Multinational Design Evaluation Programme

Common Position

CP-HPR1000WG-04

Common Position Addressing the Vienna Declaration on Nuclear Safety for HPR1000

Countries involved in the MDEP working group discussions:	ARN (Argentina) NSSA (People's Republic of China) NNR (South Africa) and ONR (the United Kingdom)
Countries which support the present common position:	ARN (Argentina) NSSA (People's Republic of China) NNR (South Africa) and ONR (the United Kingdom)

Contents

List of abbreviation and acronyms

CDF	Core Damage Frequency
CP-STC-02	Common Position Addressing Fukushima Daiichi Nuclear Power Accident
DBAs	Design Basis Accidents
DECs	Design Extension Conditions
DiD	Defence-in-depth
DSWGs	Design Specific Working Groups
HPR1000WG	HPR1000 Working Group
IAEA	International Atomic Energy Agency
LRF	Large Radioactive Release Frequency
MDEP	Multinational Design Evaluation Programme
NNSA	National Nuclear Safety Authority
ONR	Office for Nuclear Regulation
PSA	Probabilistic Safety Analyses
PWR	Pressurized Water Reactor
STC	Steering Technical Committee
WENRA	Western European Nuclear Regulators Association

1. Introduction

On the 9th of February 2015 the Vienna Declaration on Nuclear Safety was adopted at the Diplomatic Conference of the Convention on Nuclear Safety[1]. The declaration states a number of principles related to the design, operation and regulation of new and existing Nuclear Power Plants. In September 2016, the Common Position Addressing Fukushima Daiichi Nuclear Power Accident (CP-STC-02) was published by Multinational Design Evaluation Programme (MDEP) Steering Technical Committee (STC), which mentioned that the following principle of Vienna Declaration is relevant in view of the MDEP objectives:

> *"New nuclear power plants are to be designed, sited, and constructed, consistent with the objective of preventing accidents in the commissioning and operation and, should an accident occur, mitigating possible releases of radionuclides causing long-term off-site contamination and avoiding early radioactive releases or radioactive releases large enough to require long-term protective measures and actions."*

The reactor designs considered by the MDEP are designed with the aim of preventing events that might lead to early radioactive releases or radioactive releases large enough to require long-term protective measures and actions. Part of the activities of the MDEP Design Specific Working Groups (DSWGs) is to consider, from a regulatory perspective, how these objectives are adequately addressed.

Considering the CP-STC-02, as well as practice of other MDEP DSWGs, the MDEP HPR1000 Working Group (HPR1000WG) members, referred to herein as "regulators", consists of members from the national nuclear safety regulatory authorities of the United Kingdom, South Africa, Argentina and People's Republic of China, have produced this common position on the understanding of the above principle and how the HPR1000 design complies with the principle.

In order to develop this common position, the HPR1000WG members had a thorough discussion and were aware that the above principle focused on the design should practically eliminate the early radioactive release or large radioactive release. Relevant technical documents have been published by International Atomic Energy Agency (IAEA) and Western European Nuclear Regulators Association (WENRA), which, in the view of

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[1] Diplomatic Conference to consider a proposal to amend the Convention on Nuclear Safety: Vienna Declaration on Nuclear Safety, on principles for the implementation of the objective of the Convention on Nuclear safety to prevent accidents and mitigate radiological consequences. Adopted by the Contracting parties meeting at the Diplomatic Conference of the Convention of Nuclear Safety, CNS/DC/2015/2/Rev.1, Vienna, Austria, February 9, 2015

HPR1000WG members, provide a relatively systematic and acceptable methodology for the realization of the practical elimination of early radioactive releases or large radioactive releases. These efforts have provided a good basis for reaching the common position.

It is recognised that not all members of the HPR1000WG have completed their regulatory reviews of the HPR1000 design and how the design meets the Vienna Declaration principles. This common position therefore will be reviewed and updated as necessary in the future as these reviews are completed.

2. Practical elimination of early radioactive releases or large radioactive releases

For the design of new Nuclear Power Plants, IAEA SSR-2/1 (Rev. 1), Safety of Nuclear Power Plants: Design, states:

> *"The safety objective in the case of a severe accident is that only protective actions that are limited in terms of lengths of time and areas of application would be necessary and that off-site contamination would be avoided or minimized. Event sequences that would lead to an early radioactive release or a large radioactive release are required to be 'practically eliminated'".*
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> *"The design shall be such that the possibility of conditions arising that could lead to an early radioactive release or a large radioactive release is 'practically eliminated'".*

Practical elimination of early radioactive releases or large radioactive releases has been investigated and discussed widely since it was put forward. Although no consensus on quantitative standards and criteria has been formed internationally up to now, some documents provide demonstration methodology and approach, including:

- *IAEA, Deterministic Safety Analysis for Nuclear Power Plants, SSG-2 (Rev. 1), 2019.*
- *WENRA, Practical Elimination Applied to New NPP Designs - Key Elements and Expectations, 2019.*

The view of the HPR1000WG members is that the above two technical documents share the same basic ideas on the demonstration of practical elimination and provide an acceptable approach towards practical elimination.

