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MDEP Design-Specific Common Position CP-HPR1000WG-01

HPR1000 WORKING GROUP

COMMON POSITION ADDRESSING FUKUSHIMA DAIICHI NPP ACCIDENT-RELATED ISSUES

Participation

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

Multinational Design Evaluation Programme

HPR1000 Working Group

COMMON POSITION ADDRESSING FUKUSHIMA DAIICHI NPP ACCIDENT-RELATED ISSUES

Context:

A severe accident involving several units took place in Japan at Fukushima Daiichi Nuclear Power Plant (NPP) in March 2011. The immediate cause of the accident was an earthquake followed by a tsunami coupled with inadequate provisions against the consequences of such events in the design. Opportunities to improve protection against a realistic design basis tsunami, such as taking into account analyses providing frequency/magnitude information on tsunamis in the region, were not taken.

As a consequence of the tsunami, safety equipment and the related safety functions were lost at the plant, leading to core damage in three out of the four units and subsequently to large radioactive releases (INES 7).

Several studies have already been performed to better understand the accident progression and detailed technical studies are still in progress in Japan and elsewhere. In the meantime, on-going studies on the behaviour of NPPs in very severe situations, similar to that experienced at Fukushima Daiichi NPP during and after the accident, seek to identify potential vulnerabilities in plant design and operation; to suggest reasonably practicable upgrades, or to recommend enhanced regulatory requirements and guidance to address such situations. Likewise, agencies around the world that are responsible for regulating the design, construction and operation of HPR1000 plants are engaged in similar activities.

Based on the MDEP Common Position CP-STC-02, issued by steering technical committee (STC) in September 2016, this common position is developed by the MDEP HPR1000 Working Group (HPR1000 WG) members, consisting of regulators from Argentina, People's Republic of China, South Africa and the United Kingdom. This report supplements CP-STC-02 and should be read in conjunction with that document. Since the regulatory reviews of the HPR1000 design have not yet been completed by all of the member countries, this paper identifies common preliminary approaches and regulatory expectations to address potential safety improvements for

HPR1000 plants, as related to lessons learned from the Fukushima Daiichi accident or Fukushima Daiichi-related issues. In seeking a common position, regulators will provide input to this paper to reflect their regulatory expectations regarding the HPR1000 design and how the design could be enhanced to address Fukushima Daiichi issues. This paper can be updated as appropriate to reflect regulatory conclusions when the relevant member countries have completed their regulatory reviews. This report is organized into six sections, namely, ***evolutionary improvements in safety, hazards, reliability of safety functions, accidents with core melt, spent fuel pools, and emergency preparedness in design***, in line with CP-STC-02.

CP-STC-02 also includes a "STATEMENT REGARDING THE VIENNA DECLARATION ON NUCLEAR SAFETY". HPR1000 MDEP working group members intend to consider a separate Technical Report/Common Position on the issue.

It should be noted that the HPR1000 design includes two specific options; Option 1 is currently under construction at Fangchenggang, and Option 2 is currently under construction at Fuqing. Designs being considered outside of China are variations on one of these two options. Differences between the two options that are relevant to this common position are described in the following sections. Different regulators within the HPR1000 WG are assessing different options and therefore the common positions outlined in this paper are high level principles that relate to both options.

Lessons Learned from the Fukushima Daiichi Accident:

The Fukushima Daiichi NPP accident demonstrates the importance of reinforcing the Defence-in-Depth (DiD) principle, correctly identifying external hazards including their magnitude and credible combinations, and design provisions to protect the installation. This should be reflected in licensing requirements and detailed in the installation safety case. The accident also reinforced the need to have a comprehensive safety analysis using both deterministic and probabilistic methods in a complementary manner to provide coverage of all safety factors. In the safety assessment, specific consideration needs to be given to both multi-unit sites and to address long-term measures protecting the plant.

One has to bear in mind that the specific nature of individual events and challenges can never be completely taken into account in design and operation of a nuclear power plant (or indeed any other industrial facility). However, a robust design based on DiD with reliance on passive design principles, sizeable safety margins and diverse means for delivering critical safety functions as well as flexible, symptom-based operator response plans will help to address accidents beyond the current design basis (i.e. latest licensing basis).

