Date: 29 August 2017
Validity: **until next update or archiving**
Version 1

MDEP Design Specific Common Position CP-APR1400-02

Related to: APR1400 Working Group activities

COMMON POSITIONS ON THE APR1400 POST LOSS OF COOLANT ACCIDENT (LOCA) STRAINER PERFORMANCE AND DEBRIS IN-VESSEL DOWNSTREAM EFFECTS

Participation

Regulators involved in the MDEP working group discussions:	KINS (South Korea), FANR (United Arab Emirates) and US NRC (United States)
Regulators which support the present common position:	KINS (South Korea), FANR (United Arab Emirates) and US NRC (United States)
Regulators with no objection:	-
Regulators which disagree:	-
Compatible with existing IAEA related documents:	Yes

Multinational Design Evaluation Program

APR1400 Working Group

APR1400 Accidents and Transients Technical Experts Subgroup

COMMON POSITIONS ON THE APR1400 POST LOSS OF COOLANT ACCIDENT (LOCA) STRAINER PERFORMANCE AND DEBRIS IN-VESSEL DOWNSTREAM EFFECTS

Purpose

To identify common positions among the regulators reviewing the APR1400 accidents and transients in order to:

1. Promote understanding of each country's regulatory decisions and basis for the decisions,
2. Enhance communication among the members and with external stakeholders,
3. Identify areas where harmonization and convergence of regulations, standards, and guidance can be achieved or improved, and
4. Supports standardization of new reactor designs.
5. Ensure new plant designs to have minimum risk of experiencing sump strainer blockage and maintain sufficient long term core cooling.

Discussion

The MDEP APR1400 Technical Expert Subgroup on Accidents and Transients has chosen to prepare a common position on post loss of coolant accident (LOCA) emergency core cooling system (ECCS) strainer performance and debris in-vessel downstream effects. For in-vessel downstream effects, this common position addresses specifically the reactor core coolant flow rate reduction caused by potential debris bed formation at the core inlet and the first spacer grid. During a LOCA, fiber and particulate debris could be generated by the discharged high temperature and high pressure fluid emanating from a break in the reactor coolant system. The debris types generated depend on the plant design and generally those using fiber insulation material are more susceptible to potential debris issues. For a reactor design using reflective metallic insulation (RMI), the break flow could wash away the latent fiber and particulate debris into the in-containment refuelling water storage tank (IRWST). After the primary system pressure drops to a low pressure set point, the emergency core cooling system (ECCS) starts to recirculate the water from the IRWST through the sump strainers back to the primary system. The debris can accumulate on the containment sump strainer and cause a pressure drop across the strainer and reduce the ECCS pump NPSH margin. A certain fraction of the debris may by-pass the strainer surface and reach the reactor fuel assemblies. Debris that accumulates in the reactor core region may have an adverse impact on the reactor core long term cooling performance. In order to maintain sufficient core cooling during the post-LOCA long term cooling period, reactor vendors and licensees have made significant efforts to quantify the debris generation, evaluate the debris transport to the sump strainer, measure the debris bed pressure drop across the strainer surface and perform tests to identify the pressure loss across debris in the core. Because different licensees have different insulation materials installed at their plants and different analytical approaches, it becomes evident that a common position is needed to establish high level regulatory requirements and a framework regarding the sump strainer performance and debris in-vessel downstream effect evaluations.

Common position

The APR1400 design relies on the ECCS safety injection system to maintain core cooling during the post LOCA long term cooling period. The APR1400 reactor vendor, KHNP/KEPCO has performed different types of tests, analyses and evaluations to demonstrate compliance with ECCS performance criteria in different countries. Therefore, all these analyses, tests and evaluations need to follow a performance based evaluation framework and satisfy the essential safety injection pump NPSH and core cooling requirements. The deterministic evaluation results and potential design changes can be further assessed or refined according to country specific regulatory practices.

Background

The APR1400 relies on its safety injection systems to maintain core cooling and overcome the potential additional pressure drop caused by debris accumulation in the reactor core. The selection of insulation materials may influence the sump strainer design and long term core cooling performance. Currently, all APR1400 units in Korea and UAE are using fiber insulation material. For US APR1400, RMI insulation material has been proposed to prevent the heat loss from the primary system during normal operation. As a result of these design differences, MDEP participants have established a common position on high level regulatory requirements about the sump strainer performance, debris by-pass testing, fuel assembly head loss testing and post-LOCA long term cooling thermal-hydraulic analysis.

