The influence of the facility nuclear safety case on the design of naval refit support equipment

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Synopsis

Continuous review, adaptation and improvement through upkeep and maintenance periods has enabled the Royal Navy submarine fleet to remain fit for purpose through successive life extension programmes. Devonport Royal Dockyard, Plymouth, provides nuclear submarine dry dock facilities for maintenance. The Site Licences which authorise operations of these nuclear facilities are administered by the Office for Nuclear Regulation which ensures that the intent of the facility nuclear safety case is maintained throughout all operations. As such, any dock modifications and refit support equipment or structures must be designed within the framework of the safety case.

A requirement to undertake refit activities external to the hull of a nuclear submarine while in dock resulted in a design and build project for a temporary dock-bottom building to provide a safe and capable environment. The design of this building's structure and sub-systems was heavily influenced by the nuclear safety case.

This paper explores the challenges of designing equipment within the constraints of the nuclear licensed site, identifies the provenance and the requirements of the nuclear safety case of a dry dock nuclear facility, and examines the influence of this safety case upon requirements management, and the design lifecycle. The design of the dock-bottom building is presented, including an outline of the technical challenges which arose, and some of the novel solutions developed, including; a modular, seismically-qualified, primary structure; and a modified crane incorporating a crushable element. The paper explores the issues of finite element analysis of the primary structure to substantiate performance and satisfy the safety case. The paper also presents a discussion of the influence and impact of the safety case upon the building design project.

Keywords: Nuclear safety case; Submarine maintenance; Requirements management; Equipment design.

1 Introduction

Chernobyl, Fukushima, Three Mile Island, Windscale – these are widely known, well studied, and often highly emotive incidents where the control of nuclear work has failed causing widespread human and ecological harm. The risk appetite within the nuclear safety field has reduced markedly since the early days of nuclear experimentation, and operators of nuclear installations worldwide are now rightly bound by significant legislative and ethical responsibilities. High levels of control are exercised at civilian and defence nuclear installations to prevent accidents; either contamination with radioactive isotopes or ionising radiation dose.

The nuclear submarines of the Royal Navy fleet are critical defence assets which require maintenance and periodic system upgrade to ensure availability and capability. Babcock operates Devonport Royal Dockyard, Plymouth, where this maintenance is undertaken in dedicated dry docks with the appropriate workshops, docking aids and cranes to support refit periods. The responsibility for the vessel and its *Nuclear Steam Raising Plant (NSRP)* passes from the Ministry of Defence to Babcock, who must then adhere to a special regulatory framework to assure the safety of the NSRP through the docking period, and control risks to personnel, the public and the environment.

This paper examines the influence and impact of this regulatory framework upon:

- The design lifecycle of a new item of *Refit Support Equipment* (RSE) for a nuclear facility.
- The design of one such item of RSE, through a case study of the *Submarine Support Building (SSB).*

Author's Biography

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2 Nuclear Safety

2.1 Regulation of a UK Nuclear Licensed Site

The *Office of Nuclear Regulation* (ONR) is the licensing authority for UK nuclear installations, in accordance with the Nuclear Installations Act 1965 [Ref 1]. The ONR administers *Nuclear Site Licences* to which *Licence Conditions* are attached; these define controls for the handling of nuclear matter. The site operator must substantiate to the ONR's satisfaction that the licence conditions are met and that the risks are at an *As Low As Reasonably Practicable* (ALARP) level; this body of substantiation is contained within the *Safety Case* [Ref 2]. This relationship is shown in Figure 1.

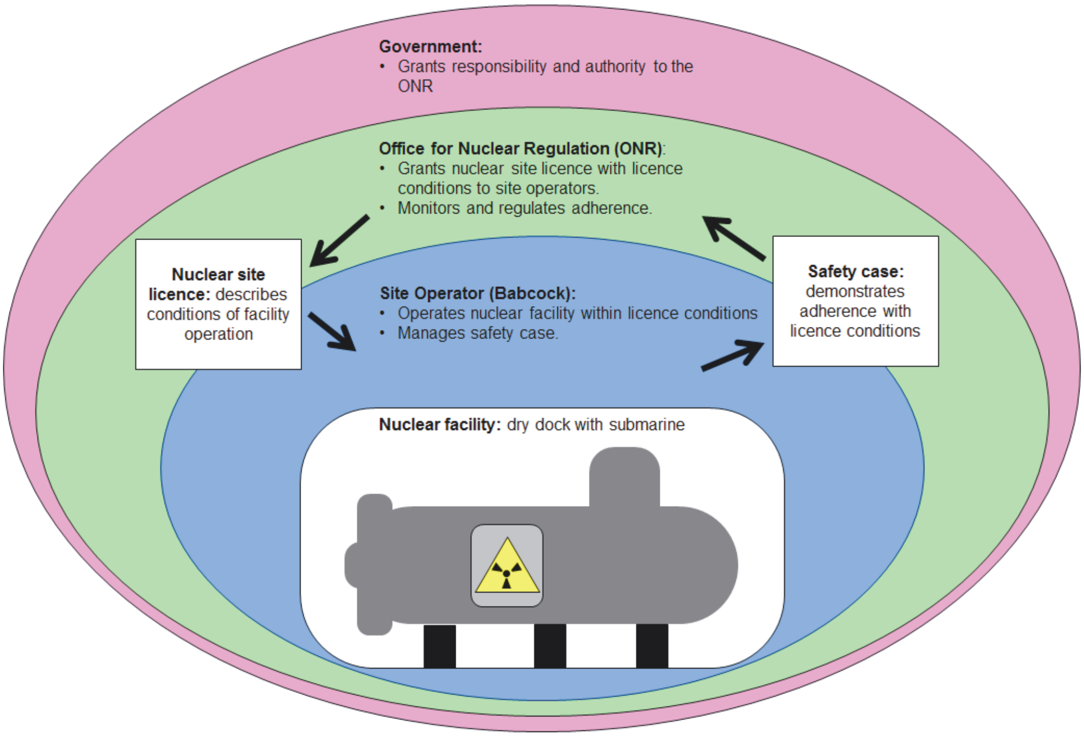

Figure 1: Regulation of a UK nuclear submarine maintenance facility

2.2 The Safety Case

The safety case documentation contains; a listing of nuclear / radiological hazards arising from normal and faulted operations; assessments of the risks; descriptions of the *safeguards*; and demonstration that outstanding risks are ALARP, and that acceptance criteria for fault consequence and frequency are met [Ref 3].

At Devonport, each separate nuclear facility (i.e. each dock) has a *Plant Manager* who manages the safety case. The following principal nuclear safety requirements are relevant for a nuclear submarine dry dock facility:

- Allow movement of the submarine in a seismic event; the submarine is demonstrated to withstand the accelerations of a 1:10000 year *Design Basis Earthquake* (DBE) when free to move upon its docking cradle, which is resiliently mounted.
- Prevent excessive impact energy to the submarine; this could lead to "bounce" of the reactor control rods (leading to criticality exceeding the available cooling capacity), or coolant loss through NSRP damage.
- Maintain coolant to the reactor; decay heat must be removed from the reactor to prevent overheating (achieved through cooling with water).
- Prevent excessive impact energy to the dry dock; this could damage dock structure and safeguards.
- Prevent fire or explosion; this could damage dock structure and safeguards.