The design, construction, manufacturing and installation of Structures, Systems and Components (SSCs) should rely on appropriate engineering measures and sufficient margin beyond the design criteria required for a design basis accident to avoid cliff edge effects[1]. Operation, including examination, maintenance inspection and testing, must not undermine these engineered measures and margins. Such an approach will help to ensure an appropriate response, should a beyond design basis accident occur. Provisions aiming at facilitating the repair/recovery of impaired safety functions should also be considered.

EVOLUTIONARY IMPROVEMENTS IN SAFETY

I. The Fukushima Daiichi NPP 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, management of severe accident situations…)

Design Features

As compared to most current operating reactors, the HPR1000 applies the DiD concept and incorporates design features to address the learning obtained from the Fukushima Daiichi accident. The reactor has safety systems using both active and passive features, which are designed with the capability to cool the core, containment, and spent fuel pool for 72 hours without the need for off-site support. Loss of Ultimate Heat Sink (LUHS) and Station Blackout (SBO) are also considered in the design. In addition, there are systems to provide for severe accident management and protection against external events such as earthquakes and flooding.

In order to enhance the emergency response capability, as a post-Fukushima Daiichi resilience measure, mobile diesel generators and mobile pumps are also included in the HPR1000 design. The mobile diesel generator provides power to limited safety functions upon extended total loss of alternating current (AC) power (i.e. loss of off-site power + loss of Emergency Diesel Generators (EDGs) + loss of SBO generators), and the mobile pump provides water to the primary circuit, the secondary circuit and the spent fuel pool. The HPR1000 design has considered the need for mobile equipment to be protected from potential common cause failures caused by internal and external hazards.

Common Position

i. The regulators of the HPR1000WG expect that the independence between levels of DiD is achieved to the extent that is reasonably practicable.

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[1] Cliff edge effects are the effects of those hazards for which a minimal increase in the hazard's magnitude can have a much higher impact. For example, the external flooding hazard may have little to no impact to a nuclear power plant below a prescribed flood level. However, a small increase beyond that prescribed flooding level could impact many of the nuclear power plant's functions and lead to a severe accident.

ii. The regulators of the HPR1000WG expect that equipment for severe accident response is designed with appropriate integrity, availability and robustness to ensure resilience to all relevant external hazards.

iii. Mobile pumps and power supplies play a positive role in accident mitigation. The regulators of the HPR1000WG expect that measures will be taken to protect mobile equipment from common cause failures. However, considering that these are supplementary measures which are not part of the generic design, different member countries may have different requirements and expectations for ensuring the availability of mobile equipment in emergency situations.

HAZARDS

II. While acknowledging that external hazards are primarily site dependent and that the adequacy of the design has to be reviewed on a case-by-case basis considering the site characteristics, it is important that the safety systems of reactors are designed and protected to tolerate external hazards and internal events, mostly by applying adequate physical separation and protection against dynamic loads.

Design Features

The accident at Fukushima Daiichi has reinforced the need to undertake a comprehensive analysis of external hazards, including consideration of relevant combinations of events. This should include analysis that addresses how these hazards could impact areas of the proposed NPP where significant amounts of radioactive material are expected to be present.

The designers claim that the HPR1000 design considers external events and defines a conservative design basis with appropriate margin (e.g. seismic events, external flooding, extreme temperature, extreme wind, tornado, etc.), as well as the extreme scenario resulting from beyond design basis external events.

a) Seismic Design

For the HPR1000 design, the peak ground acceleration adopts 0.3g in the horizontal direction and 0.2g in the vertical direction for Safety Shutdown Earthquake (SSE) (IAEA SL-2 seismic design basis). The safety-related structures are designed to defend against SSE using site, national and/or international design response spectra. Safety classified SSCs including mechanical and electrical equipment are designed using resultant floor response spectra to withstand SSE.

b) External Flood Design

For the HPR1000 design, a risk assessment of flooding has been undertaken, and the plant layout has been designed to protect against or eliminate the possibility of flooding inundation.. Design Basis Flood (DBF) has been used to determine the height of the plant/site and considers the influence of the coastal flooding hazard including tsunami. The NPP drainage design protects the site from accumulated ponding with analysis undertaken to check that the capacity of the drainage system in the plant area is sufficient.

