MDEP Design-Specific Technical Report TR-HPR1000WG-02

HPR1000 WORKING GROUP

Technical Report on Regulatory Requirements and Practices for Severe Accidents

Participation

Regulators involved in the MDEP working group discussions:	ARN (Argentina), NNSA (China), NNR (South Africa), ONR (UK)
Regulators which support the present technical report:	ARN (Argentina), NNSA (China), NNR (South Africa), ONR (UK)
Regulators with no objection:	none
Regulators which disagree:	none

MDEP HPR1000 – Severe Accidents TESG

Technical Report on Regulatory Requirements and Practices for Severe Accidents

Introduction

The HPR1000 design is currently under review in the UK and the People's Republic of China. A Multinational Design Evaluation Programme (MDEP) design-specific working group for the HPR1000 has been established consisting of the following members, referred to as 'regulators' herein:

- Office for Nuclear Regulation (ONR) – UK;
- National Nuclear Safety Administration (NNSA) – China;
- Autoridad Regulatoria Nuclear (ARN) – Argentina; and
- National Nuclear Regulator (NNR) – South Africa.

A Severe Accidents (SA) Technical Expert Sub-Group (TESG) was established as part of the HPR1000 MDEP design-specific working group. Early in the establishment of the SA TESG, it was agreed that a technical report would be produced in order to compile the expectations of the regulators that are applied when assessing safety submissions and design aspects associated with severe accidents.

This document summarises the regulatory requirements and expectations of the regulators, and highlights where consensus or differences exist. A survey was produced and sent to all regulators regarding various aspects of the regulation, analysis, and management of severe accidents. This report compiles the information provided within the responses to the survey and summarizes the information presented by the regulators.

It should be noted that whilst there is a close relationship between the severe accident analysis and the demonstration of practical elimination of large or early releases, the concept of practical elimination is addressed by a separate common position paper currently being produced under the HPR1000 MDEP design-specific working group .

Regulatory Requirements

Definition of a Severe Accident

China, Argentina and South Africa define a severe accident in terms of an accident condition involving significant damage to the core. The UK definition is not specific to reactors, and is expressed in terms of an accident with potential off-site dose consequences in excess of 100 mSv or "substantial unintended relocation of radioactive material within the facility that places a demand on the integrity of the remaining physical barriers". However, the definitions are broadly aligned and serve the same purpose.

For reactors, NNSA specifically adopt the Design Extension Condition (DEC) approach within its regulatory requirements. Whilst not explicit guidance/policy, ONR, ARN and NNR's expectations for deterministic severe accidents analysis align with those of DEC-B, and these expectations are implicitly expressed in their respective guidance/policy documents.

With the above in mind, whilst there are differences in the definitions of severe accidents in the respective regulatory frameworks, the intent of the definition for the purpose of light water reactors is aligned, in that it relates to significant core degradation and mitigation.

Slight differences arise in the approach to severe accidents analysis in the spent fuel pool. NNSA require that the designer/licensee demonstrate that significant fuel degradation in SFP should be "practically eliminated" via adequate water supplies and monitoring to reduce the probability of occurrence to extremely low values, whereas the other regulators are non-prescriptive. In practice, however, the demonstration of reducing risks as far as reasonably practicable (as is expected by the other regulators), should drive the designer/licensee to demonstrate that scenarios with the potential to lead to large or early releases are practically eliminated by keeping fuel adequately cooled to avoid significant fuel degradation.

Relevant legislation, requirements and guidance

In general, the regulatory framework for regulators' consideration of severe accidents comprises a hierarchy:

i. National legislation (of various forms); and
ii. Policy, regulations, and/or guidance originating from the nuclear regulatory body.

Item (ii) directs that severe accidents be addressed in the design and operation of nuclear power plants in all regulatory frameworks. NNSA and ONR has established guidance and expectations to inform their independent regulatory reviews of designer/licensee severe accident analysis safety reports. NNR and ARN are still developing their guidance however their regulatory frameworks require the expectations of IAEA safety standards to be met.

All regulators expect designer/licensees to comply with their domestic regulatory framework, and to meet the expectations of guidance and/or guidelines issued by the regulator so far as reasonably practicable. In all cases, the domestic requirements/expectations are at least aligned with IAEA safety standards.

Severe Accident Analysis

All regulators are aligned on the use of Severe Accident Analysis. The regulators agree that it should be used to:

- identify severe accident scenarios beyond the design basis;
- identify reasonably practicable features to prevent or mitigate severe accident scenarios;
- demonstrate the effectiveness of the severe accident features;
- define the environmental conditions in a severe accident;
- support the Level 2 PSA; and
- support the development of severe accident management guidelines (SAMGs).

In pursuit of developing the SAMGs, the regulators also expect the designer/licensee to identify design features that could be used in severe accident scenarios, which are not directly dedicated to the prevention and mitigation of severe accident phenomena, but which may benefit situational awareness or provide additional safety benefits.

All regulators agree that the severe accident analysis should cover all plant operating states, from reactors at power through refuelling, as well as severe accidents in the spent fuel pool. A shared expectation is that large or earlier releases are practically eliminated. For severe accident analysis, the designer/licensee is expected to demonstrate that unlikely events with large consequences have been considered, and that adequate safety features are incorporated in the design to either prevent escalation or mitigate consequences of severe accident phenomena.

When performing SAA, the designer/licensee is expected to consider the relevant severe accident phenomena that may occur if measures provided for design basis accidents fail or are not effective in preventing fault escalation. The designer/licensee is expected to demonstrate that those phenomena will not result in failure of the last barrier to release. None of the regulators are prescriptive in how it expects the designer/licensee to define which phenomena should be considered.

Regulators consider that the majority of the deterministic analysis to support Severe Accidents Analysis should focus on the demonstration of the effectiveness of the severe accident features. Where a designer/licensee does not consider it appropriate to design to mitigate a certain phenomenon, regulators expect that it is demonstrated through qualitative and quantitative arguments, drawing on international research and experience as appropriate, that these phenomena can be excluded due to sufficiently low probability or physical impossibility. However, it is also expected by the regulators that some of the excluded phenomena be analysed in order to demonstrate an understanding of the progression of severe accidents.

The means by which the designer/licensee demonstrates the effectiveness of the SA safety features and performs analysis to support the Level 2 PSA is not prescribed by any of the regulators. It is the designer/licensee’s choice on which analysis tools it uses in its severe accident analysis. However, the designer/licensee is expected to provide justification for the use of methodologies in the severe accident analysis in the context of the HPR1000. Whilst codes and methodologies are not prescribed, regulators expect that the designer/licensee perform the analysis using codes and methods that are aligned with relevant good practice in the international community and their own guidance. In addition, the regulator may choose to perform independent analysis of severe accident sequences in order to gain confidence in the designer/licensee’s severe accident calculations or to unearth uncertainties that may require further attention.

All regulators agree that the validation and verification (V&V) of the analysis tools used should be submitted as part of the designer/licensee’s safety submissions. As the designer/licensee may not be the code developer, the regulators do not expect that the V&V activities and related documentation be performed by the designer/licensee. Moreover, the regulators expect that an understanding of the limitations of the code is demonstrated and that uncertainty analyses are performed appropriately.

All regulators expect that some form of numerical criteria or limits be used to determine the adequacy of the design. ONR does not define limits (e.g. a limit core damage frequency), but instead uses numerical targets defined in its guidance to judge whether risks have been reduced to as low as reasonably practicable.

All regulators expect that technical criteria be set by the designer/licensee in determining the effectiveness of the severe accident mitigation strategies identified. The technical criteria are ultimately linked to the demonstration that the last barrier to release (containment) remains intact throughout the severe accident progression. For technical criteria not prescribed by the regulator, it is expected that the designer/licensee provide adequate justification for their use, even if those criteria have been adopted from other international practices.

Design

In general, the severe accident equipment is determined by the designer/licensee and the adequacy of such equipment is reviewed by the regulator. Whilst none of the regulators prescribe the choice of severe accident strategies/equipment, all regulators will draw conclusions on the adequacy of the severe accidents dedicated equipment informed by relevant good practice and international research. In cases where there is divided opinion on the inclusion of a certain design feature (for example, containment venting), the regulators' judgements will be informed by the strength of the arguments presented by the designer/licensee.