2.3 *Changing the Safety Case*

The safety case is subject to regular change, for example to incorporate new equipment required for emergent refit needs (e.g. fitting a new system, or removing items from the submarine). This is termed RSE, and may consist of buildings, tools, lifting equipment etc.

When such a change is made to the safety case, the new or changed system is assessed against the principal nuclear safety requirements. Where there is a potential for a breach, *Safety Functional Requirements* (SFRs) are assigned – these define criteria which must be met to uphold the principal nuclear safety requirements. Safeguards are then developed to fulfil these SFRs. This hierarchy is shown in Figure 2.

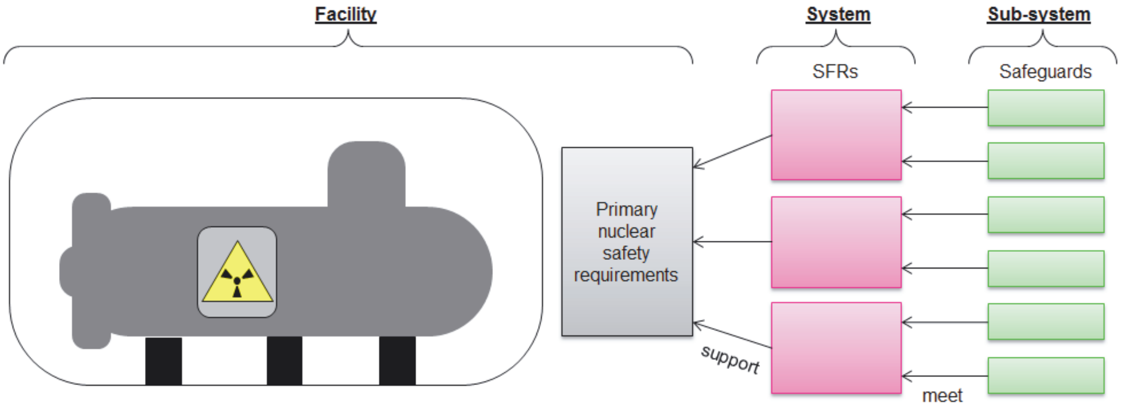

Figure 2: Hierarchy of nuclear safety requirements

Safeguards fall into different categories, as follows:

- Position in the hierarchy of risk reduction (i.e. role in the fault sequence, as shown in Figure 3:
  - *Preventative safeguards* prevent hazardous events from occurring (e.g. limiting the volumes of chemicals, demonstrated structural strength etc.)
  - *Protective safeguards* stop hazardous events from evolving into accidents (e.g. hard limiting end-stops, shut-down safety control systems, catch plates for dropped loads etc.)
  - *Mitigative safeguards* reduce or limit the consequence of an accident which has occurred (e.g. evacuation plans, emergency cooling systems, last resort dock flooding etc.)
- Method of action:
  - *Management arrangements* rely on processes to ensure that people take action to prevent, protect or mitigate hazards (e.g. a limit on chemical volumes, or checks before lifting).
  - *Engineered safeguards* are sub-systems that deliver safety functions (e.g. crane rail end stops, or an extraction fan).
    - NB. Engineered safeguards are preferred as greater reliability can be claimed and thus the ALARP justification is stronger.

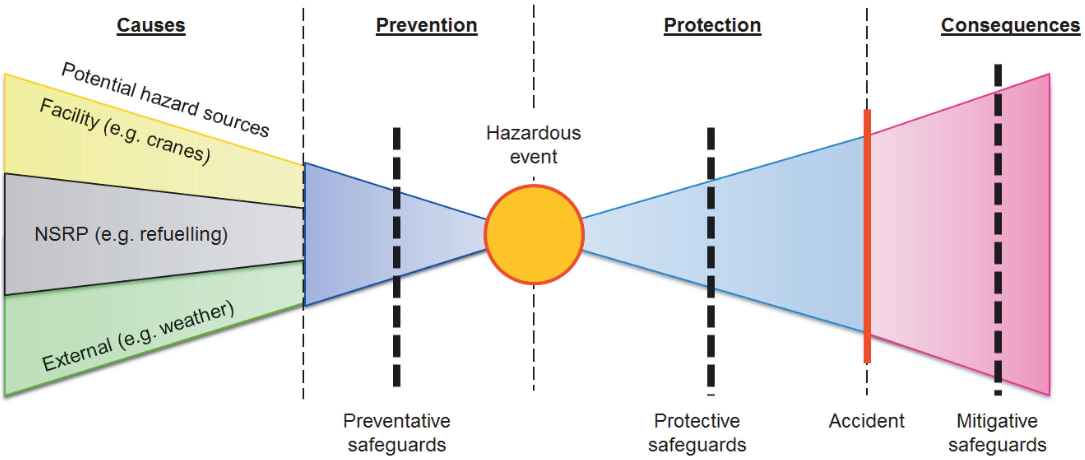

Figure 3: "Bow Tie" diagram showing a fault sequence and safeguards

3 Influence of the Safety Case on the RSE Design Lifecycle

Validation and verification is key for RSE design; validation that the requirements are met to support a strong ALARP argument; and subsequent verification to ensure that the system has been correctly delivered against the design intent.

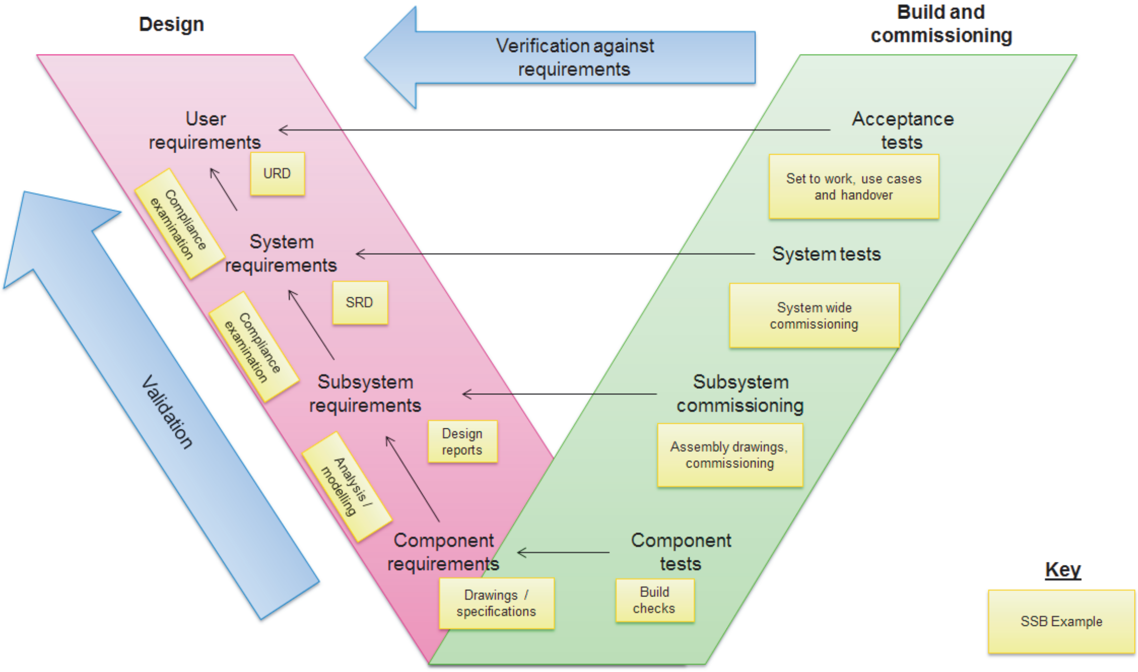

Figure 4: "V-Diagram"