Important equipment such as EDG is located at higher elevations. The design basis flood level should be used to superimpose the 1 in 1000 years' precipitation hazard to assess the depth of water entering the plant. According to the assessment results, flood defence measures both at ground-level and underground are adopted. Generally, permanent waterproof sealing should be adopted. For cases where permanent waterproof sealing is not possible, temporary waterproof flooding measures can be adopted after evaluation.

c) Extreme wind and extreme temperature

The HPR1000 has been designed against a range of extreme environmental conditions. Extreme wind speed is determined by the relative low return period gust wind speed. For example, 64.3m/s and 68.4m/s are set as the design basis of the nuclear island buildings at the Fangchenggang (Option 1) and Fuqing (Option 2) sites respectively. Extreme high/low temperatures are determined by the statistical value of the relative low return period. For example, 38.5°C/-1.8 °C and 42℃/-4.4℃ are set as design basis at the Fangchenggang (Option 1) and Fuqing (Option 2) sites respectively.

Common Position

iv. The regulators of the HPR1000WG expect all relevant external hazards to be systematically identified and characterised, screened using defined criteria and analysis of those screened-in hazards to enable the selection of design basis in accordance with national regulations and guidance. For those external hazards characterised by a hazard curve (i.e. typically natural hazards), the analysis could extend the hazard curve to an appropriate, low frequency to support beyond design basis, probabilistic and severe accident analyses. Credible combinations should be defined as additional design basis events.

v. The plant will be assessed against these hazards in accordance with established assessment methodologies and criteria, including consideration of beyond design basis hazards and cliff-edge effects to demonstrate the robustness of the plant and availability of margin. The hazard assessment should consider combined and consequential hazards that may increase the plant challenge.

vi. External events could exceed the assumptions used in the design and licensing of a plant, as demonstrated by the events at Fukushima Daiichi. International practice is to establish design input parameters by both deterministic and probabilistic methods, but to proceed with the design in a deterministic manner (e.g. selection of a design basis value from the hazard curve). There is a "beyond design basis" component to consider for those hazards which can be evaluated to very low return periods (albeit with increasing levels of uncertainty), well below the design basis frequency. External events beyond those accounted for in the design basis are unlikely to occur, but could present challenges to NPPs should they transpire. In order to address these challenges, licensees need to enhance their ability to cope with conditions resulting from external events exceeding those considered for design.

vii. It is generally accepted that there are two aspects of beyond design basis analysis. Firstly, the design is analysed for cliff-edge effects just beyond the design basis and to identify the margin to the point(s) where safety functions are no longer achieved, as a function of increasing hazard severity. Second is consideration of extreme events that could severely challenge plant safety functions across the site to understand how SSCs required for nuclear safety respond, the failure modes that can occur and how the ability of SSCs and operators to deliver safety functions degrades.

viii. Design basis definitions differ between member countries. The design basis external events for the HPR1000 design have been derived according to extreme conditions at the candidate sites. These particular design basis values should be compared with the specific expectations in different countries to assess the adequacy of the HPR1000 design for specific sites.

RELIABILITY OF SAFETY FUNCTIONS

III. It is observed to date, from those regulators who have made safety findings in the review of their design applications, that since most safety functions depend on electric power that the reactors could suffer cliff-edge effects after a limited period of time following infrequent and severe external hazards, particularly those involving a common-cause failure that results in long-term loss of power and cooling. Those regulators acknowledge that safety improvements have been proposed to address those situations. Continued discussions, detailed design, and analysis will be needed to make final approvals of these improvements.

Design Features

The key safety functions that should be protected are reactivity control, reactor cooling and cooling of spent fuel in the spent fuel pool and confinement of radioactive material. Ensuring adequate protection, through appropriate design, plant layout, electrical and physical separation and segregation, electrical isolation, etc. of the power supplies against infrequent and severe external hazards is a lesson from the Fukushima Daiichi NPP accident.