Aligned with IAEA's DEC approach, NNSA have specific requirements that a designer/licensee must not credit mobile equipment in the DEC-B analysis. Whilst ONR, NNR and ARN do not have specific requirements for use of mobile or fixed equipment, these regulators judge the adequacy of the design on international relevant good practice. Therefore, for a new reactor, like the HPR1000, all regulators expect that the design incorporates permanent equipment to mitigate severe accidents, supplemented by the ability to connect mobile equipment.

In the severe accident analysis of a generic site (for which DEC-B forms part of), where the local emergency arrangements are unknown and the site-specific details are unknown, all regulators agree that the severe accidents safety demonstration should not be dependent on off-site and on-site mobile equipment in the short term. General assumptions should be made on their availability after an appropriate time to account for the uncertainty (typically hours for on-site and days for off-site equipment).

The safety performance requirements are design specific and therefore are not prescribed by the regulator. In general, the regulators expect that the design is optimised in order to deliver the safety functions determined by the designer/licensee. This process is normally iterative, and achieved through analysis, research and testing.

The mission times for given equipment is not prescribed by any regulator, however, it is generally expected that a plant will be autonomous for a number of hours, and control of the safety functions can be maintained for days without the need for off-site supplies. In making a judgement on the adequacy of the design, regulators will draw comparisons to relevant good practice. ONR and ARN require the designer/licensee to demonstrate that risks have been reduced to as low as reasonably practicable. This requires a demonstration that any further enhancements would be grossly disproportionate to the cost, trouble and time required to make that enhancement. In addition, all regulators agree that the design should be optimised to a reasonable level to which mobile and off-site equipment could be aligned.

All regulators agree that severe accident safety features should be independent from other levels of defence in depth so far as reasonably practicable (with notable exceptions, such as the containment). The levels of defence in depth should be sufficiently independent that they are not susceptible to common cause failures. In addition, the implementation of a severe accidents design strategy should not negatively impact other levels of defence in depth, so far as reasonably practicable.

None of the regulators expect that the single failure criterion is applied in severe accident analysis; i.e. none of the regulators expect that SA safety features be single failure tolerant or that the worst single failure be applied in the deterministic analysis of severe accidents. Notwithstanding this, uncertainty in the severe accident scenarios often means that it is reasonable to incorporate redundancy or sufficient margin in the design, to account for cliff-edge effects and to improve the overall reliability. The regulators make their judgement based upon relevant good practice in a particular area.

Whilst different approaches to the classification of severe accident equipment exist between the regulators, the intent of the classification is the same. Regulators agree that the classification of the equipment should be commensurate with the frequency in which its safety function is demanded and the significance of the consequences of the failure of the safety function to be delivered. The implications for this are that severe accident safety features tend to be of lower safety classification than design basis accident safety measures. There are notable exceptions to this where failure of the severe accident features would initiate a design basis accident, or where a design basis safety measure is also credited in severe accidents mitigation (e.g. severe accident primary depressurisation valves, passive autocatalytic recombiners credited in design basis faults, containment etc).

The regulators agree that equipment and instruments needed to deliver SA safety features should be demonstrated to function during severe accident environmental conditions. It is agreed that the standard of equipment qualification be commensurate with the safety classification of the equipment, which may result in a lower standard applied to SA safety features. However, the environmental conditions in which the SA safety features are required to perform their safety functions are likely to be harsher than those of design basis safety measures. In addition, regulators agree that it is often appropriate that equipment credited in severe accidents have a relatively high standard of seismic qualification.

Severe Accidents Guidelines and Procedures

All regulators agree that site-specific severe accident management guidelines and procedures should be developed, to guide the operator to most effectively manage an accident scenario. The basis for development is expected to be informed by the severe accident analysis; however, the form of this may vary dependent on the facility in question.

For the HPR1000, it is expected that the severe accident management guidelines be developed, in part, with knowledge taken from computer analyses performed as part of the severe accident analysis.

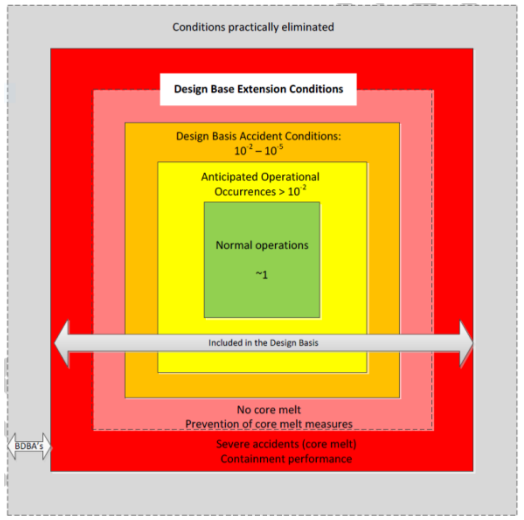
None of the regulators prescribe criteria for initiation of severe accident management procedures/guidelines. The regulators agree that the designer/licensee should demonstrate the reasoning for the choice of said criteria and justify the applicability of the criteria to the design. The regulators take cognisance of international good practice relevant to similar reactor designs when making a regulatory judgement on the adequacy of the design.

None of the regulators prescribe any severe accident management guidelines, and they will vary from one site to another. However, there are slight differences in the requirements related to the involvement of the regulators in decision making during emergency response, which impact severe accident management.

Conclusion

The Severe Accidents (SA) Technical Expert Sub-Group (TESG) of the Multinational Design Evaluation Programme (MDEP) design-specific working group for the HPR1000 has performed a review of each of the regulators' regulations and expectations for severe accident analyses and the implications for reactor design.

The review has found that whilst there are differences in the way that the laws are applied in their respective countries, the expectations of the regulators are aligned. In general, the methodology for performing severe accident analyses and design features are not prescribed by the regulators. However, all regulators agree that severe accident features should be incorporated in the design and will assess the design based on relevant good practice for new reactors.

Topic	Question	Comment	ONR – UK Response	NNSA – China Response	NNR – South Africa Response	ARN – Argentina Response
Regulatory requirements	1. How is a severe accident defined, and how does this relate to other accident conditions considered?	Please explain how you define what constitutes a severe accident	From SAPs paragraph 664. An accident with off-site consequences with the potential to exceed 100 mSv, or to a substantial unintended relocation of radioactive material within the facility that places a demand on the integrity of the remaining physical barriers.	According to HAF102-2016, a severe accident is an "accident condition that exceeds the design basis accident and causes a significant damage of the core." The frequency of these accidents is generally below 1E-6/reactor per year, with multiple failures occur, resulting in an accidental damage of the core. The severe accident management in industry generally takes the core outlet temperature above 650 °C as the criterion. The fuel building that contains spent fuel pool does not have the same leak tightness like containment. The fission product inventory is much larger than the core inventory. However, the decay heat power is low, the water inventory in the pool is large, and the accident progression is slow. The NNSA requires the power plant is designed with adequate water supplementary and water level monitoring measures after the Fukushima accident. The frequency of a significant fuel degradation accident in the spent pool is low. Utility should prove that the significant fuel degradation accident in the spent fuel pool has been "practically eliminated", so it does not need to be considered in the safety analysis report. HAF102-2016 adopts the concept of design extended conditions, which comprise conditions in events without significant fuel degradation and conditions in events with core melting (severe accident). The core melting (severe accident) conditions considered in the design are mainly used for the design of relevant SSCs, which is reflected in Section 19.2 of the Safety Analysis Report. In addition, severe accident analysis is also applied in the fields of PSA, SAMG development, emergency response, etc.	From Section 2 of the NNR's Draft Specific Nuclear Safety Regulations: Nuclear Facilities [1]: '"severe accident" means an accident condition involving significant core degradation;' From Section 5 of [1]: '(3) The selected events shall be classified, based on the results of probabilistic safety assessment and engineering judgment, into the following categories of events: … (c) Design base extension conditions, which include all events with frequencies of less than 10^{-5}, including severe accident conditions.' From p.12 of NNR RG-0019 "Interim Guidance on Safety Assessments of Nuclear Facilities" [2]: 	ARN follows IAEA in the definition of a severe accident: Accident more severe than a design basis accident and involving significant core degradation. For the HPR 1000 project, severe accident is an accident with off-site potential consequences exceeding 100mSv.
	2. What is the regulatory framework for consideration of severe accidents?	Please explain applicable legal framework (laws, regulations etc.)	The Health and Safety at Work Act – 1974, requires that risks have been demonstrated to be reduced to as low as reasonably practicable. The starting point for meeting the standards of ALARP (As Low As	China's nuclear safety laws and regulations are divided into three levels: national laws, State Council Ordinances, and department rules. The NNSA has also developed policy requirements document and nuclear safety	From Chapter 1, Section 1 of National Nuclear Regulator Act (Act No. 47 of 1999) [3]: '(xiii) "nuclear accident" means any occurrence or succession of occurrences	The Argentinean legal framework is formed by the National Constitution, the treaties and conventions (like Convention on Nuclear Safety), the National Law of Nuclear Activity No. 24,804 enacted in April