The systems engineering "*V-Diagram*" (shown in Figure 4) shows the validation and verification activities for a system against the requirements hierarchy:

- *User Requirements* (URs), contained in *User Requirements Document* (URD)
- *System Requirements* (SRs), contained in *System Requirements Document* (SRD)
- *Subsystem requirements*
- *Component requirements*

Design, build and commissioning of RSE is managed with project policies which define validation and verification activities. The design lifecycle for RSE (shown in Figure 5) is divided into three phases of developing maturity – *Concept, scheme and detailed* design. The purpose of each design phase is described thus:

- *Concept design* defines the problem, and demonstrates that the correct solution approach has been selected. Figure 6 shows an example concept design process.
- *Scheme design* validates that the developed engineering solutions meet the requirements, including any SFRs.
- *Detailed design* unambiguously and prescriptively defines the design, and any verification activities to take place during build and commissioning to ensure design intent is met.

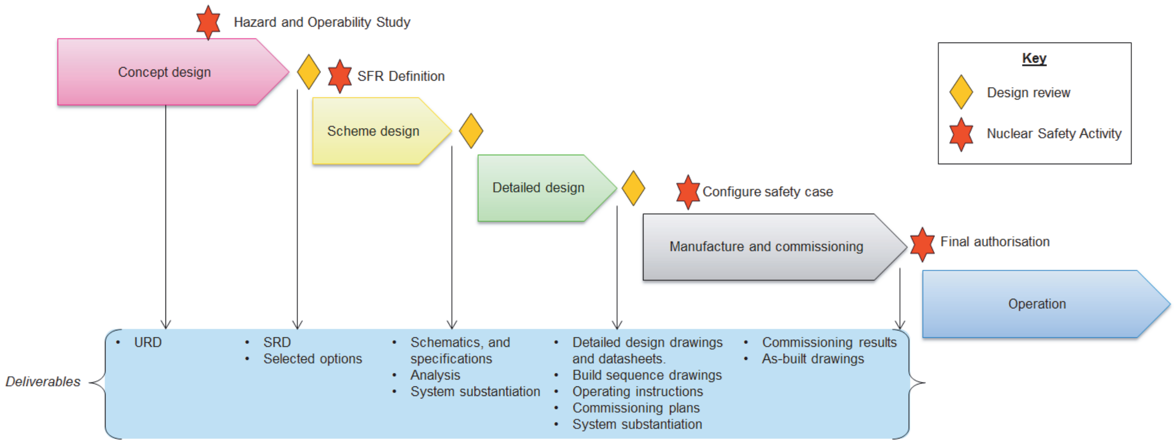

Figure 5: Typical RSE design lifecycle

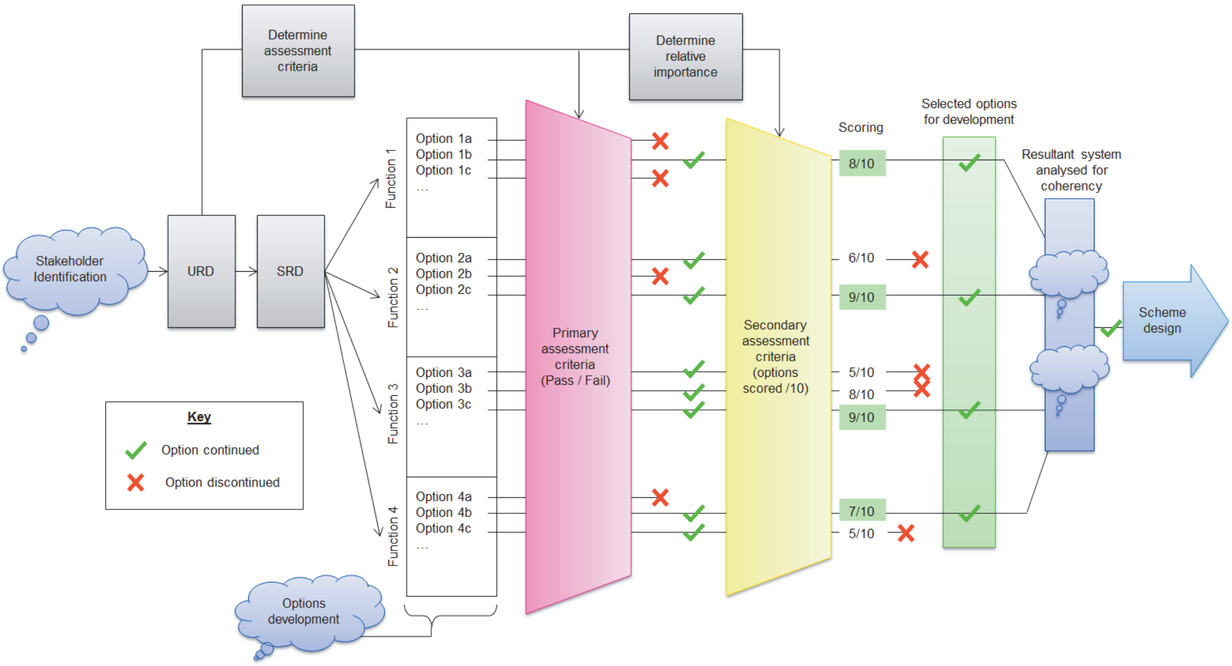

Figure 6: An example of concept design activities, including an options study

Appendix 1 describes the activities of each phase, and the influence of the nuclear safety case by comparison with a non-nuclear design. To summarise; nuclear safety requirements result in additional design activities, a more onerous level of demonstration, more complex design interfaces, and increased stakeholder management. Project timescales increase as validation activities are reviewed by many stakeholders, sometimes including the ONR.

4 Overview of the SSB Design

The following sections present the SSB as a case study of the influence of the safety case on a specific RSE design project. The SSB provides an enclosed environment for fitting components to the hull of a submarine. This process requires:

- Controlled atmospheric conditions.
- The lifting and fleeting of heavy loads.
- Access to a large area of hull.
- The use of hazardous chemicals (explosive and toxic).
- High quality execution.

