Multinational Design Evaluation Programme
Design-Specific Common Position
CP-VVERWG-03

Related to: VVER Working Group's activities

COMMON POSITION ON REACTOR PRESSURE VESSEL AND PRIMARY COMPONENTS RELIABILITY FOR AES-2006 DESIGNS

Participation

Regulators and TSOs involved in the MDEP working group discussions:	AERB, HAEA, NNSA, SEC NRS (on behalf of Rostechnadzor), STUK and NDK
Regulators which support the present common position:	AERB, HAEA, NNSA, Rostechnadzor, STUK and NDK
Regulators with no objection:	
Regulators which disagree:	

Purpose of the common position

The reactor pressure vessel (including vessel, reactor head, internals and bolt connections) and primary components (main coolant pipelines, reactor coolant pump, pressuriser, pressuriser safety valve, pressurised surge line, steam generator primary side) are playing a significant role for the safe operation of NPP. The aim of this paper is to represent the common position developed by the participating regulators to ensure consistency in the assessment of these components of the NPP design. This will also enable appropriate representation of work carried out by the applicants supporting the safety justification of VVER design.

Introduction and background

The MDEP VVER Working Group (VVERWG) members, referred to herein as "regulators", consist of members from the Russian Federation (Rostechnadzor), Finland (STUK), India (AERB), Turkey (NDK), China (NNSA) and Hungary (HAEA).

It is important to note that not all of these countries have yet completed the regulatory review of their VVER applications. Thus this paper identifies common preliminary approaches to address potential safety improvements for VVER plants, as well as common general expectations for new nuclear power plants.

These common preliminary approaches are based on their national regulatory requirements and those safety assessments of design documentation that have been completed to date. Consequently, some technical details presented in VVER design features have not been evaluated yet by some member countries and they may in the future differ from those presented. When these are completed, the regulators will update this paper to reflect their safety conclusions regarding the VVER designs.

The common preliminary approaches are organised into seven sections, namely:

I. Application of leak before break (LBB) concept,
II. Manufacturing of primary components,
III. Radiation embrittlement of RPV regarding use of new base materials including influence of Ni and Mn,
IV. Pre- and in-service inspection of primary components (including hydrostatic pressure test),
V. Design basis of primary components (loadings and their combinations),
VI. Cladding of primary circuit,
VII. Protection against overpressure of primary circuit.

Common position

I. Application of leak before break concept

Context

The application of leak before break concept is a common approach used in new VVER designs to justify a reduction of amount of pipe whip restraints. The group has formulated three LBB fundamentals in its common position statement.

Discussion

The following aspects of leak before break (LBB) concept of primary components were discussed in the Technical Report on Regulatory approaches and oversight practices related to reactor pressure vessel and primary components:

- Country's regulatory requirements related to application of LBB concept;
- Methodology of the LBB concept;

- LBB analysis procedures;
- List of equipment and pipelines to which LBB concept may be applied;
- Restrictions for application of the LBB concept;
- Requirements for leak detection system.

Discussion of different countries approaches related to application of LBB concept showed the following commonalities identified:

- Finnish, Russian, Turkish and Chinese requirements for LBB are based mainly on US NRC standard review plan and German break preclusion (BP) concept. Indian requirements of LBB are addressed in AERB/NPP-LWR/SC/D.
- If LBB is applied, pipe whip restraints are not necessary. Shielding shall be implemented to protect against the maximum jet loading that could impinge from postulated through-wall crack. These requirements are quite similar for all member countries.

The main differences identified during discussion are design basic loads for pressure transient differential (blowdown) effects of a double-ended guillotine break (DEGB):

In Hungary, Russia and China the dynamic effects of DEGB are allowed not to be considered in the design, if LBB concept is applied;

In Finland the design basis are DEGB of a pipe connected to MCL or RPV limited by optional whip restraints and having the most adverse pressure impact. In addition, blowdown effects on some primary circuit items still need consideration as a design extension condition (DEC) with realistic assumptions;

In India, the transient pressure differential (blowdown) effects on reactor pressure vessel internals (RPVI) and certain safety related primary circuit items (measuring instruments etc.) shall be analysed for DEGB loads. The break size for LBB pipelines should be limited to complete DEGB of the largest connected pipeline where LBB criteria are not met.