The HPR1000WG members recognize the interpretation of relevant terms:

> *The possibility of certain conditions arising may be considered to have been **"practically eliminated"** if it would be physically impossible for the conditions to arise or if these conditions could be considered with a high level of confidence to be extremely unlikely to arise.*
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> *An **"early radioactive release"** in this context is a radioactive release for which off-site protective actions would be necessary but would be unlikely to be fully effective in due time.*
>
> *A **"large radioactive release"** is a radioactive release for which off-site protective actions that are limited in terms of lengths of time and areas of application would be insufficient for the protection of people and of the environment.*

3. Common positions agreed on the HPR1000 reactor in response to the Vienna Declaration

Some MDEP common positions have already been agreed by the HPR1000 Design Specific Working Group. This Common Position in response to the Vienna Declaration is based upon those agreed CPs, in particular the Common Position Addressing Fukushima Daiichi NPP Accident-Related Issues (CP-HPR1000WG-01). The regulators have already developed the following common position with regard to the general design objectives of the HPR1000 design:

> *The Fukushima Daiichi nuclear power plant accident confirms the relevance of the general safety objectives that have been considered for Generation III reactors, such as the HPR1000 (lower probability of core melt, limitation of releases, and management of severe accident conditions).*

This is now supplemented by an additional common position focusing on the expectations of the Vienna Declaration for the reactor design:

> *I. All the HPR1000WG members are aware that the practical elimination of early radioactive releases or large radioactive releases is a high-level safety objective and that the application of enhanced defence-in-depth (DiD) concept[2] in the design is essential for achieving this objective, particularly the first four levels of defence-in-depth. In the enhanced DiD concept, Design*

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[2] More information on "enhanced defence-in-depth (DiD) concept" can be referred to IAEA-TECDOC-1791-2016 (Section 4).

> *Extension Conditions (DECs) are introduced, corresponding design requirements for the safety features are established, as well as independence between different DiD levels. By doing so, the plant's capability to manage accidents more severe than Design Basis Accidents (DBAs) is enhanced.*

As a new-generation Pressurized Water Reactor (PWR) designed by China, HPR1000 adopts the active combined with passive safety design philosophy, further reinforces DiD implementation and has a lower Core Damage Frequency (CDF) as well as a lower Large Radioactive Release Frequency (LRF) compared with previous generation reactors.

In case of DBAs, HPR1000 is equipped with safety systems which comply with single failure criterion and the principles of redundancy, independence and diversity. Based on the experiences and lessons learned from the Three Mile Island, Chernobyl and Fukushima nuclear accidents, HPR1000 has adopted comprehensive severe accident prevention and mitigation measures with necessary reliability and availability, and developed accident management programmes. External events that may lead to early radioactive releases or large radioactive releases, including external natural and anthropogenic events, are carefully considered. Appropriate measures and adequate margins are considered in the design for specific beyond design basic external hazards, such as floods and earthquakes.

Deterministic analyses are performed on DBAs and DECs. Meanwhile, level 1 and level 2 Probabilistic Safety Analyses (PSA) are conducted on internal and external events both in power operation and shutdown conditions, to identify safety weakness, optimize and balance design, and to achieve the safety objective of practical elimination.

> *II. All HPR1000WG members agree that the categories of accident sequences or conditions which may lead to early radioactive releases or large radioactive release identified in IAEA and WENRA technical documents provide valuable reference for HPR1000 and should be considered in the design.*

HPR1000 accident sequences or conditions that may lead to early radioactive releases or large radioactive releases are identified mainly through deterministic analyses, probabilistic analyses and engineering judgement, and both the reactor core and spent fuel pool are considered. Accident sequences or conditions which need to be practically eliminated include severe accident sequences that could lead to early failure or late failure of the containment, severe accident with containment bypass, as well as significant fuel degradation in the spent fuel pool, etc. The list of accident sequences or conditions of HPR1000 that may lead to early radioactive releases, or large radioactive release is consistent with the lists in IAEA and WENRA documents, as detailed in Annex 1.