The designers claim that in order to achieve the safety functions for HPR1000 the principle of DiD is applied, and SSCs important to safety will be capable of withstanding identified initiating events with sufficient robustness which is ensured by redundancy, diversity, and independence. The HPR1000 design uses active and passive design features to achieve robustness and reliability of safety functions. Different trains of safety functions are physically separated where possible, as are SSCs among the enhanced DiD levels. It is noted that the details of these systems differ between Options 1 and 2 of the HPR1000 design and each member country will assess the design against relevant national requirements and expectations.

At DiD Level 3 the HPR1000 design includes at least two active safety systems to protect against design basis accidents (DBA). These include medium head safety injection, low head safety injection, and auxiliary feed water system. These are supplemented by passive components such as accumulators.

The HPR1000 has additional DiD measures which provide diverse ways to deliver safety functions should the DBA safety measures not be available. For Option 1, the safety measures include secondary passive heat removal system (SPHRS), SBO diesel generators and extra cooling system (ECS). For Option 2, the safety measures include SPHRS, turbine-driven auxiliary feedwater system, air-cooled chilled water system and the passive containment cooling system (PCS).

Ensuring the energy supply and heat removal is an important lesson learned from the Fukushima Daiichi Accident, the HPR1000 designers claim that the following design measures are considered correspondingly.

For both Option 1 and Option 2, the power is supplied by two independent external sources during normal operation. EDG and SBO DG are provided to increase the reliability of power supplies, and mobile DG and severe accident batteries are provided to ensure power supplies to safety systems are maintained under extreme conditions. The EDG and SBO DG are diverse and separated from others to avoid the potential common cause failure, and the capacities of these diesel generators are long enough to withstand a long term of loss of offsite power event.

For both Option 1 and Option 2 the cooling chains for accidents are safety classified and redundant trains are incorporated for residual heat removal; that is, a diversified Extra Cooling System for option 1, and the air-cooled chilled water system and the PCS for option 2.

Common Position

ix. A robust and independent DiD concept should be established to ensure the reliability of safety functions.

x. Quality management arrangements covering processes throughout the lifecycle including design, manufacture, supply, installation, operation and maintenance of safety related SSCs in the design should be established.

xi. Systems performing the same safety function(s) should be designed with appropriate redundancy and diversity to ensure independence and reliability. Any exceptions to this should be justified.

xii. Redundant safety systems should be designed with adequate separation and segregation to avoid propagation of failures between systems.

xiii. LUHS and SBO should be considered in order to ensure continued delivery safety functions for extended periods. Reliability of associated support systems (such as heating, ventilation, air conditioning and water sources) should also be considered.

xiv. Probabilistic safety targets (CDF) should be established in the design to determine adequate reliability of safety functions.

xv. Different member countries may have different requirements and expectations; a typical example is that, anticipated transient without scram (ATWS) is a design basis accident in the UK but a beyond design basis accident in China.

ACCIDENTS WITH CORE MELT

IV. The regulators recognise that the generic design includes measures to mitigate the consequences of severe accidents. The design benefits from reinforced measures to prevent accident situations such as high pressure core melt, global hydrogen detonations and in-vessel and ex-vessel steam explosions, which would lead to large or early releases. Nevertheless, as some severe accident management systems rely on AC and direct current (DC) power, at least after a few hours, regulators recognise the need to reinforce existing or proposed provisions to increase the time available before cliff-edge effect. Due consideration to those cliff edge effects is to be given while tailoring long term loss of electrical power mitigation strategies.

Design Features

The designers claim that safety features have been incorporated to mitigate the potential for severe accidents in the design of HPR1000. These safety features are designed to have adequate independence from the other plant safety provisions, and also to be adequately protected against internal and external hazards. The anticipated ambient environmental conditions have been calculated and the necessary equipment and instruments have been qualified to ensure that they could perform their functions.

The HPR1000 design includes two trains of severe accident dedicated valves (SADVs) designed to depressurise the primary circuit during a hypothetical severe accident event. The SADVs are designed to reduce pressure below that in which a high pressure melt ejection can occur, thus avoiding direct containment heating.

The layout of the containment building has been designed with the principle of promoting natural circulation and mixing, in order to reduce the risk of local build-up of combustible gases. This principle has also been applied to determining the location of passive autocatalytic recombiners for the containment combustible gas control system design scheme.