Sump Strainer Performance Evaluation

The objective of this evaluation is to ensure sufficient NPSH margin for SI pumps considering the effects of debris that may accumulate on the strainers. The evaluation should consist of debris generation analysis, debris transport analysis and strainer head loss testing. The following requirements need to be satisfied in order to ensure sufficient NPSH margin.

1. Debris generation analysis should start from proper pipe break characterization, which identifies the most limiting pipe break sizes, locations, and debris combinations within the containment. Once the limiting break sizes and locations are identified, evaluations based on analysis or testing should be performed to quantify the largest amount of potential debris generated. In addition to the debris generated by the high pressure and high temperature jets from the break, the amount of latent debris within the containment should also be included as part of the debris source. For plants with pH buffers, the amount of chemical precipitates as a debris source and their formation timing should also be considered. Other potential sources of debris should also be considered in the evaluation, such as coatings.

2. Debris transport evaluations should be performed to determine the most limiting amount of debris and the types of debris which causes the maximum debris bed pressure drop across the sump strainer surface. The evaluation should consider the debris distribution within the ZOI

and any other potential areas downstream of the break flow, and the transport paths towards the strainers. The evaluation should also determine the sequence of debris arrival, i.e, the transport time of fiber debris, particulate debris, RMI debris and chemical precipitates.

3. Strainer prototypical head loss testing should be performed to determine the maximum debris bed head loss based on a conservative assumption of the available ECCS trains. The test facility should be designed and scaled properly to reflect the actual strainer and the nearby fluid field. During the head loss testing, the debris addition sequence and amounts should be determined based on the results of debris transport analysis. The strainer test should be designed and installed to maintain the same surface approach velocity as that of the actual strainer.

Sump Strainer Debris By-pass Testing

To evaluate the potential debris bypass of the strainer, it is important that the volume of debris generated and the transportation routes are identified. In addition to the design of the system, this information will inform the development, construction and operation of a prototypical strainer testing facility for debris by-pass experiments. Specifically, Korea, UAE and US regulators propose the following guidance with respect to the test apparatus and procedure:

1. The debris generation analysis should consider all credible break sizes and locations from the primary loop. The analysis should consider the most credible high energy fluid jet trajectory from the break location. For plants using fiber insulation, it may be necessary to conduct testing to evaluate the amount of debris generation for a given break.

2. The fiber only bypass tests are recommended to obtain a conservative bypass fraction. It is recommended that a prototypical strainer testing facility be constructed with a closed circulation loop to preserve the nearby fluid field and strainer surface approach velocity equal to that in the plant. To measure the debris bypass fraction, it is recommended that an appropriate downstream fiber debris mass measurement technique is used.

3. It is advised that cognisance of the debris transport model be made such that a procedure can be generated to ensure that the debris is introduced into the test apparatus in a representative manner. This is of specific concern if RMI debris is within the ZOI, as the mixture of RMI, fiber and particulate in front of the strainer surface prior to the start of forced circulation can artificially suppress the debris penetration process. It is recommended by UAE, Korea and US regulators that a conservative testing approach would be adopted to examine fiber only bypass testing.

Fuel Assembly Head Loss Testing

After the fibrous debris bypass source term has been determined, it is considered conservative to assume that all other types of bypass debris (particulate debris and chemical precipitates) is transported to the core. Accordingly, it is the view of the UAE, Korea and US regulators that fuel assembly head loss testing should be conducted to measure the total bundle head loss as the result of debris accumulation at the inlet of the fuel assembly or the first spacer grid. It is the view of UAE, Korea and US regulators that the following guidance represent good practices with respect to the test apparatus and procedures:

1. The test loop should contain at least one mock-up fuel assembly to represent the fuel pins, control rod guide tubes, actual fuel assembly debris screen and spacer grids. When only one mock-up fuel assembly is used to simulate the core, the gap size between the mock-up fuel assembly and the test apparatus wall should conservatively represent the designed gap between two adjacent fuel assemblies. The default gap size should be half of the gap size between two adjacent fuel assemblies. The installation tolerance should be controlled so that the actual gap size is within the core manufacturing tolerance. If multiple mock-up fuel assemblies are used, the gap size between the fuel assembly and the flow chamber wall should be half of the gap size between two adjacent fuel assemblies. A closed circulation loop is advised to preserve the debris mass introduced during the test.

