection capability when inspecting from the bore, and might create difficulties for interpretation when scanning from the outside if a self-tandem technique was used.

An ALARP assessment [Ref-1] was carried out to examine the practicability of various options for overcoming the above shortfalls. Four modification options were evaluated:

1. ‘Do nothing’ option (while maintaining the HIC claim) in which the present layout and initially proposed inspection techniques are retained

2. Option to modify the geometry of sections of the MCL to optimise inspectability using initially proposed UT techniques

3. Option to apply a self-tandem inspection technique to all homogeneous welds, and a 0º Longitudinal Wave reflection technique to dissimilar metal welds, to supplement the UT techniques initially proposed.

4. Option to modify the UK EPR safety case to abandon the HIC claim on the MCL pipework to address the consequences of guillotine failure of the MCL.

Due to the inability to achieve the optimum beam angles at some weld locations and the uncertainties created by the errors of form, it was concluded that the option (1) was not acceptable if the HIC claim on the MCL pipework was to be maintained, following current UK practices.

Option (2), to modify the geometry of the MCL pipework to optimise inspectability, was concluded to give significant benefits in improving inspectability of the critical MCL welds, without significant safety or commercial disbenefits. Therefore, this option was considered to be an ALARP means of complying with UK safety practices for HIC components.

Option (3), to extend the UT testing procedure to include use of a self tandem technique for all homogeneous welds, and 0^{o} Longitudinal Wave reflection for dissimilar metal welds, was concluded to give a potential safety advantage in improved defect detection capability, without identified safety or commercial disadvantages, and was thus concluded to be an ALARP means of complying with UK safety practices for HIC components.

Option (4) to modify the UK EPR safety case to remove the HIC claim on the MCL pipework, which involved installing anti-whip pipe restraints, was concluded to introduce safety drawbacks which outweighed any safety advantages, and therefore not to be ALARP.

Options (2) and (3) will therefore be implemented in UK EPR.

3.7. INCREASE IN THE INJECTION PRESSURE OF THE MHSI PUMPS

As described in Sub-chapter 17.3, the UK EPR retained a requirement for the maximum head developed by the Medium-Head Safety Injection (MHSI) pumps to be below the set pressure of the safety relief valves on the secondary system. Associated with the automatic shutdown of Chemical and Volume Control System charging pumps, this design reduces the risk of primary coolant bypassing the containment through the secondary system in Steam Generator Tube Rupture (SGTR) events by preventing liquid discharge from Steam Generator (SG) relief valves.

A study was carried out to establish whether it would be reasonably practicable to increase the injection pressure of the MHSI pumps, i.e. would it be reasonably practicable to implement new MHSI pumps like the Sizewell B High Head Safety Injection (HHSI) pumps, which are similar to the MHSI pumps of French PWR NPP (N4 and 1300MWe plant series).

This alternative design increases the risk of primary coolant bypassing the containment through the secondary system in Steam Generator Tube Rupture (SGTR). However, it could reduce the risk in the case of LOCA since it does not require any automatic initiation of Partial Cool Down (PCD) in order to reduce the RCP [RCS] pressure to enable the injection of borated water by the MHSI pumps. The costs of the HHSI pump and EPR MHSI pump are similar. However, the implementation of a HHSI pump replacing a MHSI pump would incur additional costs: some arrangements of pipes and valves of the RIS [SIS] circuit might be changed and some additional studies would be required to check that the RIS [SIS] circuit was able to sustain the higher pressure. Nevertheless there is no cliff-edge effect.

A qualitative analysis is not sufficient to weigh the advantages and disadvantages of HHSI pumps against MHSI pumps. Therefore a quantitative ALARP assessment using the Level 1 and Level 2 PSA models was performed.

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[b] This quantitative assessment concluded that it would not be reasonably practicable to replace the EPR MHSI pumps by HHSI pumps.

4. ALARP ASSESSMENTS OF OTHER DESIGN ALTERNATIVES

The PSA model developed for the UK EPR, and the application of UK ALARP methodology, were relatively new. As detailed in section 1.2 in order to confirm that no further reasonably practicable improvements could be implemented, design alternatives were selected, and assessed as described in section 3.

As part of the detailed design and site licensing phase, other design alternatives may be selected and their reasonable practicability fully evaluated.

From that perspective the formulation of emergency procedures and procedures for severe accident management, will be fully evaluated as part of the detailed design and site licensing phase.

5. CONCLUSIONS OF ALARP ASSESSMENT OF DESIGN ALTERNATIVES

HSE guidance on application of ALARP for new civil reactors in the UK recommends that arguments are presented that no further reasonably practicable improvements could be implemented in the reactor design, and therefore the risk has been reduced to ALARP.

The current sub-chapter has provided an ALARP assessment of several UK EPR design alternatives.

Design alternatives selected for analysis were based on modifications required by international regulators in their assessment of EPR, design variants belonging to the Sizewell B PWR design, or other potential improvements identified during the UK EPR GDA:

1. Addition of a third train to the Extra Boration System (RBS [EBS]),

2. Addition of a containment filtered venting system,
3. Increase in the capacity of the accumulators in the Safety Injection System (RIS [SIS]),
4. Modification of the Reactor Pressure Vessel (RPV) design to remove the circumferential weld at the core mid-height,
5. Modification of the pre-stressed inner containment to adopt ungrouted greased tendons,
6. Modifications to improve inspectability of MCL pipework subject to HIC requirements,
7. Increase in the injection pressure of the MHSI pump.

With the exception of item (6) none of the modifications considered above was indicated as reasonably practicable according to the UK EPR ALARP assessment methodology.

Other design alternatives to the EPR design may be provided as part of the detailed design and site licensing phase. In that case, the ALARP methodology consistent with UK practices will be applied.

Therefore, within the Generic Design Assessment, and subject to implementation of modifications to improve inspectability of the MCL pipework, it is judged that the risk has been reduced to ALARP.

SUB-CHAPTER 17.5 - TABLE 1

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SUB-CHAPTER 17.5 - TABLE 2

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SUB-CHAPTER 17.5 – 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] US NRC. Regulations (10 CFR), 51.55(a), Environmental Report – Standard Design Certification. (E)

[Ref-3] AREVA NP Environmental Report: Standard Design Certification, ANP-10290, Revision 0, November 2007. (E)

2. DESCRIPTION OF ALARP METHODOLOGY

[Ref-1] F. Romanet. UK EPR ALARP methodology to support the design modification process. ENSNDR100088 Revision A. EDF/SEPTEN. July 2010. (E)

2.2. QUANTITATIVE ALARP ASSESSMENT

2.2.1. Accident Cost Evaluation

[Ref-1] UK Health and Safety Executive (HSE). Technical Assessment Guide, ND Guidance on the Demonstration of ALARP (As Low As is Reasonably Practicable).

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3. RESULTS OF ALARP ASSESSMENT

3.2. ADDITION OF A FILTERED CONTAINMENT VENTING SYSTEM TO THE REACTOR CONTAINMENT BUILDING

[Ref-1] AREVA NP Environmental Report: Standard Design Certification, ANP-10290, Revision 0, November 2007. (E)

3.6. MODIFICATIONS TO IMPROVE INSPECTABILITY OF MAIN COOLANT LINES (MCL)

[Ref-1] UK EPR – ALARP Justification of Manufacturing Inspection Technique Proposed for the Main Coolant Lines Welds of the UK EPR. PEER-F DC 78 Revision A. AREVA. March 2012. (E)