The resulting SSB is a large, enclosed building (L x W x H = 16 x 6 x 10 m), situated in the dry dock bottom adjacent to the submarine as shown in Figure 7. The SSB incorporates:

- A steel primary structure, comprising 21 modules, insulated with cladding.
- Two overhead travelling cranes.
- A roof hatch.
- Various mechanical and electrical systems.
- An air conditioning system, to safely manage the hazardous atmosphere.
- Chemical mixing machines.
- Normal building subsystems (i.e. fire alarm, lighting, public address, personnel access etc.).

The SSB has two identical base structures, one on each side of the dry dock. The upper modules are assembled upon each base structure in turn to access both sides of the submarine, while the air conditioning plant is sited on the other.

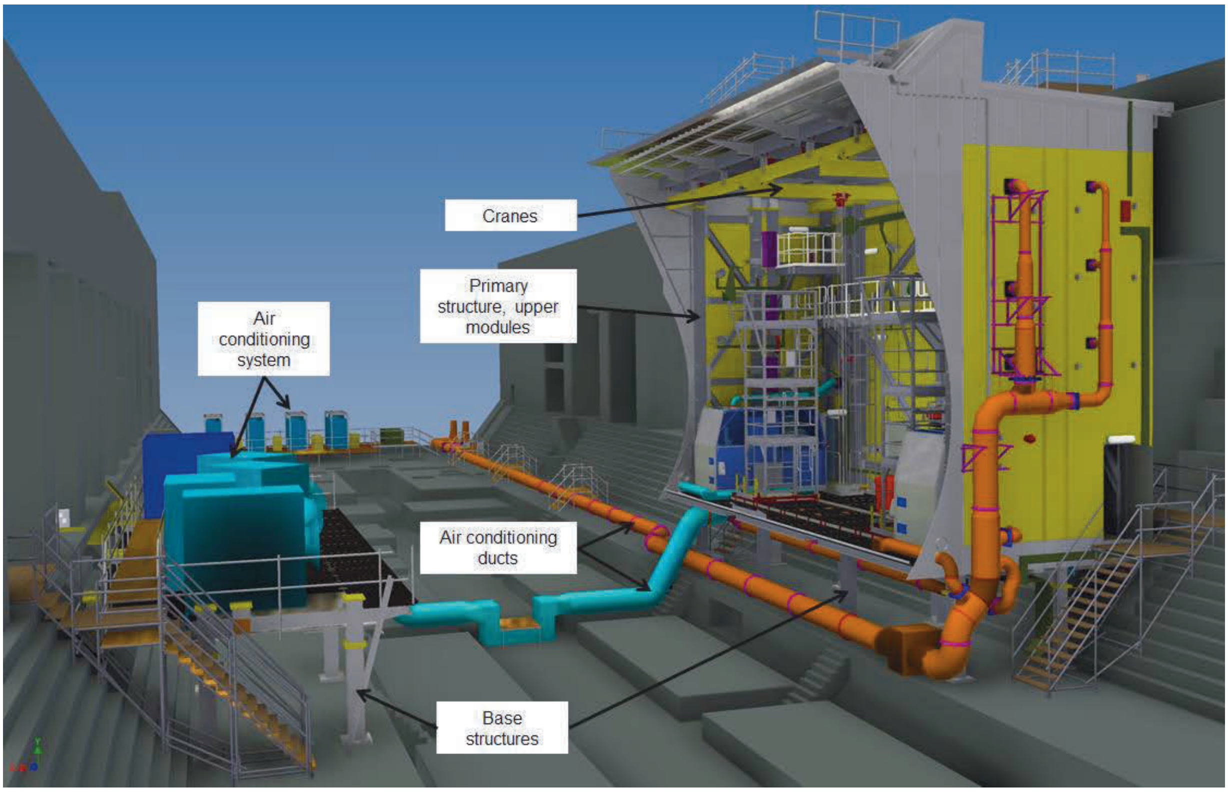

Figure 7: The SSB

5 Influence of the Safety Case on the SSB Design

5.1 SFR Determination and Compliance

An options study process was used to determine the most favourable concept designs. The proposed options included: temporary scaffold vs. dedicated fabricated structures; cranes mounted to the structure vs. to the submarine hull; cranes vs. scissor lifts and articulated arms lifting from the floor; and rolling access towers vs man baskets.

A key influence on the outcomes of an options study is determination of the assessment criteria, and their relative importance to the stakeholders. The importance of the process undertaken within the SSB led the stakeholders to assign a high relative weighting to criteria favouring functionality of the SSB systems. Thus, options which delivered robust functionality were preferred, even where they would require more work to substantiate them against the safety case. In this case, the chosen concept was a dedicated, fabricated structure incorporating overhead travelling cranes - this would give a secure environment for the process, and maximise ease of use for the operators.

The concept was analysed against the principal nuclear safety requirements of the facility, and it was determined that such a structure had the potential to breach these requirements, as follows:

- Robust structural members preventing movement of the submarine in a seismic event (either in normal operating position, or following a collapse).
- Dropped loads, or collapsed structures impacting the submarine, the dry dock, or dock systems.
- Structure preventing access to dock systems (either in normal operating position, or following a collapse).

To mitigate these potential breaches, SFRs were assigned to the SSB system – these were developed into structure and crane subsystem requirements to deliver safeguard functions to support claims against the SFRs (as shown in Figure 8). The design of these subsystems is examined in Section 5.2, where the additional level of demonstration and complexity of analysis is also described. It follows that the selection of this concept had a critical influence on the SSB design, and the level of work required.