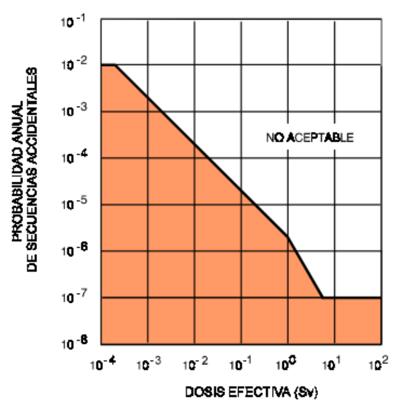
Topic	Question	Comment	ONR – UK Response	NNSA – China Response	NNR – South Africa Response	ARN – Argentina Response
			Reasonably Practicable) is that the design meets Relevant Good Practice (RGP). ONR's safety assessment principles are benchmarked against IAEA standards, and regularly reviewed to ensure that they at least meet these. SAP para – 663. "*Rigorous application of DBA and PSA should ensure that the predicted risks from fault sequences leading to significant radiological consequences are very low. Nevertheless, it is important that operators of facilities with very large hazard potentials consider possibilities such as:* • *the DBA or PSA may be incorrect or incomplete;* • *the true severity of an initiating event may exceed that considered in the analysis; or* • *a safety measure could be circumvented or fails in some unpredicted way.* *In considering these matters, further beyond design basis improvements may then be identified as reasonably practicable for either preventing severe accidents, or mitigating their consequences, eg by preventing further escalation. The insights gained from SAA are also important for planning for the possibility of severe accidents and are used to inform the response activities that would be needed were such an accident to occur.*" In addition, Article 8a of the European Nuclear Safety Directive states that: *"(1) Member States shall ensure that the national nuclear safety framework requires that nuclear installations are designed, sited, constructed, commissioned, operated and decommissioned with the objective of preventing accidents and, should an accident occur, mitigating its consequences and avoiding:* *(a) early radioactive releases that would require off-site emergency measures but with insufficient time to implement them;* *(b) large radioactive releases that would require protective measures that could not be limited in area or time."*	guidelines to guide the nuclear safety review, as well as the design and operation of NPP. Mandatory nuclear safety regulations include: 1. National laws: • Peoples Republic of China Law of prevention and control of radioactive contamination; • Nuclear Safety Law of the People's Republic of China. 2. State Council Ordinances: • HAF 001, 1986 Regulations of the People's Republic of China on the Safety Supervision and Management of Civil Nuclear Facilities. 3. Department rules: • HAF102 "Nuclear Power Plant Design Safety Regulations" (2016); • HAF103 "Nuclear Power Plant Operation Safety Regulations" (2004). 4. Policy requirements documents: • General Technical Requirements(GTR) on post-Fukushima Nuclear Accident Improvement Measures for NPPs (Tentative) (2011); • Safety Review Principle for HPR1000 Design (2019).	having the same origin which— (a) results in the release of radioactive material, or a radiation dose, which exceeds the safety standards contemplated in section 36; and (b) is capable of causing nuclear damage;' From R.388: Regulations In Terms Of Section 36, read with Section 47 of the National Nuclear Regulator Act, 1999 Act No. 47 on Safety Standards and Regulatory Practices [4]: '6.1 Criteria for the definition of a nuclear accident Any occurrence or succession of occurrences having the same origin and resulting in an unintended/unauthorised exposure to radiation or release of radioactive material, which is capable of giving rise to an effective dose in excess of 1 mSv to the public off-site in a year, or in excess of 50 mSv to a worker on site received essentially at the time of the event, is regarded as a nuclear accident as defined in section 1 (xiii) of the Act.' From Part 5, Section 3 of the NNR's Draft General Nuclear Safety Regulations [5]: (7) A set of design extension conditions shall be derived on the basis of engineering judgment, deterministic assessments and probabilistic assessments for the purpose of further improving the safety of the nuclear facility by enhancing the plant's capabilities to withstand, without unacceptable radiological consequences, accidents that are either more severe than design basis accidents or that involve additional failures. These design extension conditions shall be used to identify the additional accident scenarios to be addressed in the design and to plan practicable provisions for the prevention of such accidents or mitigation of their consequences if they do occur. Further requirements on severe accidents appear in [1].	1997, with its Regulatory Decree No. 1,390/98 and the Regulatory Standards (AR standards). Among the AR standards there are two that are of relevance when considering severe accidents in nuclear power plants: AR 10.1.1 Rev3. "Basic Radiation Safety Standard" AR 3.1.3 Rev.2 "Radiological criteria relating to accidents in nuclear power plants" These regulations provide a risk based approach and establish limiting criteria for each accidental sequence with radiological consequences for both, the worker and the public. In addition, the Memorandum of Understanding for the HPR 1000, which is also mandatory, establishes that the design of the plant must consider provisions for the prevention or mitigation of the consequences of design extension conditions including severe accidents.

Topic	Question	Comment	ONR – UK Response	NNSA – China Response	NNR – South Africa Response	ARN – Argentina Response
	3. What are the regulatory expectations for consideration of severe accidents?	Please explain any related requirements or guidance from the regulator, and how the regulator performs its review	ONR assesses the requesting parties' safety cases primarily against ONR's safety assessment principles. As stated above, ONR's SAPs are benchmarked against international relevant good practice. This includes, but is not limited to, IAEA guidance and WENRA reference levels. ONR's SAPs are technology neutral. ONR's Technical Assessment Guides provide more specific guidance and highlight relevant good practice (such as IAEA and WENRA standards) that should be considered in ONR's assessment. In addition, ONR may choose to cite another countries regulations as relevant good practice; it should be noted, however, ONR cannot impose those regulations, and that it is the responsibility of the requesting party (the vendor requesting pre-licensing design acceptance) to demonstrate that the risks have been reduced to ALARP.	Recommended or referenced documents: 1. Nuclear safety guidelines • HAD 102/06 Design of Reactor Containment Systems • HAD 102/17 Safety Assessment and Verification for NPPs 2. Technical documents • HAJ-0001-2016 Nuclear Power Plant Severe Accident Management 3. Drawing on international normative documents, • For example, NUREG-0800 (Standard Review Plan) of USA and relevant guidelines of IAEA (IAEA SSG-2 Deterministic Safety Analysis for Nuclear Power Plants, IAEA NS-G-2.15 Severe Accident Management Programmes for Nuclear Power Plants, and IAEA Safety Reports Series No. 56 Approaches and Tools for Severe Accident Analysis for NPP).	The existing NNR regulatory requirements for Nuclear Power Plants (NPP) are technology based (PWR, PBMR) and vendor country specific. Under the current regulatory strategies, the vendor country and reference plant specific safety requirements are accepted subject to also demonstrating compliance with NNR regulations. The NNR intends to keep this regulatory strategy for future NPP projects. At present, license applicants are required to meet NNR regulations and guides as well as country of origin requirements. The NNR's Regulatory Framework project aims to create a comprehensive set of regulations and regulatory guidance documents that will support new NPPs. At present, there are several new regulations waiting for Ministry promulgation. The new draft regulations ([1] and [5]) are more detailed and comprehensive compared to the existing regulations, for example [3], and Safety Standards and Regulatory Practices [4]. Further guidance on severe accidents appear in RG-0019 [2].	ARN performs review and assessment of the submissions against the AR standards and the agreed applicable codes and international standards as those from the origin country of the technology. The main purpose is the verify compliance against the regulatory requisites. It is important to mention that the Argentinean regulation is not prescriptive, instead is a goal-setting approach with fully adherence to IAEA safety standards.
Severe accident analysis	4. What are the expected outputs/uses for the severe accident analysis?	Please explain what the purpose of the analysis is (e.g. to inform SAMG etc.)	In general, the aims of SAA are to ensure that high hazard nuclear facilities are designed and operated so that, should a severe accident occur, the facility can be returned to an appropriately safe and stable condition with the radiological consequences mitigated subject to principle of ALARP. This involves determining the potential progression of the accident, the magnitude and characteristics of the consequences and any cliff edges. ONR SAPs paragraph 672. The severe accident analysis should provide information to: • assist in the identification of any further reasonably practicable preventative or mitigating measures beyond those derived from engineering analysis, DBA and PSA;	According to HAD 102/17 and IAEA SSG-2, the purpose of the SA analysis: 1. Apply to relevant SSCs design: (1) To identify risks and measures under severe accident, and propose severe accident prevention and mitigation measures; (2) Guide and support the design of severe accident mitigation measures and verify their effectiveness; (3) Determine the environmental conditions of severe accidents for equipment qualification or availability analysis. 2. Applied to support PSA, SAMG development and emergency plan zone verification: (1) Support level 2 PSA analysis; (2) Guide and support the development of SAMG and confirm its effectiveness; (3) Provide input of severe accident source terms for emergency preparedness.	From Part 3, Section 5 of [5]: '(6) A multilayer system of provisions for nuclear safety commensurate with the magnitude and likelihood of the potential exposures involved shall be applied to radiation sources or radioactive material for the purposes of – … (d) control of severe conditions in which the design basis of the nuclear facility may be exceeded, including the prevention of fault progression and mitigation of the consequences of severe accidents; and (e) mitigation of radiological consequences of significant releases of radioactive substances that could result from accident conditions.' From Part 5, Section 6 of [5]: "(1) Where a prior safety assessment or operational safety assessment has identified severe conditions in which the design basis of a nuclear facility may be exceeded –	Severe accident analysis is used for different purposes. During the licensing process, in particular during the design review, the analysis is used for the identification of adequate design provisions so that the plant can be brought into a controlled state and the containment function can be maintained, with the result that the possibility of plant states arising, that could lead to an early radioactive release or a large radioactive release, is "practically eliminated". In addition, the severe accident analysis should provide information to: • develop and validate of accident management programs, • support PSAs, • develop tech. spec. of severe accident mitigation systems and components, • support the development of emergency plans,