The In-Vessel Melt Retention external reactor vessel cooling strategy (IVMR-ERVC) has been incorporated in the design of the HPR1000 to avoid Molten Core Concrete Interaction (MCCI). The reactor cavity injection system based on passive and/or active injection (depending on Option 1 or Option 2) has been designed to remove corium decay heat.

Containment Heat Removal Systems have been designed to actively (Option 1) or passively (Option 2) remove heat independent of the HPR1000 designs. The HPR1000 containment design includes an additional containment filtration and exhaust system for when the dedicated severe accident mitigation systems have failed, which is used to prevent structural failure of the containment.

The HPR1000 is also designed with a dedicated severe accident Instrumentation and Control (I&C) system. These safety features are designed with DC batteries, which provide differing mission times dependent on the philosophy (12-24 hr for Option 1, and 72 hr for Option 2).

Common Position

xvi. Event sequences and conditions such as direct containment heating, steam explosions, large hydrogen detonation, and basemat melt-through or containment excessive pressure, should be considered in the design.

xvii. The design features for the above event sequences and conditions should be sufficiently reliable. The selection of "event sequences and conditions" should be based on engineering judgement, deterministic assessments and probabilistic assessments.

xviii. For severe accidents, maintaining the containment integrity is the main objective. This also implies that the cooling and stabilization of the molten fuel, and the removal of heat from the containment, need to be achieved in the long term

xix. Reasonable channels for circulation and diffusion should be considered in design, to prevent large volumes of local hydrogen accumulation. Layout principles should be defined for combustible gas control equipment, to control the concentration of combustible gas in containment, and supplemented by adequate assessment to demonstrate its adequacy.

xx. In accordance with the DiD approach, these safety features should be independent as far as reasonably practicable from the other plant safety provisions, and they should also be designed to be adequately protected against internal and external hazards.

xxi. The necessary equipment and instruments should be capable of performing their safety functions in the severe accident environmental conditions.

xxii. Severe accident management guidelines should be developed to inform the crisis team to take appropriate actions.

SPENT FUEL POOLS

V. The Fukushima Daiichi NPP accident also highlighted the need to fully consider safety in the design of spent fuel pools. This implies that single initiating events, multiple failure events, internal hazards as well as external hazards should be properly addressed. In particular, the cooling and structural integrity of the spent fuel pools needs to be ensured with adequate margin in case of external hazards.

Design Features

During normal operations and some design basis accidents, the Fuel Pool Cooling and Treatment System (FPCTS) is designed to remove heat from the Spent Fuel Pool (SFP). The FPCTS has been designed with the principle of redundancy and is classified as a safety related system. The heat exchangers are cooled by the Component Cooling Water System (CCWS). For option 1, an Extra Cooling System is provided which is actuated upon loss of the CCWS.

The SFP is designed to the highest seismic categorisation, and the designer claims that pond draining as a result of pond liner leakage will be slow enough to be compensated by makeup water sources. In addition, the HPR1000 SFP has been designed to avoid the likelihood of unacceptable drainage events through major pipework by placing connection points above safe water levels, and fitting those pipes with siphon breakers. During and following an accident scenario, the SFP is designed to retain sufficient water inventory to ensure the covering of the fuel stored in the SFP such that no immediate action is required.

The HPR1000 SFP is designed so that it can be provided with makeup water upon total loss of cooling chain or pond drainage faults. Makeup water measures considered include the demineralized water system, fire protection system and cask loading pit. For Option 1, the

SPHRS tank is designed to be manually aligned with the FPCTS to passively provide makeup water when necessary. In addition, the emergency mobile water injection can be aligned with the FPCTS to provide makeup water.

The HPR1000 has safety-related SFP level measurement instrumentation. The data can be displayed on the screens in the main control room (MCR).

<u>Common Position</u>

xxiii. The SFP should be designed to maintain the coverage of stored fuel in the event of internal and external hazards.

xxiv. The SFP should be designed with adequate cooling capability to ensure the safe storage of spent fuel in normal operations and design basis accident conditions.

xxv. The design should have the capability to provide make up water to the SFP.

xxvi. SFP should have reliable water level indication, the specific requirements of which (for example the depth of level measurement) should be considered on a country by country basis.