> *III. All HPR1000WG members agree that the demonstration of practical elimination by "extremely unlikely with a high degree of confidence" should be based on both deterministic and probabilistic considerations. Although probabilistic targets can be set, demonstration of the "practical elimination" of conditions that could lead to an early radioactive release or a large radioactive release should not be based solely on low probability values.*

Accident sequences or conditions of HPR1000 that may lead to an early radioactive releases or large radioactive release, are mainly demonstrated to be practically eliminated through requiring them to be "extremely unlikely with a high degree of confidence". HPR1000 has provisions and measures against these accident sequences or conditions, including design measures and operational measures, and implements enough margin to cope with uncertainties. The effectiveness of the measures is confirmed through both deterministic and probabilistic safety analysis. The deterministic analysis is used to demonstrate the effectiveness of measures to deal with typical accident sequences. The probabilistic analysis is used to prove that the event frequency of each sequence or condition is lower than a certain value, and to ensure that the total LRF meets the safety objective.

In Annex 2, the main design measures and demonstration of practical elimination for the accident sequences or conditions in Annex 1 are presented. An example, the demonstration of practical elimination of direct containment heating which may lead to an early radioactive release, is presented.

> *IV. Although the HPR1000WG members have reached consensus on key aspects on practical elimination of early radioactive releases or large radioactive releases, it is agreed that each member state may have different specific regulatory requirements, expectations and acceptance criteria based on national regulations and state of the art practice.*

The HPR1000WG members recognize the efforts performed by the HPR1000 designers to reach the realization of practical elimination of early radioactive releases or large radioactive releases. Office for Nuclear Regulation (ONR) (reviewer of Option 1[3]) and

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[3] More information on option 1 and option 2 of HPR1000 design can be referred to CP-HPR1000WG-01.

National Nuclear Safety Authority (NNSA) (reviewer of Option 1&2) have completed the corresponding safety review of HPR1000 design and confirm that design of HPR1000 can achieve the safety objective of practical elimination of early radioactive releases or large radioactive releases.

References

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IAEA (2016), *Safety of Nuclear Power Plants: Design, IAEA Safety Standards, Specific Safety Requirements, SSR-2/1 (Rev. 1),* IAEA, Vienna, https://www-pub.iaea.org/MTCD/publications/PDF/Pub1715web-46541668.pdf

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ONR (2022), *Generic Design Assessment Step 4 Assessment of Severe Accident Analysis for the UK HPR1000 Reactor*: *Assessment Report ONR-NR-AR-21-008, Revision 0*, 2021/49781*,* ONR, https://www.onr.org.uk/media/m30eqryo/onr-nr-ar-21-008.pdf

WENRA (2019), *Practical Elimination Applied to New NPP Designs - Key Elements and Expectations*, WENRA, Cologne, https://wenra.eu/sites/default/files/publications/practical_elimination_applied_to_new_npp_designs_-_key_elements_and_expectations_-_for_issue.pdf

Annex 1. Sequence or condition categories that may lead to an early radioactive release or a large radioactive release for typical PWRs

(a) Events that could lead to prompt reactor core damage and consequent early containment failure, such as:

i. Failure of a large pressure-retaining component in the reactor coolant system;

ii. Uncontrolled reactivity accidents.

(b) Severe accident sequences that could lead to early containment failure, such as:

i. Highly energetic direct containment heating;

ii. Large steam explosion;

iii. Explosion of combustible gases, including hydrogen and carbon monoxide.

(c) Severe accident sequences that could lead to late containment failure:

i. Basemat penetration or containment bypass during molten core concrete interaction;

ii. Long term loss of containment heat removal;

iii. Explosion of combustible gases, including hydrogen and carbon monoxide.

(d) Severe accident with containment bypass.

(e) Significant fuel degradation in a storage fuel pool and uncontrolled releases.

Annex 2. Demonstration of practical elimination of early radioactive releases or large radioactive releases for HPR1000

The main design measures and demonstration of practical elimination for the accident sequences or conditions in Annex 1 are summarized in Table 1. The detailed practical elimination demonstration process of highly energetic Direct Containment Heating (DCH), which may lead to an early radioactive release, is presented as an example.

Table 1. Main design provisions and demonstration of practical elimination of accident sequences or conditions for HPR1000

No.	**Accident sequences or conditions**	**Main design provisions and demonstration**
1	Failure of a large pressure-retaining component in the reactor coolant system	- Application of high-level requirements for design, procurement, construction, installation and operation, with proven materials and manufacturing technique to ensure that the frequency of containment failure due to the failure of a large component in the reactor coolant system is less than 1E-7/r.y with a high confidence level.
2	Uncontrolled reactivity accidents	– Ensure a negative reactivity coefficient with all possible combination of reactor power, pressure and temperature of coolant to avoid the accident. – Eliminate the inducing of positive reactivity through design measures. – The PSA analysis demonstrates that the frequency of this accident condition is less than 1E-7/r.y with a high confidence level.
3	Severe accident condition of early containment failure due to highly energetic direct containment heating	– The dedicated severe accident depressurization system. – The analysis of the typical high pressure melt ejection (HPME) sequences demonstrates that the dedicated depressurization system can prevent HPME efficiently. – The PSA analysis demonstrates that the frequency of this accident condition is less than 1E-7/r.y with a high confidence level.
4	Severe accident condition of early containment failure due to combustible gases	– Passive autocatalytic recombiners (PAR). – The analysis of typical accident sequence demonstrates that PARs can avoid hydrogen combustion or detonation. – The PSA analysis demonstrates that the frequency of this accident condition is less than 1E-7/r.y with a high confidence level.