Topic	Question	Comment	ONR – UK Response	NNSA – China Response	NNR – South Africa Response	ARN – Argentina Response
			• form a suitable basis for accident management strategies and procedures; • support the preparation of emergency plans for the protection of people; and • support the PSA of the facility's design and operation		(a) Accident prevention and mitigation measures shall be applied as appropriate in line with a graded approach; (b) Accident prevention and mitigation measures, accident management procedures and guidelines including emergency planning, emergency preparedness and emergency response shall be established, implemented and maintained as appropriate." From Appendix 4 of RG-0019 [2]: "The licence applicant should provide in Chapter 19 of the SAR an adequate level of documentation to enable the NNR to determine the acceptability of the risks to public health and safety associated with operation of a proposed new plant. The acceptability of the risks to public health and safety is determined from the interpretation of the results and insights of the applicant's (1) plant-specific PRA and (2) severe accident evaluations."	• provide information for plant simulators.
	5. How is the scope of the severe accident analysis determined?		The scope of the SAA is determined by the requesting party. However, ONR expect that the scope includes all possible states and configurations in which a severe accident can occur. The scope should include: a. High consequence events of low frequency beyond the design basis; and b. Design basis events where the safety provisions are assumed to fail. ONR expects that severe accident scenarios should be identified using a combination of probabilistic and deterministic approach. Further guidance on the scope can be found in NS-TAST-GD-007.	1. Severe accident sequences need to be identified through engineering judgement, deterministic assessments and probabilistic assessment; 2. Based on the existing international research results, considering severe accident phenomena that have been identified, such as hydrogen explosion, base mat penetration caused by core-concrete interaction, steam explosion, etc., resulting in loss of containment integrity; 3. Conduct severe accident analysis based on SSCs design and PSA, SAMG development and emergency plan zone verification.	From Part 8, Section 2 of [5]: '(a) The authorisation holder shall - (i) conduct a comprehensive hazard assessment of sources of exposure to evaluate worker and public radiation doses from potential accidents over a wide range of probabilities including severe accidents;'	The scope of the severe accident analysis is determined by the applicant in fully agreement with the requirements stated during the pre-licensing stage. In the Memorandum of Understanding for the HPR 1000 it is clearly stated that: *Events that could lead to a release of radioactive material outside from the plant must be identified through a systematic process. The initiating events to be reviewed must include internal events and external events, and must be grouped into categories based primarily on the nature of the events and their frequency of occurrence.* In terms of methodology for the identification, it is expected that both, deterministic and probabilistic approach, be used.

Topic	Question	Comment	ONR – UK Response	NNSA – China Response	NNR – South Africa Response	ARN – Argentina Response
	6. If particular severe accident phenomenology or analysis is excluded, how is this justified?	Please explain the basis by which the vendor can exclude particular phenomena from analysis	A full range of SA phenomena should be considered in the severe accident analysis. ONR expects that where phenomena are screened out, i.e. that the design is not specifically designed to mitigate phenomena, then appropriate arguments should be provided. This demonstration may be made through a combination of arguments which may include analyses, in-house research, international research, a demonstration that the effects have negligible impact on the progression of the transient, that uncertainties can be bound by conservatisms, or that the occurrence is of low likelihood (which may also be based on PSA or the above considerations).	1. Based on international consensus derived from research and analysis, such as the results of SERG and SERENA, that the steam explosion in the reactor pressure vessel does not threaten the integrity of the RPV lower head; 2. Phenomena with very low probability and without practical guidance for the design, adequate precautions have been taken, such as the RPV rupture, which should be demonstrated to have been practically eliminated in the design.	It is considered that similar reasoning as is used for "practical elimination" could be used. From Section 6.1 of RG-0019 [2]: "4) Practical elimination a) Accident sequences with a large or early release can be considered to have been practically eliminated if: i) It is physically impossible for the accident sequence to occur; or ii) The accident sequence can be considered with a high degree of confidence to be extremely unlikely to arise. b) In each case the demonstration should show sufficient knowledge of the accident condition analysed and of the phenomena involved, substantiated by relevant and sufficient evidence. c) The degree of substantiation provided for a practical elimination demonstration should take account of the assessed frequency of the situation to be eliminated and of the degree of confidence in the assessed frequency (uncertainties associated with the data and methods must be evaluated in order to underwrite the degree of confidence that is claimed). d) Appropriate sensitivity studies should be included to confirm that sufficient margin to cliff edge effects exist. For engineered provisions, the practical elimination can be done for instance by providing substantial increase of the protective means of reliability. e) Practical elimination of an accident sequence should not be claimed solely based on compliance with a general cut-off probabilistic value. Even if the probability of an accident sequence is very low, any additional reasonably practicable design features, operational measures or accident management procedures to lower the risk further should be implemented." It could also be considered whether phenomena to be excluded may be covered by bounding or enveloping	The exclusion may be justified on the basis of engineering judgment as well as deterministic and probabilistic assessment. Regarding engineering judgment, the knowledge available today from extensive programs of research after the Three Mile Island (TMI) accident provides a sound basis for the identification of severe accident scenarios and associated phenomena that must be addressed in the design. In addition, it may be excluded phenomena with very low probability of occurrence.