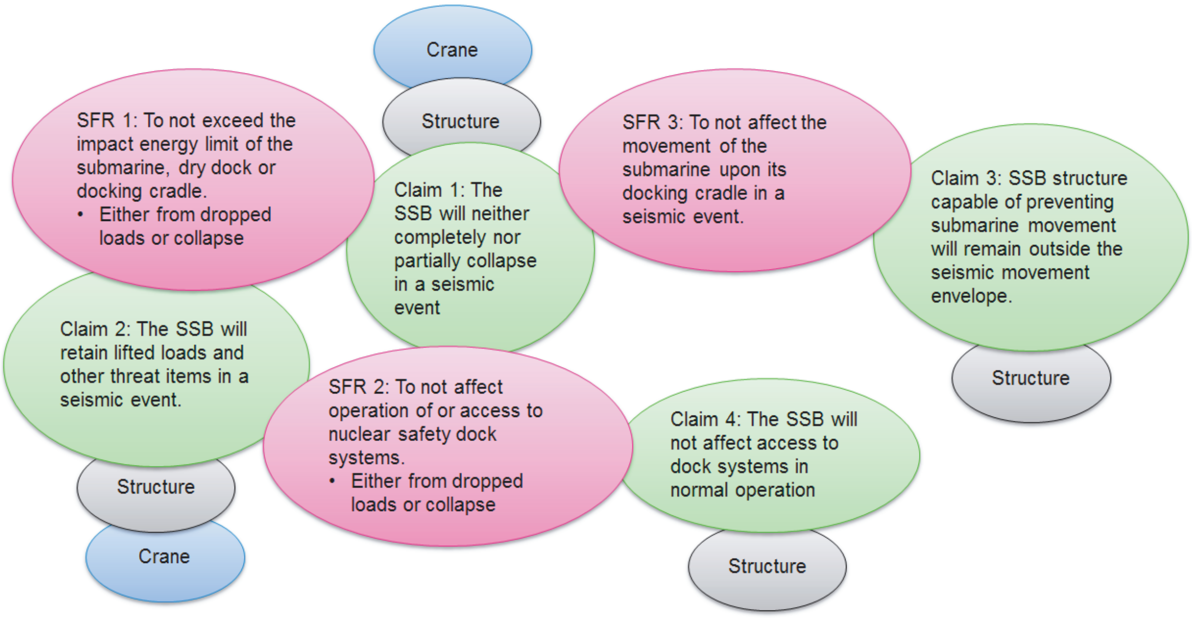

Figure 8: SFRs, corresponding claims, and systems performing safeguards

5.2 *Safeguard Sub-System Design*

5.2.1 *Primary Structure*

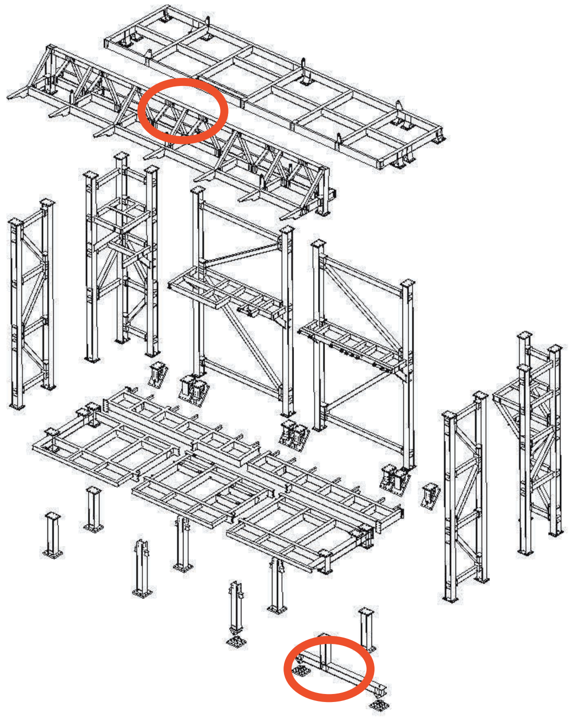

Figure 9: Primary structure modules, with key elements identified.

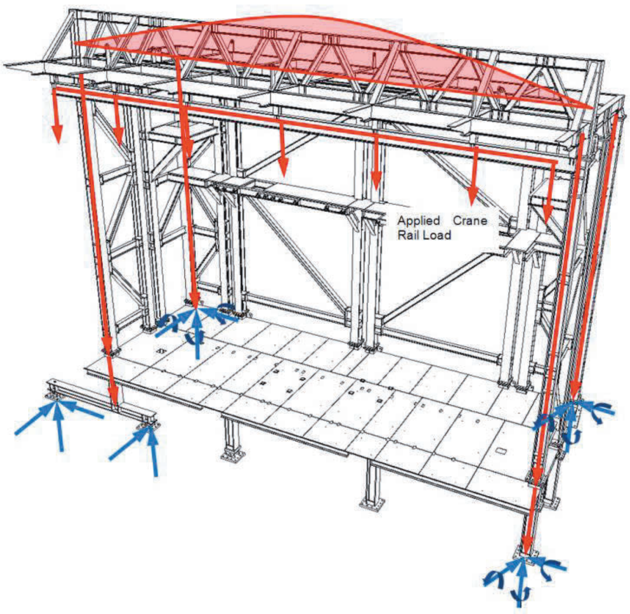

Figure 10: Loading from overhead cranes

The SSB primary structure is the main nuclear safeguard subsystem; Table 1 shows how the structure meets the claims identified in Figure 8. The structure is split into modules (see Figure 9) joined by *High Strength Friction Grip* bolted connections. The legs are grouted into pads anchored into the dry dock to secure the SSB from movement. The roof incorporates a lattice girder to stiffen the SSB's open front face. The maximum module weight was bounded by the limitations of the dry dock cranes used for installation; the safety case mandates additional controls when lifting masses above a certain limit.

The structure was demonstrated as suitable through transient *Finite Element Analysis* (FEA) of a 3D structural model of the SSB; seismic loads were applied as x-y-z accelerations to the dock plates – these theoretical values (~0.9g) were developed from previous safety case work – and structural loads such as crane loads (see Figure 10) were also applied. The model was developed to demonstrate compliance with the structural codes by demonstrating that the structure remained entirely within the elastic limit, with a resultant *maximum Utilisation Ratio* (max-UR) of 0.83. The main structural code used was BS 5950, this was selected over Eurocodes because of significant familiarity with applying the standard to seismic and nuclear safety work. Further, the seismic Eurocode 1998 specifically excludes nuclear installations, and only covers a 1:475 year operating basis earthquake, rather than the more extreme 1:10000 year DBE.

Additional work was undertaken as follows

- The SSB was demonstrated against the loads in all operational and constructional configurations (i.e. the SSB had to withstand an earthquake while partially constructed).
- Initially, the primary structure utilised common arrangements of bolted joints to reduce the volume of substantiation work required. FEA analysis showed that this was not viable, and individual joint designs were implemented.
- The structural design was "frozen" and a change control process used to manage loadings and weights from other subsystems, and ease-of-build recommendations from the manufacturer.
- Additional conservative analysis was undertaken:
    - "Beyond design basis", where the structure was excited with a larger earthquake of 1.4x magnitude of a DBE; this demonstrated that no elements were likely to undergo "cliff edge

failure" or non-ductile failure modes (e.g. shear or buckling) and that the primary failure mode would be ductile deformation. UK nuclear industry standard practice is to demonstrate beyond design basis capability though energy-absorbing, ductile failure behaviour.
    - "Key element failure", where the global effects of failure of the most highly loaded members (see Figure 9) were determined. It was demonstrated that the structure could withstand elimination of these members while remaining marginally within the elastic limit (max-UR = 0.98).
- The FEA was validated through *Independent Technical Assessment* (ITA) by an external company who modelled using alternative software.