2. A test procedure should be established to control the introduction of debris into the test loop such that the test conditions reflect a realistic arrival sequence. If the debris transport behavior is not known, consideration should be given to introducing both fiber and particulate debris into the test loop in small batches to simulate gradual transport of the potential debris and maximize the head loss. If applicable, the chemical precipitates should be introduced once all of the fiber and particulate debris have been introduced into the test loop and should be introduced gradually to simulate the generation of the chemical precipitates.

Reactor Core Long Term Cooling Thermal-hydraulic Analysis

The ability to provide long term cooling to the reactor core is a fundamental safety goal. To ensure that the decay heat removal function is maintained, consideration should be given to performing a thermal-hydraulic analysis to establish the available driving head across the core. It is required that the limiting core pressure drop in the presence of debris will be less than the available driving head to maintain sufficient core flow rate. To ensure a conservative estimate of the available driving head, consideration should be given to the following practices by the applicants.

1. The analysis should evaluate all possible break locations and select the most limiting injection location to calculate the system pressure distribution and the fluid condition. A bounding decay heat model and analysis margin should be used to estimate the core power level at the most limiting time of the transient.

2. The system model used should include two-phase flow model to conservatively estimate the core wide average void fraction and the steam generator tube side fluid conditions. Two-phase flow and heat transfer conditions specific for this reactor design should be analysed. These conditions include, but are not limited to; the steam generator tube side condensation if it exists, the potential loop seal formation or clearing, safety injection water mixing in the downcomer region and the potential for counter-current flow. In addition, if best estimate models are used, an uncertainty analysis should be considered.

Complementary Approaches For APR1400 Design With Fiber Insulation

1. Risk-Informed Approach

Risk-Informed approaches are being considered by US NRC to address debris for long-term cooling in the US for operating PWRs licensed based on 10CFR Part 50. The licensees have to ensure that the plant-specific PRA is of sufficient scope, level of detail, and technical adequacy for this approach and is updated and maintained over time and that the risk informed approach is evaluated periodically. If this approach is taken to evaluate any potential net increase in risk due to debris, the acceptable change in risk is up to 10^{-5} per year for plants with total baseline core damage frequencies (CDF) of 10^{-4} per year, or, to 10^{-6} per year for plants with total baseline CDF greater than 10^{-4} per year. If there is an indication that the CDF may be considerably higher than 10^{-4} per year, the focus of the applicant should be on finding ways to decrease rather than increase CDF. Similarly, for plants with total baseline large early release frequency (LERF) of 10^{-5} per year or less, small LERF increases are considered to be up to 10^{-6} per year, and for plants with total baseline LERF greater than 10^{-5} per year, small LERF increases are considered to be up to 10^{-7} per year. Similar to the CDF metric, if there is an indication that the LERF may be considerably higher than 10^{-5} per year, the focus of the applicant should be on finding ways to decrease rather than increase LERF.

Because the approach is risk-informed, not risk-based, other factors such as compliance with existing regulations, defense in depth, safety margins, and long-term performance monitoring must also be considered.

2. Margin Assessment Approach

FANR of UAE determined that a margin assessment approach can also be used as a complement to the deterministic approach to give additional assurance of the robustness of long term core cooling following a LOCA. This approach recognizes that prototypical testing in support of deterministic analysis may often lead to inconclusive results due to the complex nature of phenomena as well as the difference of opinions amongst experts on the prototypical nature of testing facilities. Recognizing also that the APR1400 plant design has benefited from lessons learned from previous generations of NPP designs and incorporates design provisions that limit and/or mitigate the consequences of a LOCA, the margin assessment approach – to be undertaken in a qualitative or quantitative manner – encompasses the review of the APR1400 design provisions that limit the generation of debris following a LOCA and reduce the risk of debris transport into the IRWST and then through the core. The approach aims at determining the safety margins provided by these design provisions in order to conclude with reasonable assurance that the performance of long term core cooling will be adequate.