Topic	Question	Comment	ONR – UK Response	NNSA – China Response	NNR – South Africa Response	ARN – Argentina Response
					scenarios, which should be chosen so that collectively they include cases presenting the greatest possible challenges to each of the relevant acceptance criteria and involving limiting values for the performance parameters of safety related equipment. The safety analysis should confirm that bounding or enveloping scenarios are acceptable.	
	7. How is the adequacy of the severe accident analysis determined?	Please explain how the vendor can demonstrate that their analysis is complete and suitable	ONR has produced Technical Assessment Guidance on Severe Accident Analysis (NS-TAST-GD-007), which provides guidance to inspectors on the adequacy of the severe accidents safety case. ONR also looks to SSG-2 ONR has performed Generic Design Assessment of the AP1000, UK ABWR and UK EPR, and looks to the methods, approaches, codes or models used in their safety cases as relevant good practice.	1. Review the analysis assumptions and methods in accordance with nuclear safety regulations and guidelines to confirm the rationality of the results; 2. In addition, for the key issues, the rationality of the analysis is confirmed by means of independent calculation and test verification, dedicated research program, and expert consultation.	From Part 8, Section 2 of [5]: "(a) The authorisation holder shall - (i) conduct a comprehensive hazard assessment of sources of exposure to evaluate worker and public radiation doses from potential accidents over a wide range of probabilities including severe accidents;" The demonstration that the severe accident analysis is complete and suitable should show sufficient knowledge of the accident condition analysed and of the phenomena involved, substantiated by relevant and sufficient evidence.	ARN performs review and assessment of the submission with the objective to determine whether the analysis fulfils the regulatory expectations as stated in the regulations as well as the applicable codes and guides agreed for the plant. Also, topical reports supporting the analysis hypothesis, phenomenology of the accidents, etc. are required to be submitted.
	8. What acceptance criteria are applicable for severe accident analysis?		Radiological criteria SSR2/1 states that "The design shall be such that for design extension conditions, protective actions that are limited in terms of lengths of time and areas of application shall be sufficient for the protection of the public, and sufficient time shall be available to take such measures." Besides this, ONR's safety assessment principles describe the radiological release Targets 8 and 9 which are applicable to severe accidents. ONR's SAPs often describe radiological targets in terms of "Objectives" and "Limits". In simple terms, if an Objective is not met, ALARP arguments are required to justify why they are not met. The Limits can be seen as absolute, and ONR would not accept a safety case for a new reactor which breached these limits. **Target 8** **Objective** – The sum of the sequence frequencies leading to an	According to HAF102-2016 and IAEA guidelines (SSG-2), the acceptance criteria for analysis of severe accidents should be divided into different levels: 1. High level (radiological) criteria, which relate to radiological consequences. The design shall be such that for design extension conditions, protective actions that are limited in terms of lengths of time and areas of application shall be sufficient for the protection of the public, and sufficient time shall be available to take such measures.. 2. Detailed (derived) technical criteria, which relate to the integrity of barriers to releases of radioactive material. The analysis of severe accidents should prove that the containment integrity can be ensured.	From Section 4 of [1]: "(1) The safety objectives for nuclear facility, in addition to the fundamental safety criteria and objectives specified in the Annexure 2 of the General Nuclear Safety Regulations, are: … (c) The likelihood of an exposure shall decrease as the potential magnitude thereof increases; (d) Accidents which could lead to early or large releases shall be practically eliminated and have to be considered in the design of the facility; and (e) Any offsite releases that could occur shall only require limited offsite emergency response." From Section 5 of [1]: "(4) The following acceptance criteria, in addition to the safety objectives specified in regulations 4(1) above shall apply for the various categories of events: …	ARN doesn´t prescribe acceptance criteria. The regulatory approach is objective-based: - For new plants, the safety objective is the practical elimination of accident sequences that could lead to large early radioactive releases, whereas severe accidents that could imply late containment failure would be considered in the design process with realistic assumptions and best estimate analyses so that their consequences would necessitate only protective measures limited in area and in time. - For new plants, the objective for large off-site releases requiring short term off-site response is 10^{-6} / per reactor-year. Also, severe accident scenarios shall comply with AR 3.1.3.

Topic	Question	Comment	ONR – UK Response	NNSA – China Response	NNR – South Africa Response	ARN – Argentina Response
			off-site dose greater than 1 Sv, should be less than 10^{-6} pa. **Limit** – The sum of the sequence frequencies leading to an off-site dose greater than 1 Sv should be less than 10^{-4} pa. **Target 9** **Objective** – The total risk of 100 or more fatalities should be less than 10^{-7} pa. **Limit** – The total risk of 100 or more fatalities should be less than 10^{-5} pa. Detailed criteria ONR does not prescribe acceptance criteria. However, ONR would look to RGP in order to make an assessment as to the adequacy of the requesting parties' acceptance criteria. This may include taking confidence that the requesting party meets the international regulators' specified criteria.		(b) Design base extension conditions – Minor radiological consequences outside the exclusion area are within specified limits; and (c) Severe accident conditions – Off site radiological consequences requires limited protective measures in area and time."	Figura 1 CURVA CRITERIO PARA EL PÚBLICO 
	9. How are the methodologies, approaches, codes or models used to perform the severe accident analysis specified?	Please explain whether the vendor or regulator specifies, and if so on what basis	ONR does not prescribe the methodologies, approaches, codes or models used to perform severe accident analyses. The vendor chooses the methodologies, approaches, codes or models. However, ONR has performed Generic Design Assessment of the AP1000, UK ABWR and UK EPR, and looks to the methods, approaches, codes or models used in their safety cases as relevant good practice. ONR expects that the vendors' choice at least meets these standards.	Approaches, codes and models are determined by vendors and the results are reviewed by regulator. The rationality of the model and results are confirmed through safety review, and sometimes, by independent calculation. According to HAF102-2016, the best-estimate methods and realistic assumptions can be used for severe accidents analysis.	The methodologies, approaches, codes or models used to perform the severe accident analysis are proposed by the vendor, with due regard to the regulatory framework and subject to acceptance by the regulator.	ARN doesn´t prescribe a specific methodology, code, model or approach. The responsibility for the safety demonstration including severe accident analysis is under the applicant. However, ARN expects a best estimate approach for DECs.
	10. What are the requirements for validation and verification of the severe accident analysis codes and models?		ONR does not prescribe V&V requirements for any computer codes used, nor does ONR license codes. However, ONR's Technical Assessment Guide NS-TAST-GD-042 provides guidance to inspectors on how to assess the Requesting Parties' safety documentation. ONR's expectations for documentation of V&V for SAA codes is not as involved as design basis codes.	The utility should fully demonstrate that the codes used can simulate the severe accidents of a specific power plant design. And the utility should also analyse the applicability of the codes. Regulatory requirements refer to IAEA SSG-2 and IAEA Safety Reports Series No. 56.	To support the safe, reliable operation of the currently operating nuclear power plant in South Africa, a wide range of accident analysis codes covering reactor neutronics, radiation and dose, thermal hydraulics, and so forth can be utilised. Subject to appropriate verification and validation, these codes can be used in the following applications: • Accident management guidance; • Emergency exercise scenario development; • PSA analyses; …	The regulatory expectations for V&V are aligned with the IAEA SSG-2 and IAEA SRS N° 56.

Topic	Question	Comment	ONR – UK Response	NNSA – China Response	NNR – South Africa Response	ARN – Argentina Response
					• Containment performance; … • Support for design basis, beyond design basis and severe accident procedures; See further information in the next row. Use of these software codes and the performing of accident analysis for the above applications shall be subject to the following provisions: • personnel performing analysis using software codes shall hold appropriate qualification(s) and relevant authorisation(s); • all analyses shall be carried out in accordance with approved and controlled processes and procedures; • verification and validation of the software code and its models shall be performed. The extent of applying this shall be dependent on the pedigree of the code(s) and its importance to the safety case; • all software codes and analyses shall be developed within a formal Quality Assurance and verification and validation management system in accordance with approved and controlled processes and procedures. An auditable trail shall be evident for all data and phases in the development, validation and verification process; • all software codes shall be authorised as fit for its intended use in each particular application and any limitations shall be specified; • all analyses shall be reviewed internally and independent reviews shall be considered Commensurate with the nature of the calculation and its importance to the safety case. All review comments and their resolution shall be documented; • a complete description and justification of the models, analytical approaches, equations, approximations, assumptions and empirical correlations used, the limitations of the code, sensitivity studies and demonstration of solution convergences shall be documented to conform to the principal requirements given in RG-0016 [10].	