Common position

The application of leak before break concept is a common approach used in new VVER designs to justify a reduction of amount of pipe whip restraints. The group´s common position on LBB is:

- Application of LBB concept is a recognised approach in ensuring safety of reactor installation in all countries, as it ensures a low probability of double-ended break of large diameter pipes.
- Application of LBB concept enables to simplify a layout of primary circuit of reactor installation and non-destructive testing of pipelines during NPP operation.
- Application of LBB concept allows to optimise a number of whip restraints in design basis of NPP.

III. Radiation embrittlement of RPV regarding use of new base materials including influence of Ni and Mn

Context

Radiation embrittlement of RPV core region is one of the main phenomena which influence to reactor pressure vessel ageing and limits its lifetime. The radiation embrittlement depends on the content of Ni and Mn in base and weld metals and this effect is considered in RPV integrity assessment for new VVER designs. The group has formulated three VVER-1200 specific radiation embrittlement fundamentals in its common position statement.

Discussion

The basic reason of RPV mechanical properties degradation is the neutron irradiation, resulting in hardening and embrittlement of the steel of which the RPV is made. The prediction of radiation embrittlement is performed usually in accordance with relevant regulatory documents that are based on a large amount of information from surveillance data and test reactor irradiation results, see comparative summary Table 1. The approach for the RPV steel irradiation embrittlement analysis is similar in all countries – using the steel chemical composition information, surveillance data, etc.

Table 1. Comparative summary for VVER RPV integrity assessment

Country	Regulatory documents	Brittle fracture analysis	Radiation shift factors	Surveillance results for service life assessment
Finland	YVL E.4 Chapter 6 (ASME XI, ASTM E 1921)	ASME K_{IC} reference + Master curve	Fluence, steel alloying elements, impurities	Yes
Russia	RD EO 1.1.2.09.0789-2012 (VVER-1000) RD EO 1.1.2.99.0920-2014 (VVER-1200 design stage)	VVER reference curve + Unified curve	Fluence, Ni, Mn	Yes
Hungary	NSC-3a	VVER reference curve + Master curve	Fluence, Ni, Mn	Yes
Turkey	IAEA standards PNAE G-7-002-86 PNAE G-7-008-89	VVER reference curve + ΔT_F	A_F max	No information available
China	PNAE G-7-002-86	VVER reference curve + ΔT_F	A_F max	Yes
India	Indian IAEA ASME	ASME K_{1C} reference curve + Master curve	Fluence, Cu, Ni	Yes

Discussion of different countries approaches related to VVER-1000/1200 radiation embrittlement assessment revealed that in all countries the brittle fracture analysis of RPV is performed by methods of fracture mechanics:

- For cracks postulated in potential fracture points, margins with regard to their sudden growth,
- Comparing the stress intensity factor K_1 with the material's fracture toughness K_{1C} (K_{JC}),
- Elastoplastic methods in plastic zone.

It is generally accepted that the presence of nickel in RPV steels increases its sensitivity to radiation embrittlement even at low deleterious impurity (Cu and P) concentrations. The potential effect of manganese and nickel on radiation embrittlement of RPV materials was presented in IAEA-TECDOC-1441 "Effects of Nickel on Irradiation Embrittlement of Light Water Reactor Pressure Vessel Steels". It was demonstrated that high manganese content leads to much greater irradiation-induced embrittlement than low manganese content for both VVER and PWR materials.

Requirement to probability analysis of RPV failure is obligatory in Russian Federation. In Finland the construction plan shall include an analysis of brittle fracture probability, if the risk of brittle fracture cannot be concluded as negligible according to deterministic safety analysis.