No.	Accident sequences or conditions	Main design provisions and demonstration
5	Severe accident condition of early containment failure due to large steam explosion	– The possibility of containment failure due to in vessel steam explosion could be ignored based on international research (NUREG-1524 and NEA/CSNI/R(2014)15). – The In-Vessel Melt Retention (IVR) strategy to maintain the integrity of pressure vessel corresponding to ex-vessel steam explosion. – The analysis of typical accident sequences demonstrates that the reactor cavity flood injection system can achieve the safety function. – The PSA analysis demonstrates that the frequency of this accident condition is less than 1E-7/r.y with a high confidence level.
6	Severe accident condition of late containment failure due to basemat penetration	– IVR is realized with the dedicated depressurization system and reactor cavity flood injection system. Molten core concrete interaction (MCCI) leading to basemat penetration is avoided. – The PSA analysis demonstrates that the frequency of this accident condition is less than 1E-7/r.y with a high confidence level.
7	Severe accident condition of late containment failure due to long term loss of containment heat removal	– The independent containment heat removal system. – The analysis of typical accident sequences demonstrates that the containment temperature and pressure of severe accident conditions are within design limits. – The PSA analysis demonstrates that the frequency of this accident condition is less than 1E-7/r.y with a high confidence level.
8	Severe accident condition with containment bypass	– Design of secondary heat removal and primary depressurization to avoid Steam Generator Tube Rupture (SGTR). – Application of the efficient designed provisions and isolation monitoring measures for prevention of interfacing system Loss of Coolant Accident (LOCA). – Clear requirements have been established for opening the containment when the reactor is shut down, and for the rules of maintenance of safety important systems. Operator can isolate the relevant penetrations timely even when core damage occurs within the condition.

No.	Accident sequences or conditions	Main design provisions and demonstration
		– The PSA analysis demonstrates that the frequency of this accident condition is less than 1E-7/r.y with a high confidence level.
9	Significant fuel degradation in a storage fuel pool and uncontrolled releases	– Adopt water make-up to ensure long-term spent fuel cooling and radiation shielding to avoid fuel assembly uncovering. – Development of spent fuel pool (SFP) accident management guideline. – The PSA analysis demonstrates that the frequency of this accident condition is less than 1E-7/r.y with a high confidence level.

Practical elimination of Direct Containment Heating (DCH) which may lead to an early radioactive release:

Accident scenario

Reactor Pressure Vessel (RPV) may fail under severe accident if there is no available mitigation measure. In high-pressure scenario, HPME may happen when RPV fails. The corium could be ejected into containment and the dispersal of debris in containment could cause DCH which may threaten the integrity of the containment and led to an early radioactive release or a large radioactive release.

Enhanced DiD concept considered in design

In case of initiating events, diverse reactor protection systems are designed to ensure reactor trip. Safety systems for DBAs, including safety injection system, emergency feedwater system, and atmospheric steam dump system, can mitigate the accidents and maintain the reactor in a safe state.

If DBA combined safety system failure occurs, it becomes a DEC-A accident, and the DEC-A features ensure the reactor in the safe state. The DEC-A features mainly include manual feed-bleed operation, emergency boration system, secondary passive heat removal system, etc.

If the reactor trip fails, it becomes Anticipated Transient Without Scram (ATWS) which is a DEC-A event and it can be mitigated by emergency feedwater system, atmospheric steam dump system and emergency boration system.

The safety systems for DBA and DEC-A features are designed to prevent core damage. If these measures fail, core melting occurs and it becomes a severe accident. For DCH, severe accident dedicated valves are designed to switch from high pressure sequence to low pressure sequence, so that DCH can be avoided, and the containment integrity can be ensured.

Demonstration of practical elimination

Deterministic analysis: A comprehensive DBA list and DEC-A list are identified and analysed. The results show that consequences of all the DBA and DEC-A can meet acceptance criteria. The assessment of severe accident dedicated valves shows that the discharge capacity is sufficient to achieve a pressure under 2.0 MPa abs. to avoid the HPME and DCH.

Probabilistic analysis: According to the results of Level 2 PSA, the frequency of large release due to DCH is lower than 1E-07/ry.

According to the deterministic analysis and the probabilistic analysis, an early radioactive releases or large release caused by DCH is extremely unlikely with a high degree of confidence and is practically eliminated consequently.