Table 1: Nuclear safety claims supported by the structure

#	Claim	Mechanism of compliance	Type of safeguard	Method of demonstration
1	The SSB will neither completely nor partially collapse in a seismic event.	The structure remains within the elastic limit of the materials when subjected to DBE.	Preventative, engineered.	FEA of structure demonstrates elastic limit.
2	The SSB will retain lifted loads and other threat items in a seismic event.	Structure supports crane loading in a DBE.	Preventative, engineered.	FEA of structure demonstrates elastic limit.
		Where the structure supports items which present a threat to the submarine or dry dock, these remain captive in a DBE.	Preventative, engineered.	Structural analysis demonstrates which components are robust & energetic enough to present a threat. FEA of structure demonstrates captivity.
3	SSB structure capable of preventing submarine movement will remain outside the seismic movement envelope.	Structure that is robust enough to prevent movement of the submarine is positioned so that the movement envelope does not conflict with the submarine.	Preventative, engineered.	Structural analysis demonstrates which components are robust enough to prevent submarine movement. Existing analysis shows submarine movement. FEA demonstrates SSB movement, and structural design incorporates conservative margin (see Figure 11).
4	The SSB will not affect access to dock systems in normal operation	Footprint does not affect access.	Preventative, engineered.	General arrangement drawings.

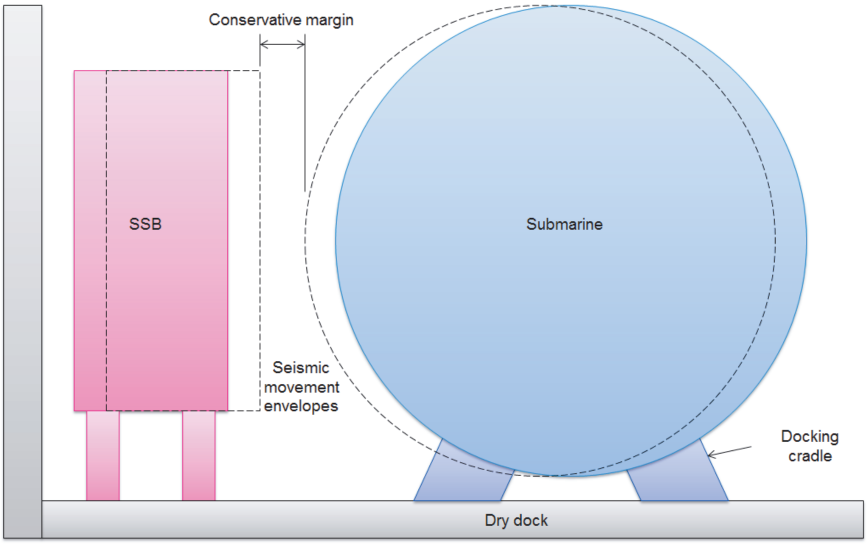

Figure 11: Interface of seismic movement envelopes

5.2.2 Cranes

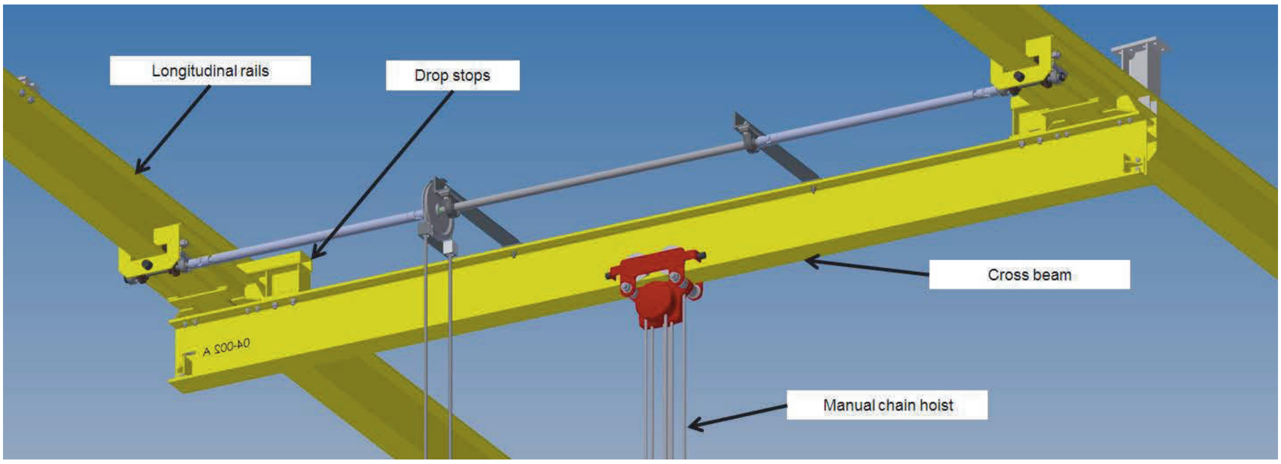

Figure 12: SSB manually powered cranes, showing principal components

The SSB incorporates dual overhead travelling cranes (see Figure 12); shows how the cranes meet the claims identified in Figure 8. The cranes are manually powered by chains to meet explosion protection requirements, and move on longitudinal rails that comprise part of the primary structure.

Certain activities within the SSB require the crane to be connected to the submarine structure. To isolate the movement of the submarine from the crane in a seismic event, a crushable element is included in the crane hoist load path. The element comprises a stainless steel honeycomb restrained between two robust platens (see Figure 13); the honeycomb was carefully designed to support lifting loads in normal operation, but to be crushed by the platens in a seismic event with increased loads. The crushable element required substantiation through calculation and repeated destructive testing to demonstrate that the right loads were supported, and that the element crushed in the expected manner. Figure 14 shows images from one such test.

Table 2: Nuclear safety claims supported by the cranes

#	Claim	Mechanism of compliance	Type of safeguard	Method of demonstration
1	The SSB will neither completely nor partially collapse in a seismic event.	The cranes incorporate drop stops which restrain the crane in a DBE.	Protective, engineered.	The drop stops are demonstrated to withstand the loading by structural analysis.
		The cranes incorporate a crushable element to isolate the crane from submarine movement.	Protective, engineered.	The crushable element is demonstrated to withstand crane loading in normal usage, and to crush under imposed seismic loading.
2	The SSB will retain lifted loads and other threat items in a seismic event.	The cranes retain lifted items in a DBE.	Preventative, engineered.	The crane load path is overrated by a factor of 2 which encompasses seismic loading.

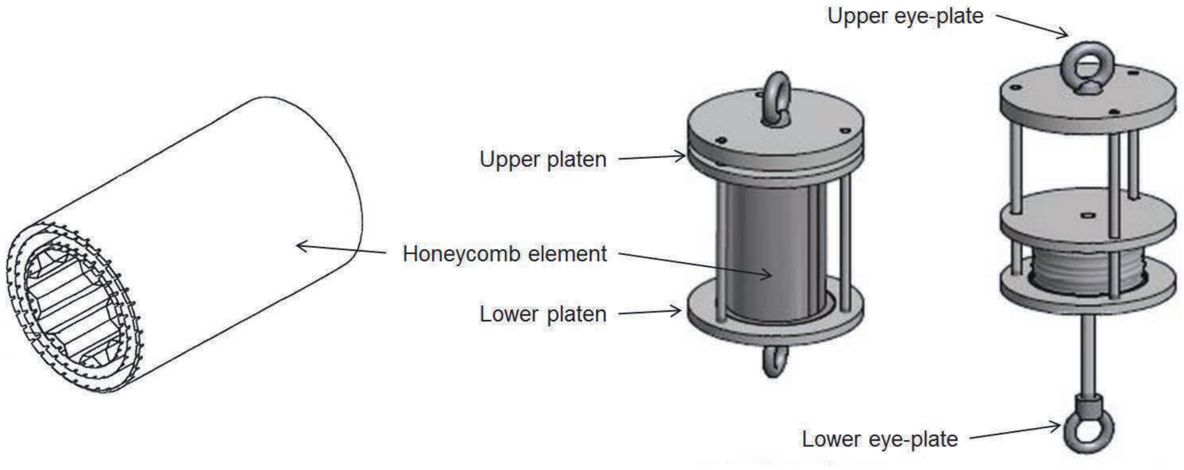

Figure 13: Crushable element; honeycomb detail, normal operating condition, and crushed state.