Microstructural investigations, including transmission electron microscopy and atom probe tomography, have shown, for both VVER and PWR materials, that nickel associates with copper in the irradiation-induced copper-enriched precipitates, and that manganese and silicon are similarly associated.

The influence of Ni and Mn on VVER RPV radiation embrittlement could be substantial in case of Ni content in welds more than 1.3%. However, in the modern VVER-1000 and VVER-1200 RPVs the Ni content in base metal and welds is below 1.3%.

Common position

Radiation embrittlement of RPV core region is one of the main phenomena which influence to reactor pressure vessel ageing and limits its lifetime. The group´s common position on radiation embrittlement in new VVER designs is:

- The influence of Ni and Mn on VVER RPV radiation embrittlement could be substantial in case of high Ni content in welds. In the modern VVER-1000 and VVER-1200 RPVs the Ni content in base metal and welds is below 1.3% which indicates an enhancement lifetime forecast compared to VVER-1000 design with high Ni content in welds;
- The radiation embrittlement of RPV is controlled by surveillance programme in VVER-1000 and VVER-1200. Surveillance specimen testing results are to be taken into account in evaluation of RPV radiation embrittlement in periodic safety assessment;
- The brittle fracture analysis of RPV is performed by fracture mechanics methods, which provide the reliable assessment for cracks postulated in potential fracture points, margins with regard to their sudden growth. Elastoplastic methods of fracture mechanics are used in plastic zones. Comparison of stress intensity factor K_1 with the material's fracture toughness K_{1C} (K_{JC}) is performed.

IV. Pre- and in-service inspection of primary components (including hydrostatic pressure test)

Context

Pre- and in-service inspection of primary components (including hydrostatic pressure test) is an important factor to provide 60 years lifetime for new VVER designs. The group formulated four PSI/ISI fundamentals in its common position statement.

Discussion

The following aspects related to pre- and in-service inspection of primary components were considered:

- Regulatory documents of different countries that established requirements related to pre- and in-service inspection of reactor pressure vessel and primary components and hydrostatic pressure test.
- Requirement for Quality control of welds and claddings (if necessary).
- Requirements for pre- and in-service inspection procedures.
- Methods of examination and testing during pre- and in-service inspection.
- Requirement for Inspection programs and their content.
- Requirements for scope of inspection for reactor pressure vessel and primary circuit component.
- Requirements for Intervals for in-service inspection.
- Requirements for pre- and in-service inspection acceptance criteria.

- Requirements for hydrostatic pressure test parameters (pressure, temperature) and intervals of in-service pressure test for reactor pressure vessel and primary components.
- Requirements for Qualification of NDT inspection system.
- Requirements for risk-informed in-service inspection.
- Requirements for surveillance programme.
- Requirements for Reporting documentation.

Discussion of different countries approaches related to pre- and in-service inspection of primary components showed the following commonalities identified:

- The scope of inspection for primary circuit components is similar (not much difference).
- Intervals for in-service non-destructive inspection and hydrostatic pressure test of primary circuit components of VVER units vary from 3 to 10 years.
- The values of hydrostatic test pressure are approximately the same for all countries.
- The quality assessment regulations (acceptance criteria) to assess the results of inspection are similar for all countries nevertheless there is some difference.

Common position

Pre- and in-service inspection of primary components (including hydrostatic pressure test) is an important factor to provide 60 year lifetime for new VVER designs. The group´s common position on radiation embrittlement in new VVER designs is:

- Scope and intervals of pre- and in-service inspection should be sufficient to identification of possible defects in the metal of reactor pressure vessel and primary components during a component's lifetime of 60 years for new VVER designs.
- Periodic hydrostatic pressure tests of reactor pressure vessel and primary components are carried out at pressure and temperature which should be sufficient to demonstrate structural integrity of component during new VVER design lifetime of 60 years. Values of pressure and temperature for hydrostatic pressure tests are approximately the same for all countries.
- Acceptance criteria for defects identified during pre- and in-service inspection of reactor pressure vessel and primary components are different but they are sufficient to demonstrate structural integrity of component during 60 years of NPP operation.
- Design phase structural design location and geometry of welds should ensure that accessibility has been reserved for inspections and that it is technically feasible.