Topic	Question	Comment	ONR – UK Response	NNSA – China Response	NNR – South Africa Response	ARN – Argentina Response
Design	11. How is the list of severe accident related equipment specified?	Please explain whether this is done by the regulator or vendor, and how	ONR does not prescribe the severe accident related equipment.	The vendor (utility) determines the severe accident related equipment according to the system design and management requirements of the severe accident. The regulator reviews its adequacy and rationality in accordance with the relevant requirements.	The list of severe accident related equipment is proposed by the vendor subject to acceptance by the regulator. In the context of a possible new build programme in South Africa, the NNR also considers guidance as provided in, for example, IAEA SSR-2/2 (Rev. 1) Safety of Nuclear Power Plants: Commissioning and Operation [9]: "5.8B. The accident management programme shall include instructions for the utilization of available equipment — safety related equipment as far as possible, but also items not important to safety (e.g. conventional equipment). 5.8C. The accident management programme shall include contingency measures, such as an alternative supply of cooling water and an alternative supply of electrical power, to mitigate the consequences of accidents, including any necessary equipment. This equipment shall be located and maintained so as to be functional and readily accessible when needed."	The list of equipment is developed by the applicant according to the severe accident analysis. It is important to stress that by regulatory requirement, the list must also include equipment for monitoring severe accidents.
	12. Is there a preference over how the severe accident related equipment is implemented?	Please explain how the decision over whether to use mobile or specific on site equipment is made	ONR does not prescribe the severe accident related equipment and does not have a preference; however, if mobile equipment is credited in the analysis, ONR expects that it is on-site, readily available, and any actions required to implement the safety equipment are timely and feasible. For new reactors, ONR benchmark it's expectations against IAEA's SSG-2.	Mobile equipment should not be used in the severe accident analysis to demonstrate the safety objective. In the process of severe accident management, mostly, priority is given to specific on site equipment, while the mobile equipment is used as a backup device, and it is depend on the specific scenarios.	Any preference is informed by the safety benefit. For example, mobile equipment might be the last resort in case of extreme external events.	ARN doesn´t prescribe specific requisites for severe accident related equipment.
	13. How are the performance requirements for severe accident related equipment determined?	Please explain whether the equipment requirements (e.g. capacity, mission times etc.) are determined by performance needs or are prescribed	The vendor determines the performance requirements of the severe accident related equipment. However, ONR looks to RGP and OPEX when determining the adequacy of the safety claims. For example, the AP1000, UK ABWR and UK EPR all have available DC power ≥ 24 hours following an SBO.	The performance requirements for severe accident related equipment is determined by the utility and reviewed by the NNSA. The requirements for severe accident-related equipment (equipment capacity, time allowance, etc.) are determined through function analysis, iterative design, and good practice. the requirement is that the three safety functions should be maintained.	From p.61 of [8]: "**Preventive domain (prevention of significant fuel rod degradation):** In Emergency Operating Procedures (EOPs), at least one success path relies on structures, systems and components qualified, as required by Requirement 30 of SSR-2/1 (Rev. 1) [3], for design basis accidents and for the design extension conditions those structures, systems and components were designed to cope with. However, EOPs may be implemented by using all available equipment (e.g. mobile, portable).	Engineering requirements for severe accident related equipment are determined from the functional analysis. In contrast to events on other DID levels there usually is not a single accident analysis available that would allow for identification of the safety functions necessary in severe accidents. Instead the design of the different severe accident features is usually based on a set of deterministic and/or probabilistic analyses from which the necessary information can be taken. According to IAEA SSG-30, the functions necessary to mitigate severe accidents are

Topic	Question	Comment	ONR – UK Response	NNSA – China Response	NNR – South Africa Response	ARN – Argentina Response
					Mitigatory domain (mitigation of the consequences of significant fuel rod degradation): SAMGs favour the use of structures, systems and components with capabilities consistent with the performance and environmental conditions expected in a severe accident, as required by paras 5.28 and 5.29 of SSR-2/1 (Rev. 1) and para. 5.8B of SSR-2/2 (Rev. 1). However, SAMGs may be implemented by using all equipment still available and alternatives (i.e. non-permanent equipment) to fulfil the fundamental safety functions; available systems may also be used beyond their design limits, if appropriate." The latter wording "if appropriate" implies preference for performance needs over prescriptions when determining equipment requirements. From p.18 of [8]: "2.59 Guidance should be prepared for testing the permanent and non-permanent equipment and for testing any assembled subsystems necessary for the equipment to meet its planned performance. The frequency and type of testing should be conducted in accordance with the manufacturer's recommendations. Tests should address necessary local actions, contingencies, the proper connection of non-permanent equipment to plant equipment, access to the site, off-site actions, emergency lighting and the possibility of events affecting multiple units, as well as the time needed to implement these actions, if appropriate. Accident management guidance should be provided for maintenance and periodic testing to ensure the proper functioning of equipment and may include the need for plant walkdowns." See also the responses to Question 16.	assigned to Safety Category 3 and from this category can be derived the equipment requirements.
	14. What are the requirements for severe accident equipment related to: a. Independency?		ONR has no requirements for independency, SFC, or safety classification. However, ONR has expectations for the following:	a. According to HAF102-2016, as fourth level of DID, equipment used for SA mitigation should be independent as far as possible from other level of DID. For some equipment that cannot be stripped, such as	In the context of the currently operating Koeberg nuclear power plant, the following approach to the analysis of severe accidents provides some indications. In the context of a possible new build programme	Paragraph 5.29 of IAEA SSR 2/1 requires that "the analysis undertaken shall include identification of the features that are designed for use in, or that are capable of preventing or mitigating, events considered

Topic	Question	Comment	ONR – UK Response	NNSA – China Response	NNR – South Africa Response	ARN – Argentina Response
	b. Single Failure criteria? c. Safety classification?		a. Independency between levels of defence in depth as far as reasonably practicable; b. The single failure criterion is not expected to be applied to SA measures; c. ONR expects that systems structures and components are classified based upon the categorisation of safety function that they provide, and the contribution to that safety function they provide. ONR does not prescribe the classification of the SSCs, however, it is expected that the SA safety measures are safety classified. Whilst it is likly that the safety function to be delivered by a SA measure is of lower categorisation than those for design basis accidents, ONR expects that measures that could negatively impact other levels of defence in depth be of a higher classification where necessary. In addition, it is often necessary for SA measures to operate during seismic events; these SSCs require a high standard of seismic qualification.	containment, the independence is not considered in practice. b. Single Failure criteria is not necessary in SA. According to HAF102-2016 and IAEA SSG-2, for the design extension conditions with core melting, the Single Failure criterion is not required. The utility may consider certain redundancy or design margin to improve the reliability, such as the pressure release value dedicated to severe accident. c. The current requirement of safety classification is in Safety Functions and Component Classification for BWR, PWR and PTR HAD103-1986, the HPR1000 uses IAEA SSG-30 and TECDOC-1787.	some of these requirements may be updated to reflect international good practices. **Analysis Method for Beyond Design Basis Accidents (Including Severe Accidents)** For the deterministic and probabilistic analysis of BDBAs, including severe accidents, it is acceptable to use best estimate computer codes combined with realistic assumptions and initial and boundary conditions that reflect the likely plant configuration and conditions and the expected response of plant systems and operators in the analysed accident scenario, together with an evaluation of the uncertainties associated with the relevant phenomena. However, an uncertainty analysis is not always practicable or even possible, and should not necessarily be performed when determining what measures should be taken to mitigate the consequences of severe accidents. The single failure criterion does not need to be applied in the analysis of BDBAs. Where it is not possible to use realistic assumptions and/ or initial and boundary conditions, reasonably conservative assumptions and / or initial and boundary conditions should be used in which the uncertainties in the understanding of the phenomena being modelled are considered and bounded based to the extent possible on available experimental data or expert judgement. **Assumptions Used for the Analysis of Beyond Design Basis Accidents Except Severe Accidents** The following assumptions may be used for the analysis of BDBAs: • When the reactor is initially at power, the power level is at 100% full power. • Control devices are considered to be operating normally. • Credit for actuation of non-safety-classified systems may be given. • Off-site electrical power supply remains available (except for Blackout scenario).	in the design extension conditions. These features: (a) Shall be independent, to the extent practicable, of those used in more frequent accidents; (b) Shall be capable of performing in the environmental conditions pertaining to these design extension conditions, including design extension conditions in severe accidents, where appropriate; (c) Shall have reliability commensurate with the function that they are required to fulfil." Related to independency requirements, ARN follows the IAEA SSR 2/1, which requires the independence of safety provisions at different defence in depth levels: "The levels of defence in depth shall be independent as far as practicable to avoid the failure of one level reducing the effectiveness of other levels. In particular, safety features for design extension conditions (especially features for mitigating the consequences of accidents involving the melting of fuel) shall as far as is practicable be independent of safety systems." According to SSR-2/1 Requirement 20, the analyses of the DECs may be performed using realistic assumptions. In particular, redundancies necessary to comply with the single failure criterion are not required, provided the reliability of the function to be accomplished is adequate. For safety classification the regulatory requirement is to follow the methodology stated in IAEA SSG-30and TECDOC 1787.