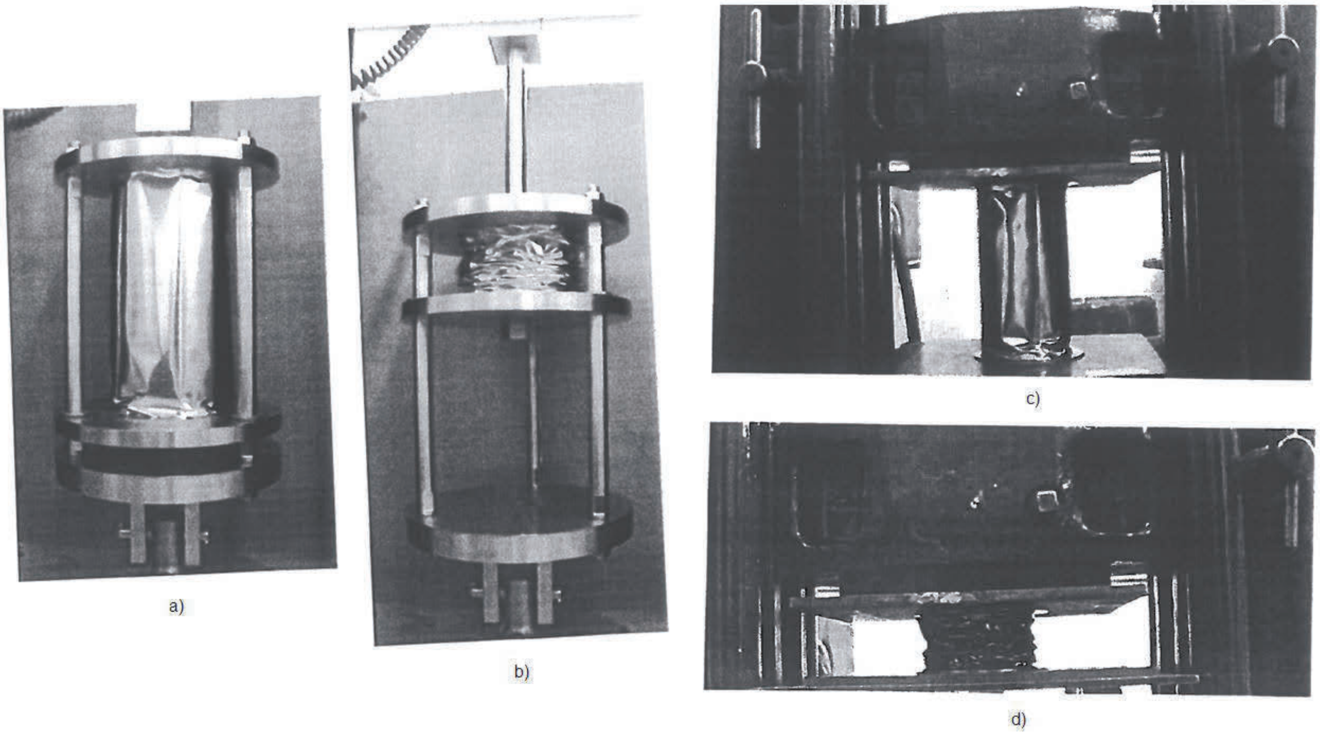

Figure 14: Crushable element testing – a) unit test prior, b) unit test post, c+d) element compression test (design load 42 kN, actual 41.6 kN)

5.3 Wider Influences

The nuclear safety case and design of the safeguard subsystems influenced the non-safeguard subsystem designs as follows:

- The structural modules were designed to be pre-fitted with services to reduce the number of dock crane lifts; this reduces nuclear safety risks. This increased the complexity and depth of the service designs (e.g. boundary breaks).
- The structure was not substantiated against impacts by internal items in a seismic event. Thus, all items within the SSB were demonstrated to not pose an impact threat.
- Dock systems constrained the siting of the air conditioning system, resulting in a complex system design.

- The detail of fitting services to the structure is typically left to the installation contractor, but the SSB structure could not be modified without design approval; thus detailed attachment designs prescribed every arrangement.
- The safety case imposed flammable inventory limits, including chemicals and construction materials; this constrained the structural design and spatial layout.

The safety case requires extensive verification of the system, with the following influences:

- The structural detailed design drawings were prescriptive to prevent any ambiguity which could lead to the manufacturer making independent decisions that might affect the design intent.
- Additional manufacturing quality requirements were defined, including inspection, testing, and material provenance.
- The build sequence and associated restrictions were prescribed though management arrangements to ensure that the build configurations were as substantiated.

6 Impact of the Safety Case

The influence of the safety case on the SSB design increased the complexity of the design, the volume of work produced, and, ultimately, led to a design project with costs and durations in excess of those for a typical non-nuclear facility. The SSB is a significant structure with unique requirements – but has comparatively few nuclear safety considerations; other RSE have direct interfaces with nuclear material requiring more safeguards of increasing complexity, and thus require significantly more effort to demonstrate safety case compliance, for example:

- Cranes or fluid systems which handle nuclear material.
- RSE which interfaces with the NSRP or operates in radiological areas.
- RSE with significant moving parts or mechanisms.

One such RSE of note is the *Reactor Access House* (RAH) fitted to a dry dock in Devonport – the design totals in excess of ~80,000 documents. Where a nuclear facility has multiple instances of such RSE, it can be plainly seen that significant work is required to produce and manage the safety case and supporting documentation.

The impact of the SFRs placed upon the SSB design was significant – if alternative concepts had been selected, then these SFRs could have been different or avoided altogether. For example, scaffold structures are not considered to be robust enough to prevent seismic movement of the submarine on the cradle; though selection of this concept would have led to compromises in environmental quality.

It follows that, if reduced project complexity (i.e. ease of substantiation) is the goal, then concepts which avoid modification of, or complicated demonstration against, the safety case should be favoured where possible. For the SSB and RAH this was not achievable, but this principle has been demonstrated effectively on other Babcock RSE design projects where functional demands are less; production stakeholders have adopted alternative methods of working, thus enabling design solutions which comply with the safety case, and a commensurate reduction in project complexity and cost.