V. Design basis of primary components (loadings and their combinations)

Context

Loadings and their combinations are an important part in defining the design basis. All relevant loadings and their combinations should be taken into account during safety assessment of NPP unit. The group formulated three design basis loading fundamentals in its common position statement.

Discussion

The following aspects related to design basis of primary components (loadings and their combinations) were considered:

- Regulatory documents of different countries that established requirements related to design basis of primary components (loadings and their combinations).
- Loading combinations for different service conditions (normal and abnormal operation).
- Requirements for combination of dynamic and static loadings.
- Requirements on strength analysis procedure.
- Requirements for loadings when LBB concept is applied.

Discussion of different countries approaches related to design basis of primary components (loadings and their combinations) showed the following commonalities identified:

- All considered regulatory documents require to evaluate primary components integrity under the action of all possible loadings (mechanical, temperature, irradiation).
- All regulatory documents require evaluating of earthquake impact on components and aircraft crash loadings.
- There are no requirements for use of numerical strength analysis methods (FEM, for instance) in any considered regulatory documents.

Common position

Loadings and their combinations are an important part in defining the design basis. All relevant loadings and their combinations should be taken into account during safety assessment of NPP unit. The group´s common position on design basis loadings in new VVER designs is:

- For new VVER designs all relevant loadings should be taken into account.
- The level of seismic loadings varies for different NPP sites. However, there are new plant specific requirements that increase the minimum level of seismic loadings for new VVER units which minimise the difference between loadings for different units.
- Type of aircraft for airplane crash analysis should be defined in design basis individually for new VVER designs according to national regulations.

VII. Protection against overpressure of primary circuit

Context

Protection against overpressure of primary circuit is an important part in safety assessment of NPP with new VVER designs. The group formulated two design basis loading fundamentals in its common position statement.

Discussion

The following aspects related to protection against overpressure of primary circuit were considered:

- Regulatory documents of different countries that established requirements related to protection against overpressure of primary circuit.
- General requirements on overpressure protection.
- Requirements for pressure relief devices:
  - requirements on capacity and number of pressure relief devices;
  - requirements on actuation/deactuation pressure value of pressure relief device;
  - requirements on design, fabrication, mounting and service of pressure relief devices;
  - requirements on sites (positions) of pressure relief device installation;
  - requirements on inspections, testing and checking operability of pressure relief devices.

Discussion of different countries approaches related to protection against overpressure of primary circuit showed the following commonalities identified:

- NPP primary circuit shall be protected from excessive pressurisation, which is primarily realised by safety relief valves.
- Number of relief valves, set points and exhaust capacities are specified by a system designer.
- Maintenance and testing programs are drawn up for relief valves and followed during operation in order to ensure their operability if actuation is required.

Common position

Protection against overpressure of primary circuit is an important part in safety assessment of NPP with new VVER designs. The group´s common position on protection against primary circuit overpressure is:

- Number and technical parameters of pressure relief devices, set points and exhaust capacities are specific for new VVER designs and determined by designer of reactor.
- Differences in requirements to intervals of inspections, testing and checking operability of pressure relief devices do not influence on protection against overpressure of primary circuit and provide safe operation of primary components of new VVERs.

List of acronyms and abbreviations

AERB	Nuclear Regulatory Body in India
DEC	Design Extension Condition
HAEA	Nuclear Regulatory Body in Hungary
NNSA	Nuclear Regulatory Body in China
NPP	Nuclear Power Plant
Rostechnadzor	Nuclear Regulatory Body in Russian Federation
SEC NRS	Scientific and Engineering Centre for Nuclear and Radiation Safety
STUK	Nuclear Regulatory Body in Finland
NDK	Nuclear Regulatory Body in Turkey
VVER	Water Moderated, Water Cooled Power Reactor

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