Topic	Question	Comment	ONR – UK Response	NNSA – China Response	NNR – South Africa Response	ARN – Argentina Response
					• Residual power is evaluated without any margin as a function of burn-up. • The times at which the relevant systems are assumed to start-up are calculated realistically. **Assumptions Used for the Analysis of Severe Accidents** The following assumptions may be used in the analysis of severe accidents: • Expert judgement from recognised sources may be used where benchmarked models are not available. • Realistic credit is taken for the availability of all SSC including instrumentation even when required to operate outside of their design basis. • Best estimate severe accident analysis programmes are used where practical and when their models include the relevant phenomena. • For instrumentation, no margin need be considered, but where possible, readings are validated by multiple/diverse means. However, consequential effects on instrumentation accuracy due to post accident environmental conditions shall be considered. • Credit can be taken for the recovery of failed systems or equipment. • Uncertainties regarding severe accident phenomena and the outcome of mitigating measures may be accommodated through the trade-off between positive and negative impacts. • Credit may be taken for operator action. The risk benefit of operator actions in SAMGs should be assessed and actions that would result in a significant risk reduction in all conditions applicable to the set of guidelines must be considered to be assigned a mandatory status. From p.25 of IAEA SSR-2/1 (Rev. 1) Safety of Nuclear Power Plants: Design [11]: “5.29. The analysis undertaken shall include identification of the features that are designed for use in, or that are capable[15] of preventing or mitigating,	

Topic	Question	Comment	ONR – UK Response	NNSA – China Response	NNR – South Africa Response	ARN – Argentina Response
					events considered in the design extension conditions. These features: (a) Shall be independent, to the extent practicable, of those used in more frequent accidents; (b) Shall be capable of performing in the environmental conditions pertaining to these design extension conditions, including design extension conditions in severe accidents, where appropriate; (c) Shall have reliability commensurate with the function that they are required to fulfil. 15 For returning the plant to a safe state or for mitigating the consequences of an accident, consideration could be given to the full design capabilities of the plant and to the temporary use of additional systems." From p.21 of IAEA-TECDOC-1791 [12]: 'SSR-2/1 also requires the independence of safety provisions at different defence in depth levels: 4.13A. "The levels of defence in depth shall be independent as far as practicable to avoid the failure of one level reducing the effectiveness of other levels. In particular, safety features for design extension conditions (especially features for mitigating the consequences of accidents involving the melting of fuel) shall as far as is practicable be independent of safety systems." The issue of the independence of the different levels of defence in depth is addressed in detail in Section 6 of this publication.'	
	15. How is equipment qualification determined?		ONR's SAPs (EQU.1) sets the expectations that "Qualification procedures should be applied to confirm that structures, systems and components will perform their allocated safety function(s) in all normal operational, fault and accident conditions identified in the safety case and for the duration of their operational lives." ONR expects that the environmental conditions in which SSCs claimed in severe accidents are expected to operate, are derived from the SAA.	According to HAF102-2016, The design features for DEC Shall be capable of performing in the environmental conditions pertaining to these design extension conditions, including design extension conditions in severe accidents, where appropriate, and they Shall have reliability commensurate with the function that they are required to fulfil. As for HPR1000, for equipment or instruments dedicated to severe accidents, equipment qualification under severe accidents conditions were	Based on p.24 of IAEA SSG-2 [6]: It is understood that typical equipment qualification programmes for design extension conditions with core melting might not always be applicable and an assessment of the operability of structures, systems and components is acceptable. The term 'survivability assessment' is sometimes used for such an assessment.	Equipment qualification refers to environmental and seismic qualification. Environmental qualification includes harsh and mild environment qualification. For seismic qualification, acceleration corresponding to a DBE (SSE) has to be considered. The regulatory requirement is to follow the IAEA SRS N°3 and TECDOC 1818.

Topic	Question	Comment	ONR – UK Response	NNSA – China Response	NNR – South Africa Response	ARN – Argentina Response
			The environmental conditions are likely to be harsher than those experienced in design basis accidents. Because the ONR expects that the qualification be carried out in the accident conditions identified, this often leads to the seismic qualification requirements being defined separately to the safety function categorisation. This may lead to higher or similar seismic qualification standards in the SAA as the design basis.	carried out, taking into account environmental conditions such as temperature, pressure, humidity and irradiation		
	16. Are there specific requirements related to the design of severe accident equipment for: a. C&I for severe accident conditions? b. Combustible gas control in (a) containment (b) elsewhere? c. Control of the pressure in (a) primary circuit (b) containment? d. Removal of decay heat? e. Mitigation of molten core debris (a) in-vessel (b) ex-vessel? f. Mitigation of radioactive releases to the environment? g. Electrical power supplies?	In the answer please explain • Any preferences of passive or active safety • Any preferences for in-vessel or ex-vessel cooling strategies • Any requirements for inclusion of a filtered containment vent in the design	ONR has no specific requirements related to any of the queries a-g. ONR has no preference over passive or active safety for SAA mitigation strategies. ONR has no preference over in-vessel or ex-vessel cooling strategies. ONR has issued design acceptance confirmation to both the AP1000 and EPR. ONR has no preference over the inclusion of a filtered containment vent in the design.	The vendor gives an overall consideration, including the safety, economy, maturity, etc., and determines the type of severe accident mitigation measures, such as active or passive, in-vessel or ex-vessel cooling, or whether a Containment Filtration and Exhaust System is needed. The AP1000, VVER and EPR, which used different design concept/philosophy, are reviewed and accepted by NNSA. The regulator is only responsible for reviewing whether the relevant design can meet the safety requirements.	From Section 4 of [1]: (e) The design shall apply the following measures in order of priority to the extent practicable: (i) Passive safety measures that do not rely on control systems, active safety systems or human intervention; (ii) Automatically initiated active engineered safety measures; (iii) Active engineered safety measures that need to be manually brought into service in response to the fault; (iv) Administrative safety measures; and (v) Mitigation safety measures. In the context of a possible new build programme in South Africa, the NNR also considers guidance as provided in, for example, IAEA SSG-54 Accident Management Programmes for Nuclear Power Plants [8]: "3.100 Plant capabilities should be analysed in connection with the in-vessel phase of a severe accident, including consideration of the following: (a) Hydrogen production in the vessel and its release, as input information for the design of the hydrogen treatment system; (b) Retention of the molten core within the vessel both by internal and external vessel cooling; (c) The composition and configuration of the molten core and failure of the reactor	There are not specific preferences related to the design of severe accident equipment. It is the applicant´s responsibility to propose the suitable technological solution and justify it. ARN is responsible for reviewing whether the design meets the safety requirements.

Topic	Question	Comment	ONR – UK Response	NNSA – China Response	NNR – South Africa Response	ARN – Argentina Response
					pressure vessel as inputs to the design of the core catcher; (d) Reliable depressurization to allow low pressure water injection and avoid high pressure vessel failure; (e) Long term release of fission products from the reactor core. 3.101 For the ex-vessel phase, plant capabilities should be analysed including: (a) Reliable depressurization of the containment to avoid high pressure containment failure; (b) Sources, distribution and the potential leak paths of combustible gases, as input information for the design of the combustible gas treatment system; (c) Issues relating to ex-vessel steam explosion, high pressure melt ejection and direct containment heating; (d) Composition and configuration of the molten core as inputs to the design of ex-vessel melt retention devices; (e) Fission product sources and the distribution of fission products within the containment, with special attention given to the long term behaviour of such sources Further guidance from IAEA SSG-54 [8]: “3.27 The plant control and logic interlocks that may need to be defeated or reset for the successful implementation of severe accident management strategies should be systematically identified. It should also be verified that the potential negative effects of such actions have been adequately characterized and documented. 3.28 The definition and selection of strategies applicable to severe accidents should consider the potential usefulness of maintaining strategies initiated when significant fuel rod degradation had not yet occurred. For example, subcriticality of the core or the core debris should be maintained, and a path should be provided to transfer decay heat from the core or molten core debris to an ultimate heat sink, where possible.”	