EMERGENCY PREPAREDNESS IN DESIGN

VI. The accident at the Fukushima Daiichi NPP highlighted how complicated emergency response can be if multiple reactors on the same site are affected at the same time and electrical power is unavailable. For such large accident scenarios there is a need to ensure that all reasonably practical measures are in place to mitigate accident consequences, and to ensure that the design of the installation will minimize any radiological consequences. Additional reviews should consider the need for additional emergency staff and the power requirements of emergency response equipment.

<u>Design Features</u>

While many aspects of emergency preparedness in design will be country and site specific, the HPR10000 designers have considered features to support emergency management response. Emergency response facilities are designed to coordinate and manage site actions under normal and emergency conditions, such as the MCR, Remote Shutdown Station (RSS), and on-site Emergency Control Centre (ECC).

The MCR Air Conditioning System maintains the environment (including temperature, humidity, concentration of radioactive materials) of the MCR and associated rooms in normal operating condition and accident condition. The system has two iodine filtration trains with a fresh air and return air filtering function that consist of pre-filters, HEPA filters, and iodine absorbers. The on-site ECC shares the same dose acceptance criteria as MCR, which considers the protection measures against external hazards and radioactive releases.

Systems are provided in the on-site ECC for collation, storage and display of data for multiple units. The communication channels and distribution points of communication systems are set in the MCR, RSS and ECC and other important locations at the plant to meet the requirements for emergency response.

Radiation monitoring equipment is incorporated, and equipment locations are distributed to be reasonable and representative for the HPR1000. A severe accident I&C system is provided to monitor important plant parameters during and following a beyond design basis accident.

Common Position

xxvii. An on-site Emergency Control Centre (ECC), separate from both the Main Control Room (MCR) and the Remote Shutdown Station (RSS), should be provided from which an emergency response can be directed at the NPP.

xxviii. The importance of the accessibility and habitability of MCR and on-site ECC under accident conditions in the HPR1000 design is fully recognized by the regulators. The regulators expect that accessibility and habitability assessment should be undertaken for both DBAs and also beyond design basis accidents.

xxix. The MCR and the ECC should be sufficiently protected against internal and external hazards to ensure the plant can be taken to a safe state and remain there.

xxx. Suitably reliable I&C monitoring and emergency communication equipment should be provided in the reactor building and SFPs to survive beyond design basis accidents and enable continued monitoring and communication of important plant parameters. Information about these important plant parameters and radiological conditions should be provided to the relevant emergency facilities. Each unit should be provided with means of communication with important locations at the plant as appropriate, and with on-site and off-site emergency organisations. The robustness of necessary off-site communications for severe accidents involving widespread disruption may require provision of equipment with satellite communications capability.

xxxi. Access to appropriate locations to implement mobile means to recover safety functions should be possible when necessary. Access and connection points should be clearly identified.

xxxii. Events that may simultaneously affect several units should be explicitly considered in the emergency preparedness on multi-unit sites, if applicable.

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ABBREVIATIONS

AC	Alternating Current
ATWS	Anticipated Transient Without Scram
CCWS	Component Cooling Water System
DBA	Design Basis Accident
DBF	Design Basis Flood
DC	Direct Current
DG	Diesel Generator
DiD	Defence-in-Depth
ECC	Emergency Control Centre
ECS	Extra Cooling System
EDG	Emergency Diesel Generator
FPCTS	Fuel Pool Cooling and Treatment System
HPR1000WG	MDEP HPR1000 Working Group
LUHS	Loss of Ultimate Heat Sink
MCCI	Molten Core Concrete Interaction
MCR	Main Control Room
MDEP	Multinational Design Evaluation Programme
NPP	Nuclear Power Plant
PMP	Probable Maximum Precipitation
RSS	Remote Shutdown Station
SADV	Severe Accident Dedicated Valves

SBO	Station Black Out
SFP	Spent Fuel Pool
SPHRS	Secondary Passive Heat Removal System
SSCs	Structures, Systems and Components
SSE	Safety Shutdown Earthquake
STC	Steering Technical Committee