Safety cases have become more comprehensive in scope and depth, even within the 21st century. This can partly be explained by a greater understanding of the risks – particularly for lifting activities [Ref 4], [Ref 5] – and a progressive reduction in risk appetite, as seen across all aspects of health and environmental safety. The ONR recognises that as safety cases grow, it becomes increasingly important that they remain usable and intelligible; this increases the understanding of the end user and improves the likelihood of compliance [Ref 3]. This is an important consideration for future safety cases as submarine systems and maintenance will become more complex, thus the functional requirements placed upon nuclear facilities will continue to grow.

Although poorly substantiated claims could result in accidents, or strategy decisions made against incorrect information, a balance must be struck to ensure that the engineering substantiation work is commensurate with the risks and the safety case remains usable.

7 Conclusions

This paper has described the regulatory framework for nuclear licensed sites, and described the role of a safety case that substantiates that the risks are tolerable for a nuclear facility.

The influences of the nuclear safety case on the design lifecycle of RSE have been identified; additional safety case requirements increase the complexity of the system interfaces and design decision making process, and the volume and the level of robustness of work is increased.

The paper has presented the SSB as a case study of the safety case influencing RSE design, and has noted that concept design decisions to prioritise functionality were critical and ultimately resulted in SFRs being assigned to the design. The nuclear safeguards of the SSB design, and the increased complexity and conservatism of the design substantiation, have been described. The influence upon the whole system design has been identified; ultimately, an increase in the number of design interfaces and more robust demonstration.

The impact on the SSB design project has been identified; the volume of work, and ultimately the project cost and time, was increased. The paper has compared the SSB with another design with more onerous nuclear safety requirements, and concluded that designs which comply with the safety case should be favoured where possible. The paper has discussed the importance of ensuring a balance between the risks, and the level of substantiation, and has noted the guidance of the ONR to ensure that a safety case remain usable even as the scope of work to be undertaken within a facility increases.

8 References

1 Nuclear Installations Act 1965

2 ONR: “Licensing Nuclear Installations”, 4th edition, January 2015.

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9 Glossary of Terms

ALARP	As Low As Reasonably Practicable
DBE	Design Basis Earthquake
DSR	Design Substantiation Report
FEA	Finite Element Analysis
HAZOP	Hazard and Operability Study
ITA	Independent Technical Assessment
Max-UR	Maximum Utilisation Ratio
NSRP	Nuclear Steam Raising Plant
ONR	Office of Nuclear Regulation
RAH	Reactor Access House
RSE	Refit Support Equipment
SFRs	Safety Functional Requirements
SRs	System Requirements
SRD	System Requirements Document
SSB	Submarine Support Building
URs	User Requirements
URD	User Requirements Document

10 Appendix 1 – Influence of the Safety Case on the RSE Design Lifecycle

The activities of each design phase are described in Table 3, along with a discussion of the influence of the nuclear safety case on each activity, by comparison with non-nuclear design processes.

Table 3: Design activities, and the difference for a non-nuclear design lifecycle.

Step	RSE lifecycle	Influence of the nuclear safety case (comparison with non-nuclear design lifecycle)
Concept design (see also Figure 6)		
1	Complete set of stakeholders identified and their URs elicited.	Nuclear safety stakeholders such as nuclear safety engineers, facility managers, Plant Manager must be consulted. URs include requirements pertaining to the safety case, are more numerous and more complex.
2	URs collated into a URD which undergoes formal stakeholder verification.	Formal verification is a lengthy process which is not carried out for a non-nuclear design.
3	Functional Requirements identified. Functions grouped into subsystems (e.g. the functions “lower equipment” and “raise equipment” could be combined into a “crane” subsystem).	-
4	Preliminary concepts are developed for each function and examined through a *Hazard and Operability Study* (HAZOP) to identify where the design has the potential to challenge the nuclear safety case.	Not carried out for a non-nuclear design.
5	Wide ranging and diverse concept options are developed to meet each function, guided by the outcomes of the HAZOP.	Options must be demonstrated to be diverse, and consider multiple strategies to ensure that all mechanisms for meeting functions are identified.
6	Options study is undertaken: • Assessment criteria are developed in conjunction with the stakeholders • The stakeholders assess each option against the primary criteria, and the successful options are scored against the secondary criteria. • The highest scoring subsystem options are grouped, and the overall system is validated to ensure that it is a relevant and coherent design. • The highest scoring options are selected for development through scheme design	Options study must be formally and robustly recorded to provide demonstration that most favourable option has been correctly selected. Conventional health and safety, and nuclear safety requirements can conflict, leading to decisions between options which favour the ease of proving compliance with one aspect of safety. These decisions must be substantiated robustly. Additional coherency check of selected subsystem options provides further robustness.
7	URs, and Functional Requirements developed into SRs collated in SRD.	-
8	Concept design review held.	The design review must demonstrate to a higher robustness that the problem is understood, and correct approach has been chosen.
Scheme design		
9	**Plant Management Organisation:** SFRs developed through the analysis of potential nuclear safety hazards	Not carried out for a non-nuclear design.
10	Subsystem requirements are developed.	Safeguard subsystems may have additional requirements to aid SFR compliance.
11	Subsystems developed into workable engineering solutions	-
12	Subsystems interfaces (such as weight, space and service demands) are continually managed	Safeguard subsystems take precedence over other subsystems, leading to impact on those designs.

Step	RSE lifecycle	Influence of the nuclear safety case (comparison with non-nuclear design lifecycle)
13	Documentation produced to define each subsystem (engineering drawings, schematics, specifications etc.). The activities that will define verification are identified and scoped (i.e. manufacturing / commissioning checks).	Increased level of detail for safeguard subsystem documentation.
14	Calculations and analysis performed and documented. Activities are undertaken to ensure that the design work is valid (e.g. ITA, parallel analysis by alternate methods etc.)	Highly robust demonstration required for safeguard subsystems. Additional validation required for safeguard systems.
15	System substantiation produced to validate against the requirements.	Requirements compliance must be robustly demonstrated for all safeguard subsystems and interfacing subsystems.
16	Scheme design review held.	The design review must demonstrate substantiation of all subsystem and interfaces robustly, particularly SFRs.
	Detailed design	
17	Detailed designs for manufacture are developed (e.g. detailed drawings, datasheets, build sequence drawings)	Detailed designs must be highly prescriptive for safeguard subsystems and interfacing subsystems to ensure design intent met.
18	Documentation to define verification is produced (e.g. operating and commissioning instructions).	Documents must be thorough and highly prescriptive to enable robust verification against design intent.
19	System substantiation updated with maturity of information.	Requirements compliance must be robustly demonstrated for all safeguard subsystems and interfacing subsystems.
20	Safety assessment report produced to demonstrate that conventional safety risks have been reduced to an ALARP level.	-
21	Detailed design review held.	The design review must demonstrate that the design intent is met from previous phases, that the stakeholders are content with the design, that the SRs and URs are met, and that the design is ready for manufacture.
22	**Plant Management Organisation:** Safety case configured to incorporate the claims made in the DSR and authorise the RSE to be integrated in the facility and operated.	Not carried out for a non-nuclear design.