Topic	Question	Comment	ONR – UK Response	NNSA – China Response	NNR – South Africa Response	ARN – Argentina Response
	17. Are there specific requirements for criteria for initiating severe accident mitigation strategies?	Please explain requirements for implementing severe accident measures and filtered containment venting, including the regulators role in making those decisions	ONR does not prescribe criteria for initiating severe accident mitigation strategies. The vendor must justify the use of any criteria used. ONR, however, takes cognisance of international practice for these criteria when performing assessment of the safety case. With regards the regulators role in making decisions during emergencies - The licensee is responsible for making decisions during all modes of operation, including emergencies. In the unlikely event that ONR disagreed with a course of action proposed by the licensee, ONR has the power to intervene.	The severe accident management in industry generally takes the core outlet temperature above 650 °C as the criterion, also other criteria, but it is not prescribed by NNSA. The opening of the containment venting system should be reported and approved by the nuclear safety regulatory authorities and emergency management authorities for the off-site emergency preparedness. Some technical issues of HPR1000 containment venting system is still under being demonstrated and discussed.	The NNR considers developments related to filtered containment venting, for example in the context of lessons learned from the Fukushima Daiichi accident as presented in IAEA-TECDOC-1812, "Severe Accident Mitigation through Improvements in Filtered Containment Vent Systems and Containment Cooling Strategies for Water Cooled Reactors", 2017. It is claimed that a reliable containment venting system provides more effective accident management during severe accidents, especially for smaller volume containments in relation to the rated nuclear power.	There are no regulatory criteria for initiation of severe accident mitigation strategies. However, the decision of opening the containment must be communicated and approved by the regulatory body for the off-site emergency preparedness.
Management of a severe accident	18. What are the regulatory expectations for management of severe accidents?	Please explain what is expected regarding SAMG etc. and how this is under regulatory control	ONR expect, so far as reasonably practicable, that SAMGs are based upon the SAA. An extract from ONR's TAG NS-TAST-GD-007 states that: "*The SAA, in providing a systematic analysis of all potential severe accidents that could occur at the facility, should be a key contributor to the development of a comprehensive suite of EOPs and SAMGs. The suite of EOPs and SAMGs should address all identified potential severe accidents and cover all permitted operating modes of the facility (e.g. strategies on an LWR for a severe accident during refuelling will need to be different to those that could be used for accidents during power operation as the vessel head will have been removed).* *Key aspects where the SAA can provide input to the EOPs and SAMGs include:* *i. Identifying the symptoms that will allow the operators to identify the true state of the plant and / or imminent escalations in severity;* *ii. The timescales and priorities for action;* *iii. Appropriate points for enacting the transition from EOPs to SAMGs;* *iv. Identifying alternative scenarios for how the accident might escalate and an analysis of the likely effectiveness of different*	Regulations such as "HAF103" and "General Technical Requirements(GTR) on post-Fukushima Nuclear Accident Improvement Measures for NPPs (Tentative)" require the development of Severe Accident Management Guidelines. Technical document such as HAJ-0001-2016 (mainly based on IAEA NS-G-2.15) gives the detail guidance of SAMG development and use. The vendor should develop the SAMG and related management procedures, and carry on training and drills and other work. Nuclear safety inspections and peer review are conducted to verify the effectiveness of the SAMG preparation and implementation.	In the context of a possible new build programme in South Africa: From Part 3, Section 5 of [5]: "An applicant for, or holder of, a nuclear authorization, shall ensure that: … (6) A multilayer system of provisions for nuclear safety commensurate with the magnitude and likelihood of the potential exposures involved shall be applied to radiation sources or radioactive material for the purposes of – … (d) control of severe conditions in which the design basis of the nuclear facility may be exceeded, including the prevention of fault progression and mitigation of the consequences of severe accidents; and (e) mitigation of radiological consequences of significant releases of radioactive substances that could result from accident conditions." From Part 5, Section 3 of [5]: "(7) A set of design extension conditions shall be derived on the basis of engineering judgment, deterministic assessments and probabilistic assessments for the purpose of further improving the safety of the nuclear facility by enhancing the plant's capabilities to withstand, without unacceptable radiological consequences, accidents that are either more severe than design basis	The emergency operative procedures (EOP) as well as the SAMGs are mandatory documentation that the operator has to submit to the regulatory body as a pre-requisite for the Operating Licence. During the pre-licensing stage, SAMGs are out of scope of the regulatory activities. In general, the EOPs are based on engineering judgment, experiences in other similar plants and validated against simulations in a full-scope simulator on site; while SAMG strategies are based on computer simulation with a validated system code for these purposes. It is expected that the SAMG contain a description of the positive and negative potential consequences of the proposed actions, including quantitative data when available and relevant; should be simple, clear and unambiguous; and should contain sufficient information for the plant staff to reach a timely decision on the actions to take during the evolution of a severe accident. ARN expectations are aligned with the IAEA SSG-54.

Topic	Question	Comment	ONR – UK Response	NNSA – China Response	NNR – South Africa Response	ARN – Argentina Response
			strategies, including the pros and cons of each; *v. Analysis of the expected radiation dose levels and means of minimising exposures;* *vi. Through task analysis, whether the procedures and SAMGs could reasonably be expected to be followed in the likely severely degraded plant condition following a severe accident;* *vii. Helping to quantify the numbers of operators needed to address steps in the procedures / stages in the SAMGs;* viii. *Other human factors aspects of the EOPs and SAMGs as discussed in the previous section, e.g. the availability and use of communications systems and control structures."* During GDA (pre-licensing generic design assessment), detailed SAMGs are outside of the scope of the assessment. The SAA, however, forms a sound basis for the future licensee to draft SAMGs. ONR attaches licence conditions to every GB licensed site, which requires the licensee to have adequate emergency arrangements for accident management. This, in addition to other licence conditions, sets the requirement for emergency preparedness.		accidents or that involve additional failures. These design extension conditions shall be used to identify the additional accident scenarios to be addressed in the design and to plan practicable provisions for the prevention of such accidents or mitigation of their consequences if they do occur." From Part 5, Section 6 of [5]: 6. Accident management (1) Where a prior safety assessment or operational safety assessment has identified severe conditions in which the design basis of a nuclear facility may be exceeded – (a) Accident prevention and mitigation measures shall be applied as appropriate in line with a graded approach; (b) Accident prevention and mitigation measures, accident management procedures and guidelines including emergency planning, emergency preparedness and emergency response shall be established, implemented and maintained as appropriate. (2) An accident management programme shall – (a) Be established, where applicable, that covers the preparatory measures and guidelines that are necessary for dealing with accident conditions not considered in the design of the facility, including severe accident conditions; (b) Include instructions for utilisation of the available safety related equipment as far as possible, conventional equipment and the technical and administrative measures to mitigate the consequences of an accident; (c) Include organisational arrangements and facilities for accident management, communication networks and training necessary for the implementation of the programme; and (d) Be periodically reviewed and revised as necessary. (3) Arrangements for accident management shall provide the operating staff with appropriate systems and technical support in the event of accident	

Topic	Question	Comment	ONR – UK Response	NNSA – China Response	NNR – South Africa Response	ARN – Argentina Response
					conditions not considered in the design of the facility. These arrangements and guidance shall address the actions necessary following severe accident conditions.	
References	N/A	N/A	N/A	N/A	[1] NNR Draft Specific Nuclear Safety Regulations: Nuclear Facilities [2] NNR RG-0019 "Interim Guidance on Safety Assessments of Nuclear Facilities" [3] National Nuclear Regulator Act (Act No. 47 of 1999) [4] R.388: Regulations In Terms Of Section 36, read with Section 47 of the National Nuclear Regulator Act, 1999 Act No. 47 on Safety Standards and Regulatory Practices [5] NNR Draft General Nuclear Safety Regulations [6] IAEA SSG-2 Rev 1, "Deterministic Safety Analysis for Nuclear Power Plants", 2019 [7] NNR RG-0011 "Interim Guidance for the Siting of Nuclear Facilities" [8] IAEA SSG-54 Accident Management Programmes for Nuclear Power Plants, 2019 [9] IAEA SSR-2/2 (Rev. 1) Safety of Nuclear Power Plants: Commissioning and Operation, 2016 [10] NNR RG-0016, "Guidance on the Verification and Validation of Evaluation and Calculation Models used in Safety and Design Analysis" [11] IAEA SSR-2/1 (Rev. 1) Safety of Nuclear Power Plants: Design, 2016 [12] IAEA -TECDOC-1791 Considerations on the Application of the IAEA Safety Requirements for the Design of Nuclear Power Plants, 2016 [13] NNR Position Paper PP-0014 Considerations of External Events for New Nuclear Installations	N/A